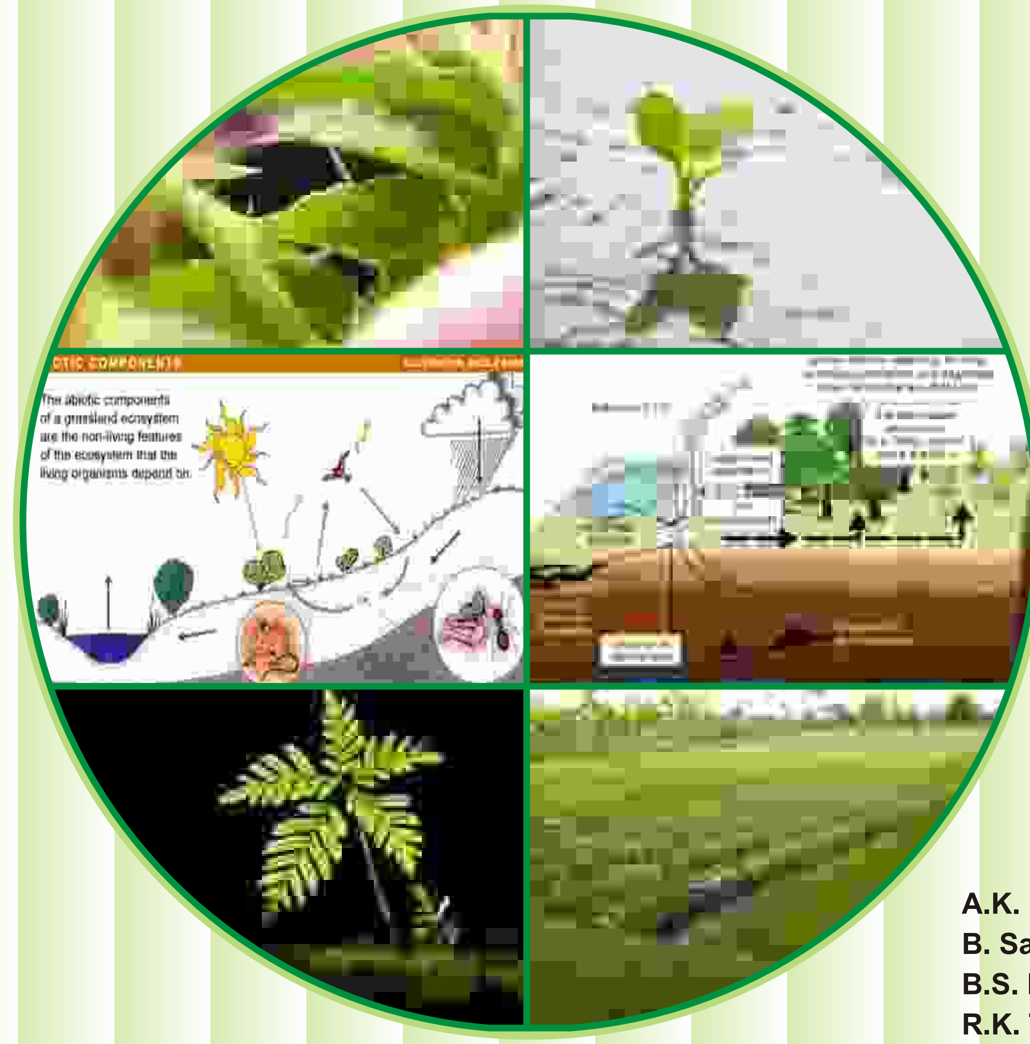
Jawaharlal Nehru Krishi Vishwavidyalaya, Jabalpur (M.P.)

TRAINING ON

Biotic and Abiotic Resources Management for Eco-friendly and Sustainable Agriculture

3-23 October, 2011



A.K. Rawat
B. Sachidanand
B.S. Dwivedi
R.K. Thakur

CENTRE OF ADVANCED FACULTY TRAINING
Department of Soil Science & Agricultural Chemistry
Jawaharlal Nehru Krishi Vishwavidyalaya
Jabalpur 482004 (M.P.)

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CENTRE OF ADVANCED FACULTY TRAINING

Course Programme on

Biotic and Abiotic Resources Management for Eco-friendly and Sustainable Agriculture

(03-23 Oct. 2011)

Compiled by

A.K. Rawat

B. Sachidanand

B.S. Dwivedi

R.K. Thakur

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Department of Soil Science and Agril. Chemistry
Jawaharlal Nehru Krishi Vishwavidyalaya
Jabalpur – 482 004 (M.P.)

Preface

One of the most important challenges facing humanity today is to conserve/sustain natural resources, including soil and water, for increasing food production while protecting the environment. Biotic and abiotic resources both come under natural resources. The area deals with the basic scientific principles that govern the interrelationship between biotic (e.g. plants, microorganism etc.) and abiotic factors (e.g. Climate, soils) in major ecosystems and the use of these principles for environmentally sound management of natural resources is of prime importance. Agriculture is a soil-based system that extracts nutrients from the soil, effective and efficient approaches to slowing that removal and returning nutrients to the soil will be required in order to maintain and increase crop productivity and sustain agriculture for the long term.

The overall strategy for increasing crop yields and sustaining them at a high level must include an integrated approach to the management of biotic and abiotic resources, along with other complementary measures. An integrated approach recognizes that soils are the storehouse of most of the plant nutrients essential for plant growth and that the way in which nutrients are managed will have a major impact on crop productivity and soil fertility for ecofriendly and sustainable agriculture. The proposed training programme will be able to educate the participants and highlight those aspects which are significant to manage the biotic and abiotic resources for sustainable agriculture.

ICAR sponsored Centre of Advanced Faculty Training (erstwhile Center of Advanced Studies) was established in the year 1995 and since then 24 training programmes have been organized on different themes of Soil Science. In the series, present training programme has been organized on **"Biotic and abiotic resources management for ecofriendly and sustainable agriculture"** for Asst. Professors/Scientists, Assoc. Professors/Sr. Scientists of SAUs, ICAR institutes and other Agricultural institutes from 3-23 October, 2011.

It is my proud previlege to express my sincere thanks to Dr. S. Ayyappan, Hon'ble Director General (ICAR) & Secretary (DARE), Dr. Arvind Kumar, Deputy Directoer General (Education) ICAR and Dr. Kusumkar Sharma, ADG (HRD), ICAR for their keen interest in the CAFT project at JNKVV, Jabalpur. My sincere thanks are due to Prof. Gautam Kalloo, Hon'ble Vice Chancellor, JNKVV, Jabalpur for his pains taking efforts, keen interest and full support in CAFT activities.

My sincere thanks to Dr. S.S. Tomar, Dean Faculty of Agriculture and Director Research Services, Dr. O.P. Veda, Director Instruction, Dr. P.K. Jain, Director Extension Services and Dr. D.K. Mishra, Dean, College of Agriculture, JNKVV, Jabalpur for their unfailing help to CAFT.

I would like to express my special gratitude and thanks to Dr. D.K. Benbi, ICAR National Professor, Department of Soils, PAU, Ludhiana as an expert for evaluating the course programme, different faculty members and guest speakers for imparting their rich experiences.

My thanks and appreciations also go to my colleagues and various organizing committees for successful organizing the training programme and people who have willingly helped me out with their abilities.

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October, 2011

(A.K. Rawat)
Director, CAFT

Biotic and Abiotic Resources Management in Wheat for Sustainable Agriculture

R.S. Shukla

Principal Scientist
Department of Plant Breeding and Genetics
JN Krishi Vishwa Vidhyalaya, Jabalpur-482004 (MP)

Wheat is pre- eminent among the world's crops in regards to its antiquity and its importance as a staple food of mankind. India, one of the greatest success stories of Green Revolution, is the second largest producer of wheat in the world after China and contributes more than 12% to the global wheat basket. Wheat is there second most importance crop after rice in India and occupies approximately 27.8 m ha area. Not surprisingly the country is witnessing a record wheat production of an all-time high of 85.93 million tonnes in 2010-11.For the last ten years, India is maintaining its second position in the world next to only China. The "rate of return analysis" largely explains the success of wheat improvement programme and this is evident from the fact that the investment made in wheat research has been repaid through increased productivity and production.

The population is increasing in a geometric progression leading to an increased demand of wheat but there is no possibility of further increase in area due to growing urbanization, diversification, dwindling water resources, micro-nutrient deficiencies and soil health deterioration. Therefore, the need to produce more wheat has to be met with fewer resources in a sustainable and cost effective manner. The wheat production, currently, is hovering around 85 mt and recent estimates have shown that India will need 109 mt by 2025.

It is a matter of great concern that for the last several years, plateau in wheat productivity is being observed. There is a very little scope for increasing the area under wheat cultivation, so the major challenge is to break the yield barriers. Since a yield jump as observed in 60s does not appear to be possible now, there is need to follow an approach for gradual gain in yield in the breeding populations in order to break the yield plateau. For this purpose, already known high yielding diverse lines need to be used as base material for incorporating some useful traits from other un-adapted cultivars or lines. In this direction, the winter x spring wheat hybridization, interspecific/wide hybridization for introgression of useful genes from related wheat species may be highly effective.

Managing the natural resources is an important challenge in the highly productive rice-wheat cropping system (RWCS) which is predominant in the Indo-Gangetic plains (IGP). Furthermore, the intensive cultivation of rice and wheat for more than three and half decades continuously has put a tremendous pressure on the land thereby creating a complex situation. Problems of stagnating yields at levels far below the potential productivity and even yield declines are occurring in many areas in the rice-wheat systems of India. The total factor productivity of this system is declining due to intensive tillage leading to the depletion of soil organic carbon. The declined soil organic carbon is directly responsible for the decreased nutrient and water holding capacity of the soil thereby adversely affecting the native soil fertility. The problem is further aggravated by burning crop residues by farmers especially that of rice under rice-wheat system in north western parts. Nutrient mining, imbalanced fertilization and over-exploitation of water resources are the other factors responsible for decline in total factor productivity. Addition of organic matter to soil through green manuring and crop residue recycling, balanced fertilization, integrated nutrient management, diversification/intensification of rice-wheat system by including pulses, oilseeds and vegetables crops are some of the possible remedial measures to improve soil productivity and hence, total factor productivity.

The most serious constraints to wheat production are biotic stresses. Among the major biotic stresses, rusts and foliar blight are more critical for achieving higher yields. India in particular has not faced any rust epidemic since last three and half decades because of proper deployment of rust resistance genes. However, the threat of a new black rust race (Ug99) looms large as most of the wheat lines available in India carrying the Sr31 gene are susceptible to this race. Fortunately, timely steps have been initiated by the ICAR and also through the launching of 'Global Rust Initiative' (GRI) to combat this impending problem. Looking to the aforesaid bottle necks the following thrust areas of research will mitigate the future needs:

Breaking yield barriers

- Exploitation of heterosis for developing hybrids based on CMS system
- Broadening of genetic base of varieties
  - ✓ Through use of winter x spring hybridization
  - ✓ Use of synthetics, Buitre and Chinese germplasm
  - ✓ Use of alien species for biotic and abiotic stresses

Biotechnological interventions

- Gene pyramiding
- Marker aided selection for biotic, abiotic and quality traits
- Transgenic
- Structural and functions genomics

Resource conservation technologies

- Refinement and indigenization of machines
- Developing tillage specific varieties
- Diversification/intensification
- Water and nutrient use efficiency
- Tackling weeds and pests under new tillage practices
- Residue management
- Land leveling through laser leveler

Improving soil health

- Increasing carbon content
- Correction of micro-nutrient deficiency/toxicity
- Balance use of fertilizers

Combating diseases and insect pests

- Integrated pest management
- Survey and surveillance for new races
- Combating rusts through durable resistance
- New race of yellow rust – 78S84
- New race of black rust – Ug99
- Creating effective resistance against leaf blight and Karnal bunt
- Emerging problems of termites and aphids

In the field of crop improvement, efforts would be to develop new genotypes that are responsive to high input management and capable of yielding beyond 70 t/ha. At the same time, the new genotypes must be nutrient and water use efficient. With holding the strong base of rust resistance, emphasis will be to develop short duration genotypes resistant to leaf blight especially for eastern India. Innovative approaches to produce hybrid wheat that will have at least one tonne yield advantage over the commercial varieties will draw attention. There is need to highlight importance of abiotic stresses viz., heat, drought, salinity and water logging. Due emphasis is to be given for developing genotypes efficient in utilizing the micronutrients so as to make the wheat flour more nutritive. 4.1.7 Strategy to deploy new genes for rust resistance The AICW&BIP has strategy of replacing the rust susceptible varieties with new improved types. As an alternative to the ruling variety of 90's, alternate varieties for the NWPZ like UP 2338, WH 542, PBW 343, PBW 502 and DBW 17 have been released. These varieties have inbuilt resistance to rust and other wheat diseases with superior quality and agronomic traits. To replace HD 2285 for irrigated late sown condition, the varieties like UP 2338, PBW 373, DBW 16, UP 2425 and Raj 3765 have been released. These genotypes possess adequate levels of rust resistance under late sown situations. Many new wheat varieties viz. Sonali, NW 1014, K 9107, HW 2045, PBW 343, HD 2824, K 9107, HD 2733, HD 2643, HUW 468, DBW 14 and NW 2036 have been recommended for the NEPZ region. New varieties like GW 273, GW 322, GW 496, HD 2864 and MP 4010 etc. have been developed and recommended as an alternate to popular but susceptible variety Lok 1 of central India.

Molecular mapping and molecular assisted selection The recent developments in plant biotechnology including molecular mapping and marker-assisted selection (MAS), offer a choice of options for targeted utilization of traits/ genes. The most important activity for any molecular biology work is the availability of mapping populations for various traits of agronomic /economic importance. Indian wheat programme visualized this and several mapping populations for various traits are either already available or are under process. Some of them are listed below.

Traits	Resistant donor
Bread quality	HI 977 (good) x HD 2329 (poor)
Grain hardness	NP 4 (hard) X HB 208 (soft)
Grain hardness	Chinese spring (soft) x PBW 343 (hard)
Chapati quality	C 306 (good) x WH 157 (poor)
Gluten strength	HD 4676 (high) x NIDW 15 (low)
KB resistance	HD 29 (resistant) x HD 2009 (susceptible)
FHB resistant	Toronit (tolerant) x Lona (susceptible)
Yr16 gene tagging	Cappelle Desprez (source) x PBW 343 (susceptible)
Lr34 gene tagging	HD 2189 (carrier) x Agra Local (non-carrier)
Thermal tolerance	HUW 510 (susceptible) x WH 730 (tolerant)
Leaf blight resistance	Sonalika (susceptible) x BH 1146 (resistant)
Leaf blight resistance	Kanchan (suceptible) x Chiriya 1 (resistant)
Leaf blight resistance	HUW 234 (susceptible) x YM#6 (resistant)
Beta-glucan content	UB 466 (low) x ICARDA 54 (high)
Beta-glucan content	UB 466 (low) x K 647 (high)
Aphid resistance	EB 921 (resistant) x Alfa 93(susceptible)
Aphid resistance	BCU 390 (resistant) x Alfa 93(susceptible)

Two diagnostic markers, one for stripe rust resistance gene Yr10 and one for HMW glue 8 subunits were developed by the molecular biology programme at the DWR. Two genotypes MBL-2 and MBL-5, selected out of the RILs showing high grain protein (approximately 14%) have been registered as Genetic Stocks by the NBPGR. A research programme in form of a “Network project on gene pyramiding for resistance to multiple biotic stresses in crops” has been initiated with the objective of improving existing cultivars. Some of the genes that are targeted to be pyramided are Lr24, Lr28, Lr35 and Lr37 for leaf rust and Yr10 and Yr15 for stripe rust resistance. The varieties which have been taken as recipients are LOK 1, HUW 234, PBW 343, HD 2687, HD 2733 and WH 147. Marker assisted selection was found quite effective in segregating the genotypes with and without these genes for further selection/backcrossing. BC1F1 plants with Lr24, Lr28, Lr37 and Yr10 in different background were selected and backcrossed with the recipient parents. Similarly parental lines C 306, VL 421, NI 5439 and the donor lines viz., WH 542/* Yr Moro(Yr10), WH 542/ *Yr15 (Yr15), PBW 343/*Tc Lr37 (Lr37) and for Lr34 gene, BW 11 and HS 240 were used for crossing. The individual BC1F1 plants selected through marker assisted selection were utilized for further backcrossing. About 50 genotypes postulated to carry Lr34 and non-carriers of this gene were screened with 7 micro satellite and 3 EST based markers (reported to be on 7DS and in close vicinity of Lr34 gene). Marker gene analysis was also performed. A population has also been developed out of the cross HD 2189 x Agra Local for complimenting the Lr34 fine mapping work. With an objective to prepare Indian wheat programme to fight back the possible menace of Ug99 pathotype of stem rust, effort was made to identify lines with more than one effective stem rust resistant gene (Sr24 and Sr26) for utilization by the breeders. A set of parental lines along with their respective Near Isogenic Lines (NILs) having Sr26 and Sr24 developed at the IARI Regional Station, Wellington, Tamil Nadu were subjected to marker assisted screening with separate markers, linked to Sr24 and Sr26. When tested with marker linked to Lr24, results confirmed tight linkage between Lr24 and Sr24 as none of the NILs and other 145 genotypes having Lr24 tested, showed breakage of linkage between these genes.

Tolerance against abiotic stresses

1. Heat stress: Wheat is sown late on considerable area in north-western and north-eastern plains of India due to high cropping intensity and delayed harvest of previous crop. As a result, the crop gets exposed to higher ambient temperatures at the time of grain filling, which cause significant reduction in productivity. Studies conducted with advanced wheat genotypes have helped in characterizing the environments in terms of weather parameters and also in terms of plant responses.

It has been conclusively shown that biomass production is a key factor in high grain yield performance under late sown high temperature environments.

- KI induced leaf senescence can be used to assess variability in stem reserve utilization, if used in low concentration and avoiding spikes during spray.
- Efficient partitioning of assimilates, more number of tillers and number of grains/spike contribute to superiority of Raj 3765, Halna, NIAW 34, NW 1014, Tepoka, WH 730, CBW 12,that can be used as source of heat tolerance.

2. Water logging: Water logging situations arise in northern India due to incessant rains of high intensity and short duration at early stages of wheat growth and development. The intensity of water logging is high when rain occurs immediately after irrigation. In northern India alone, approximate. 2.5 m ha of wheat is affected by irregular water logging which is more pronounced in sodic soils. Hence, efforts are being made to identify wheat genotypes with increased tolerance to transient flood or water logging at initial stages of crop growth.

- Studies revealed considerable genetic variation in response to water logging and the genotypes showing yield reduction up to 15% have been noted as tolerant types.
- HD 2329 showed relatively high tolerance to water logging
- Some of the doubled haploid lines generated by using water logging tolerant Ducula-4 and Brootton (Australian genotype) have been found tolerant to water logging.
- Sodium and potassium ratio is important factor in determining water logging tolerance in sodic soils.

3. Seed dynamics: The identification of wheat varieties originating from identical/ similar parentage have been discouraged to ensure genetic diversity in Indian wheat varieties. The genetic diversity among wheat varieties under commercial cultivation will serve as a safeguard from any possible pathogenic hazard. Cultivation of a large number of varieties with diverse pedigree in breeder seed programme, will hinder any disease epidemic. During 1967 to 1977, there were only two varieties namely Sonalika and Kalyansona which occupied largest area in the country. In 1984- 85 there were 62 wheat varieties under breeder seed programme out of which indents of 11 varieties were higher than 50 quintals. By 1994-95, many of the varieties like HUW 234, HD 2285, WH 542 and HD 2329 were added in the list to further increase in diversity in wheat varieties. Now many new varieties like PBW 502, UP 2338, Raj 3765, HI 8498, K 9107, HS 295, VL 804, GW 322, PBW 373, PBW 343, HUW 468, HW 2045, HD 2733, DBW 14, DBW 16, DBW 17 and NW 2036 have been added in the seed production chain. For quicker replacement of old, disease susceptible or otherwise uneconomical varieties, the central research institutes, state agricultural universities and state departments of agriculture should develop a strategy to distribute small quantity of newly identified varieties.

1. Resource Management: When the dwarf wheat varieties were introduced in late 60's, it was perceived that the agronomic practices have to undergo a change since the practices followed earlier were found to be inappropriate. Package of practices for growing dwarf wheats and harvesting procedures were then reinvestigated and standardized.

2. Irrigation management: Area under irrigated wheat has increased with popularization of the Mexican wheat's. At present, nearly 95% of the area sown to wheat in Punjab and Haryana has assured irrigation. The agronomy group has demonstrated that irrigating wheat at crown root initiation stage (CRI) which is approximately 21days after sowing is most crucial. If water is available subsequently, it was advised to utilise the irrigation during tillering and at flowering stages. Using the FIRB technology, it had been demonstrated that water saving to the extent of about 30 percent could be achieved for wheat cultivation.

3. Fertilizer management: The time and placement of fertilizer is another area where significant progress was made. It was demonstrated that 120 kg nitrogen, 60 kg phosphorus and 30 kg potash per hectare were required for optimum productivity. The N was to be applied in two split doses of 60 kg as basal and the remaining 60 kg at first irrigation and full phosphorus and potash to be applied as basal. Recently, the new wheat varieties have responded up to 180 kg N/ha with optima dose around 150 kg/ha. In the Indo-Gangetic plains, application of zinc @ 25kg/ha in rice-wheat system was found to increase the yield substantially. Recently, the use of sulphur has been found beneficial for enhancing the productivity as well as the grain protein content of wheat. Response to Mn (pockets in the Indo-Gangetic plains) and boron (eastern and far eastern region) has also been realized.

Micronutrient Deficiencies: The adoption of intensive cropping systems in various parts of the country has resulted in occasional micronutrient deficiencies. Some of the common ones are:

7.1 Zinc deficiency

- This deficiency generally appears in light soils under intensive cropping. The symptoms are failure of stem elongation and necrosis and chlorosis in plant leaves in the middle. The leaves break later on..
- The deficiency can be rectified by applying zinc sulphate @ 25 kg/ha along with fertilizer once in 2-3 years or by foliar spray of 0.5% zince sulphate (21% zinc).
- For foliar spray prepare the solutions by dissolving 1 kg zinc sulphatae and ½ kg un slaked lime in 200 litres of water. This solution is sufficient for spraying in one acre of wheat once only, while 2-3 sprays at 15 days intervals are needed.

7.2 Manganese deficiency: Generally appears in light soils in intensive cropping regions specially under rice-wheat.f The symptoms appear on middle leaves as interveinal chlorosis with light grayish yellow to pinkish brown or buff coloured specks of variable sizes confined largely to 2/3 lower portion of the leaves Later the specks coalesce forming a streak or band underneath the veins which remain green. At earing stage, the symptoms become predominant on flag leaf.

Spray 0.5% $MnSO_4$ in 200 litres of water) two to four days before first irrigation and 2-3 sprays afterwards at weekly intervals.

7.3 Sulphur deficiency: Sandy soils are most prone to this deficiency. It is more severe when winter rains continue for long time in the early growth period. The symptoms first appear on the younger leaves with fading of the normal green colour. This is followed by chlorosis resulting in chlorotic stripping between the veins, stunted growth of the plants, delayed maturity and fewer tillers.

The situation can be avoided by using sulphur containing fertilizers like ammonium sulphate and single superphosphate.

7.4 Boron deficiency: Boron deficiency occurs in alkaline calcareous soils and acid leached sandy soils. In India it is generally found in certain pockets of north eastern plains. The deficiency symptoms are chlorotic patches on the middle leaves of 3 week old plants which later on become pronounced and develop bright orange colouration. The inflorescence is improperly developed zigzag axis, short swans, apical part discoloured and thus grain formation is poor Occurrence of completely sterile spikes is also reported.

To ameliorate as the situation borax @ 10-15 kg/ha should be applied in the soil by broadcast. Foliar application of "B" (Solubor 0.2-0.5%) is preferred if deficiency occurs during the growth season for which multiple sprays are needed for complete recovery.

Adverse Soil Conditions: Alkalinity and salinity are the important adverse soil conditions prevalent in certain pockets of the states.

8.1 Alkaline soils: Alkalinity is caused by an excessive concentration of carbonates and bicarbonates of sodium. The crop stand is reduced owing to poor seedling emergence, low tillering and weak plant growth. If the pH is above 9.2, wheat crop should not be grown without the adoption of recommended soil amendment practices. These may involve the use of gypsum @ 10 to 15 tonnes/ha, depending upon soil test and adoption of rice-wheat rotation. Other specific recommendations for increasing the wheat production from alkaline soils are:

- Grow tolerant recommended varieties
- Use 10-15% higher seed rate than the normal.
- Apply 20% higher dose of nitrogen
- Restrict phosphorus and potassium applications only when soil tests justify their use.
- Use compost wherever possible
- Follow a strict schedule for field preparation to avoid bad seed-bed conditions.

8.2 Saline soils: The situation arises because of an excessive concentration of chlorides and sulphates. The crop germination and growth is restricted and yield starts declining beyond 3-4 ECe. Significant yield reduction occurs beyond 6-8 ECe in most high yielding varieties. Recommendations to ameliorate the situation are:

- Use 10-15% higher seed rate
- Follow a rigid water management schedule, which involves a heavier than normal first irrigation, followed by frequent light irrigations with occasional heavy irrigation
- Use normal recommended levels of nitrogen but split into 3 equal doses to be applied at seedling, tillering and grain filling stages.

1. Weed management: The high cost of inputs brought to light the importance of weed management since weeds remove both soil moisture and nutrients. The AICW&BIP developed suitable chemical weed control strategy, and standardized the dosage and the time of application. Isoproturon recommended in early eighties provided broad spectrum weed control for more than a decade. However, sole dependence on this herbicide resulted in the evolution of isoproturon resistance in Phalaris minor. To curtail the yield reduction caused by isoproturon resistant P. minor, clodinafop, fenoxaprop and sulfosulfuron have been recommended. 4.2.4 New resource conservation technologies For sustaining the R/W system in the Indo-Gangetic plains, there was an urgent need to economise the use of natural resources as well as enhance the organic carbon content in the soil. The Zero-Tillage technology emerged as cost effective measure and farmers responded to it in many parts of NWPZ and NEPZ. More than 3000 rupees per ha can be saved through reduced ploughing cost and zero till sowing after the harvest of rice. The other RCTs which can be adopted by the farmers in near future are FIRB, Rotary Till Drill, Strip Till Drill and Laser Leveling. For seeding into surface retained loose crop residues, second generation machines like rotary disc drill and happy seeder can be found useful. Adopting conservation agriculture (seeding into surface retained residues) will help in improving the sustainability of soil and water resources by avoiding burning crop residue.

2. Diversification/intensification of Rice-Wheat system:

Rice-wheat is a major cropping sequence and due to the exhaustive nature of these crops, soil fertility is depleting leading to declining factor productivity. Therefore, need was felt to replace one crop by a short duration legume. Some of the remunerative alternate cropping systems tuned to new tillage options were rice-vegetable, pea-winter maize, rice-wheat-moong, rice-vegetable pea (FIRBS)-wheat (FIRBS), pigeon pea (FIRBS) - wheat (FIRBS) - rice-wheat (FIRBS) and, rice-mustard (FIRBS)-green gram (FIRBS)-rice-wheat (FIRBS). Crop Protection As a part of the wheat improvement programme, a continuous monitoring has been done to map the prevalence and distribution of the black (*Puccinia graminis* tritici), brown (*P. recondita* tritici) and yellow rust (*P. striiformis*) virulence. The avirulence/ virulence genes present in the pathogen are characterized by analyzing.

There is a strong association between distribution pattern of brown rust and the type of host varieties grown. During the past few years, there is a quick appearance of new pathotypes able to match gene Lr 26. Various genetic stocks and other wheat lines have been identified possessing resistance to the three wheat rusts and minor diseases such as foliar blight, loose smut and Karnal bunt. Brown rust race distribution frequency at national level shows that pathotypes of race groups 104 and 12 have reduced whereas race 77 has increased steeply. The distribution pattern of the virulences gives the much needed indications for executing the resistant gene deployment.

than that of Punjab (Ludhiana & Gurdaspur). RAPD was used to study genetic variation in natural pathogen populations of *F. graminearum* and other *Fusarium* spp. associated with the disease. This study has shown that there is a considerable genotypic variability among *F. graminearum* isolates obtained from infected

Addition of new pathotypes in Indian rust flora over years

Time Span	Black rust	Brown rust	Yellow rust
Till 1975	11, 11A, 14, 15, 17, 21, 24, 24A, 34, 34-1, 40, 42	10, 11, 12, 12A, 17, 20, 63, 77, 106, 107, 108, 162	13, 14, 19, 20, 31, 38A
1976-80	21-1, 40A, 21A-2	77-A, 104	14A, 20A, 38A, I
1981-85	117A-1	77-A, 114-A, 104B, 12-2	K
1986-90	40-1, 117-1	77-1, 77-2, 77-3, 12-1, 12-3,	L, N, P
1991-95	117-2, 117-3, 117-4, 117-5, 117-6	77-4, 77-5, 104-2, 104-3	T, U, CI, CII, CIII
1996-2K	-	77-6, 77-7	46S 119
2001-06	184-1, 58G13	77-8,12-5, 12-6, 162-1 162-2, 162-3, 5R9-7	78S84

4.3.1 Creating artificial epiphytotic conditions for rust screening

The Regional Station of Directorate of Wheat Research, Karnal at Flowerdale, Shimla. supplies the nucleus inoculum to various active breeding programmes for proper evaluation of the material and also acts as a custodian for maintenance of all the pathotypes of Puccinia infecting wheat, barley and oats. Centre has cryopreserved reference seed of all useful lines possessing seedling resistance to wheat rust.

Karnal bunt: In mid-1970's, Karnal bunt became a major production constraint and the programme quickly developed a procedure for the rapid isolation of *Neovossia indica.* Technology for mass production of the pathogen spores and procedure for field inoculation and the post inoculation as developed for creating disease. It facilitated in conducting multi-location trials to screen the wheat material and develop lines which are tolerant to KB. Among improved varieties, PDW 215, PDW 233, WH 896 in durum, TL 1210 in triticale, and WL 1562, PBW 154 and HD 2281 in bread wheat possess high degree of KB tolerance. Three variants of *Tilletia indica* causing Karnal bunt infection have been identified with the help of polymorphism in mycelial proteins.

Head scab: Six Fusarium spp. viz., *graminearum, moniliforme*, *oxysporum*, *equiseti, semitectum* and *solani* were found associated with the head scab in Punjab, Tamil Nadu and Himachal Pradesh. Inter and intra species specific variation could also be noticed. *F. graminearum* isolates of Dalang Maidan (HP) and Wellington were found more aggressive

wheat ear heads from different geographic regions of India.

Leaf blight complex: Rating scale and techniques for the rapid evaluation of wheat genotypes against B. *sorokiniana* and its toxin *'Helminthosporol'* were developed. 13 distinct isolates of B. *sorokiniana* have been characterized in India. RAPD was used to study the genetic variation among *Bipolaris sorokiniana* isolates of different geographic regions of India. 4.3.5 Nematode resistance A large number of lines now under evaluation possess multiple disease resistance and this is a complement to the interdisciplinary approach being adopted in breeding program. Wheat variety AUS15854 has been identified to be immune to the *Heterodera avenae* and the *Durgapura centre* has initiated efforts to utilize it.

Insect pest resistance: Major insect pest problems in wheat are the termites, shootfly, mite, aphids, root aphids and storage pests. Resistant lines have been identified for shootfly (PDW 215, Raj 1555, Raj 3190, HUW 234, PDW 213, HD 2307, UPD 8, HI 8381) and brown mite (A-9-30-1, C 306, DT 18, HDR 132, HPW 42, WH 589, WH 610, WH 629).

Integrated pest management: The IPM in wheat was applied at DWR Farm and the adjoining two villages (Taraori and Darar). The yield advantage in different villages and different varieties has been in the range of 9 to 15 per cent consistently over the years, which has encouraged the farmers to take up this technology on large scale.

Chemical control as emergency measure: The programme has identified several fungicides for the control of rusts, loose smut, Karnal bunt and foot rots. Though use of pesticides in wheat is low, but when seen as a wheat based cropping system, nearly 12% of the pesticides sold in India are meant for Rice- Wheat system, while 30% go to cotton-wheat system.

Challenges Ahead: After realizing the benefits of green revolution, a steep growth in productivity in front line states India was achieved from 1975 - - 1995 through churning of genepool and development of rust resistance gene in better agronomic back ground. Since significant scope exist for improvement in these new areas, one of the major challenges id to develop high yielding varieties having tolerance to abiotic stress specially heat, drought, salinity and waterlogging.

- Unavailability of quality seeds and low seed replacement
- Global climate change
- Restriction to germplasm exchange in new IPR regimes
- Reduced total factor productivity and imbalanced sue of fertilizers
- Yield gaps at farm level
- Improve varieties for abiotic and biotic stresses
- Conservation agriculture
- Integrated water, nutrient management
- Diversification/ intercropping /Companion cropping

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Wheat productivity and Enhancement under changing climate. 3rd International group meeting held at UAS Dharwad

Soil Biotic Resources: An Introduction to Soil Organisms

A.K. Rawat

Professor & Head
Department of Soil Science & Agricultural Chemistry
JN Krishi Vishwa Vidhyalaya, Jabalpur-482004 (MP)
Email ID: rawat_ashok@rediffmail.com

In general soil is considered as black box. We put things into the box and we get things out of the box, but we don't have a very good idea of what happens inside the box. We put seed, fertilizer, and water into the soil and out from the soil comes the crops we are growing. But what exactly happens inside that black box we call soil? Farmers and scientists have been studying that question for hundreds of years and continue to study it today. They have learned that many complex physical, biological, and chemical processes are carried out in soil. Lets open up that black box just a little and learn something about the biological processes that occur in soil.

Because most of the life forms in soil are extremely small which are not visible with naked eyes, "microbiology" is an appropriate term to describe the study of those life forms. Those who study soil biology quickly learn that soil life consists of intricate and complex interactions and cycles among the various living organisms in the soil. The activities and interactions of soil organisms largely determine the capacity of a soil to function in an agricultural, or any other, system. Knowing something about soil biological systems will help us to better understand how soil management impacts soil biology and the capacity of soil to function in agricultural production systems.

Before going any further, lets review the five basic functions that soils used for crop production need to be able to carry out.

- Soil must firmly anchor plant roots. It must be strong enough to hold crops and even large trees erect. Yet soil must be permeable enough to allow tiny root hairs to penetrate it.
- Soil must retain rain that falls on it in order to continuously supply water to growing plants. Yet it must also allow excess water to drain. The soil must drain because it must also supply air, more specifically oxygen, to crop roots. Too much water means too little air and the crops suffocate.
- Soil must supply nutrients for plant growth. To do so it must be able to store nutrients and then release them to the roots of growing crops.
- But soil must not release those nutrients to draining water.

Soil is a truly remarkable material to be able to perform each of these tasks that sometimes seem to be in conflict with each other. So here now we will consider how the organisms that live in soil, and the complex interactions among those organisms, give soils the capacity to perform these functions.

Think of an ecosystem that is teeming with life. An ecosystem where there is a great variety of plants and animals. An ecosystem where there is a complicated interplay between all these living creatures from the smallest to the largest. A place where fierce predators stalk the numerous animals that feed on the a rich variety of abundant plants, and scavengers clean up the mess that is left behind. Lets take a closer look at who is at home in the soil.

Specifically we want to look at

- The different kinds of organisms that live in our soils
- The kinds of functions they perform and how they make a living
- How abundant they are
- Some examples of how they interact with each other, and finally
- How our soil management practices affect soil life

To begin to understand the great diversity of soil organisms, it is helpful to place them into various groupings. We can categorize them on the basis of

- Size – grouping on the basis of how big an individual organism is,
- Species – grouping on the basis of genetic similarity, and
- Function – grouping on the basis of what the organisms do.

Soil organisms could also be grouped on the basis of those that can cause diseases and the types of diseases they cause. Because plant pathology is not the focus of this program we will not be categorizing soil organisms on this basis. A healthy soil contains a very large number of different kinds of species. Each of these species has a different function in the soil. These include animals, many of which are very familiar to us because we see them all the time. Among these are:

- All the familiar soil-dwelling mammals and snakes. These animals are also near the top of the food chain. They feed on plants and smaller animals.
- The arthropods which include spiders, insects, and insect larvae.
- The annelids which are all the various types of worms.
- The mollusks which include animals such as snails and slugs.

The arthropods, worms, and mollusks are mostly herbivores and detritovores, meaning they feed on plants and parts of dead animals and plants. They perform an important function in the decay process in that they mix these materials into the soil. They also break apart large pieces of material to make them more accessible to other degraders.

- And finally, the nematodes.

These are very small roundworms, 4 to 100 um (1/500 in) in diameter and up to a few millimeters in length (1/20 – 1/10 in). We usually hear about nematodes because they can be significant crop pests. Some will pierce the cells of crop roots to feed. This allows other plant pathogens to invade and cause infections that may severely damage or kill the plant.

Most nematodes, however, are beneficial. They feed on insect larvae, fungi, and bacteria, all of which could be plant pathogens. Since bacteria contain more nitrogen than the nematodes can use, their feeding serves to release plant available nitrogen into the soil. Nematode feeding may account for as much as 30-40% of the organic N released in some soils.

Soil organisms also include the roots of all the plants we are familiar with as well as plants we are less familiar with, the algae.

Plants are very important soil organisms because they are the primary producers, or autotrophs. That means they utilize water, energy from sunlight, and carbon dioxide from the atmosphere to build living tissues. All the other life in the soil, indeed all the other life on earth depends on these organisms.

Plants pump a lot of organic material into the soil. Of the crops we commonly grow such as corn, wheat, beans, forages, the weight of roots left in the soil averages about 25% of the above ground yield.

Like the vascular plants, algae are also photosynthetic, they use sunlight as their source of energy. Most algae range in size from 2 – 20 um (1/10,000 –1/1,000 in). The algae also add a lot of organic material to the soil. Some algae excrete sugars into the soil that help to stabilize soil structure.

In addition to adding organic matter to soil, plant roots also have a great influence on the soil biology in the volume of soil immediately adjacent to them. This volume of soil is known as the rhizosphere and usually extends about 2 mm (1/10 in) out from the surface of living roots. Plant roots exude organic materials into this zone as well as dead cells sloughed from the growing roots. These sources of organic carbon greatly increase soil microbial life in the rhizosphere compared to the bulk soil. The net effect is beneficial for plant growth since the microbial activity tends to increase nutrient and water supply to the root. Rhizosphere activity also appears to increase root soil contact and to lubricate root extension through the soil.

Now lets turn our attention to the smaller and perhaps less familiar soil organisms.

The fungi are another large group of organisms that include yeasts, mildew, molds, and rusts. Although some fungi cause significant crop diseases, many soil fungi play very important functions in overall soil and crop health. The AM fungus shown here is an arbuscular mycorrhizae, a fungus that benefits higher plants. Mushrooms are the fruiting structure of some fungi. The beautiful red balls are the fruiting structure of a slime mold.

The fungi are an extremely important group of degraders. They are able to degrade parts of plants and animals that bacteria have a hard time with. Materials like cellulose, starch, and lignin. The fungi are very important in the process of humus formation and in nutrient cycling. The thread-like strands of fungi, called hyphae, also help to stabilize soil structure. Some fungi are predators on other organisms such as nematodes. Many fungi release chemicals into the soil that may be toxic to plants, animals, and bacteria. The first modern antibiotic drug, penicillin, was obtained from the soil fungus, *Penicillium*. Some fungi are also contribute towards solubilization of fixed phosphorus into soluble plant usable form.

The protists or protozoa are a large group of single celled organisms. These organisms are highly mobile and “swim” about in the soil pore water. The protists are mostly predators that feed primarily on bacteria. Consequently they have a large influence on soil bacteria population. This feeding contributes to nutrient cycling by releasing nutrients that were contained in the bacteria. Examples shown here are an amoeba, a ciliate, a flagellate, and a water bear.

Bacteria are single celled organisms. They are also an extremely diverse group of organisms. Bacteria are capable of degrading a very broad array of organic compounds from sugars, proteins, and amino acids, to gasoline, oil, and diesel fuel, to herbicides and insecticides, to highly toxic organic chemicals such as PCBs.

Some bacteria are also extremely active in nitrogen cycling. Some have the ability to convert nitrogen from the atmosphere into forms that plants can use. We will talk more about that in a couple minutes. Others convert ammonium to nitrate (nitrification), and others convert nitrate to gaseous forms of nitrogen (denitrification). Some group of bacteria are responsible to solubilize fixed phosphorus in the soil by secreting week organic acids into available form.

The actinomycetes, like fungi, are filamentous and often highly branched. Actinomycetes are also able to degrade complex organic compounds such as cellulose, lignin, and chitin. They tend to be most active in the final stages of decay. Actinomycetes are often abundant in humus-rich soil. They release compounds known as *geosmins* that account for the earthy aroma of freshly tilled land.

A logical question to ask after that brief survey is "How much diversity might be found in a single soil, lets say in an acre of soil on your farm?"

We would expect to find

- Several species of vertibrate animals (snakes, mice, voles, chipmunks, groundhogs)
- Several species of earthworms
- 20-30 species of mites
- 50 – 100 species of insects
- Dozens of species of nematodes
- Hundreds of species of fungi
- Thousands of species of bacteria and actinomycetes. Perhaps as high as 5,000 species in a teaspoon of soil

The next question might be "How many of these organisms might we find in soil?" Just how abundant are they?

The numbers are truly staggering. Its also remarkable that as the organisms get smaller, both their numbers and their weight (biomass) tend to increase. With these kinds of numbers, it is not surprising that soil organism can have significant effects on the functions of agricultural soils.

In a diverse soil ecosystem, soil organisms are constantly interacting with each other. These interactions can occur in one of three ways.

Commensalism refers to the relationship of two organisms that live side-by-side, but have absolutely no effect on each other. These two guys could just as well be eating at separate tables and be just as happy.

Parasitism refers to a relationship between two organism where one benefits at the expense of the other.

Symbiosis refers to relationships between organisms that are mutually beneficial. These guys are helping each other. Working together they can work more effectively than working separately.

Soil organisms exhibit each of these relationships. Lets look at some examples of symbiotic or beneficial relationships.

We will look at three examples of interactions and interdependency

- Organic matter decomposition,
- Symbiotic nitrogen fixation, and
- Mycorrhizal fungi

The process of degrading fresh organic materials added to the soil is a complex process that involves intricate interplay from numerous species. If some of these organisms are absent, decomposition and related nutrient cycling will be much slower and may stop altogether.

Decomposition of complex organic material like plant litter begins with mixing and shredding. Earthworms and other soil arthropods are very adept at this. Earthworms pull litter into their burrows and mix it with soil. Insects and other macro-arthropods feed on the litter pulling it apart into small pieces. Mixing the material into the soil brings it into contact with other soil degraders and greatly increases the surface area exposed to the degraders.

When fresh organic material is mixed into the soil, bacteria respond almost immediately. They begin to feed on the simple organic compounds such as sugars, proteins, and amino acids. Bacterial numbers increase very rapidly in response to the food source. But the bacteria have a harder time with some of the more complex organic compounds in the litter, and these complex compounds sometime prevent the bacteria from getting at remaining material they could degrade. Its as if the food is locked in a cupboard.

The final degraders are the actinomycetes. They are the clean-up crew and come in at the final stages of decomposition. Like fungi they are able to degrade complex compounds like cellulose, lignin, and chitin.

No to be forgotten are the protists and nematodes. These are the predators, hunting around in the soil for the creatures that got fat from eating the plant litter. They feed on the bacteria and fungi and release nutrients into the soil.

Degradation of organic material involves in important balance between carbon and nitrogen in the material being degraded, in the degraders, and in the soil.

When fresh litter is degraded, about 2/3 of the carbon is released as carbon dioxide, and about 1/3 goes into building new biomass. This cycle repeats over and over until the material is degraded to stable soil humus.

Bacteria and fungi have an average C/N ratio in their cells of about 8:1. This ratio must be maintained. If fresh organic material has a C/N ratio of around 24/1, this provides exactly the ratio needed to keep the bacteria and fungi C/N ratio at 8:1. This is because with 2/3 of the carbon being lost as carbon dioxide, the C/N ratio of what the microbes actually use is very close to 8:1.

If the litter has a high C/N ratio, say 90:1, the microbes will be taking up material with a C/N ratio of 30:1. This is much too high in carbon. They need nitrogen and will scavenge nitrogen from the soil in a process called N immobilization. Because microbes are much better at grabbing nitrogen than plants and plants become nitrogen deficient. In general, if the litter C/N ratio is above 30:1, immobilization will result. If the litter has a low C/N ratio, say 9:1, the microorganisms will be taking up material with a C/N ratio near 3:1. This is much more N than they need, and the excess N will be released to the soil as inorganic N in a process called mineralization. Mineralization will usually occur if litter C/N ratio is less than about 20:1.

Related to nitrogen availability is symbiotic nitrogen fixation, a well-known process to farmers world-wide. Many bacteria have the ability to convert elemental nitrogen of the atmosphere into inorganic nitrogen that plants can utilize. This process, however, can be made much more efficient if the bacteria don’t have to go searching for food to keep themselves functioning.

Some species of bacteria, notably the rhizobia, have developed symbiotic relationships with the roots of leguminous plants. The plant roots keep the bacteria well supplied with the sugars they need to thrive. In return the bacteria busily fix nitrogen and supply it to the plants.

Another symbiotic relationship in the soil, that of the mycorrhizal fungi, may be less familiar. Although many fungi live by degrading organic material in the soil, there are also several fungal species that rely on a close association with plants for their livelihood. These are known as mycorrhizal fungi. The term mycorrhizae means “fungus root”. These are symbiotic relationships because they benefit both plant and fungus. Some of these fungi live on the external surfaces of roots, while some actually invade the root cells of the plant. This type of fungus is known as a “vesicular arbuscular mycorrhizal” fungus. The VAM fungus forms arbuscules inside root cells where there is an exchange of nutrients provided by the fungus, and sugars provided by the plant. The vesicles are storage organs formed by the fungus. These types of fungal – root associations are formed with almost all important agronomic crops.

The fungi benefit from the association with plant roots because they can feed on sugars produced by the plant. Because of this the fungus does not have to compete with other soil organisms for its food.

The plants benefit because in return they receive nutrients and water from the fungi. The fungal hyphae are able to reach a much greater volume of soil than the plant roots can. In many cases they extend 5 – 10 cm beyond the reach of the roots. The hyphae also can squeeze onto soil pores spaces that are too small for root hairs to penetrate. In many cases the fungi are better at extracting nutrients from soils than are plant roots. This is especially true of phosphorus, and especially true in low fertility soils.The fungi also bring water to the plant roots. Mycorrhizal fungi, and fungi generally, have a strong influence on soil structure. Their hyphal strands help to hold soil aggregates together, and they also excrete organic substances that help cement the aggregates.

Several soil environmental factors affect the growth and activity of soil microorganisms. Some of these are factors that are altered by soil management.

In general as soil organic matter increases, so too does microbial growth and activity. The type of organic matter will have some effect on the type of microbial community in the soil. The residue of a single crop may be favored by a certain microorganism. In a monoculture of that crop, the favored microorganism will predominate.

Microorganisms are sensitive to oxygen status. Most microbes that are beneficial to crop production are aerobic, or require oxygen. Aerobic organisms will have a hard time thriving in a soil that is frequently flooded.

To thrive, microorganisms require adequate moisture and are most active at temperatures ranging from about 68–86°F (20-30°C). If the soil is too dry, too cold or too hot, microbial activity will slow considerably.

Finally soil fertility, especially adequate calcium and near neutral pH will favor growth of most desirable microorganisms.

Tillage represents a major soil disruption and tends to decrease diversity. Incorporating plant residues will stimulate activity of those microbes that can most effectively degrade that type of plant litter.

As was mentioned a moment ago, adding lime or nutrients to an infertile soil will tend to increase microbial activity and biomass. Adding other organic materials, such as manure or green manures, provides another type of food, and helps to increase overall organic matter levels. Thus microbial activity and biomass will tend to increase from this management practice.

No till or reduced till systems are less disruptive of the soil and tend to build up organic matter at the soil surface. This tends to increase microbial diversity and activity.

Pesticide applications have mixed effects on microorganisms. The chemical may be toxic to some and thus detrimental. Activity of bacteria that can degrade the chemical will be increased.

There are several mechanisms by which pesticides are inactivated and lost from soil. These include:

- adsorption, getting stuck onto soil particles so they cannot be taken up by plants or attacked by microbes,
- Leaching, being moved out of the soil profile by water percolating through the soil,
- Volatilizing, essentially evaporating into the air,
- Photodecomposition, being degraded by the ultra-violet light from the sun,
- Chemical decomposition, purely chemical reactions that break apart the pesticide molecule, and finally,
- Microbial decomposition, breaking apart the pesticide molecule due to attack by soil microbes.

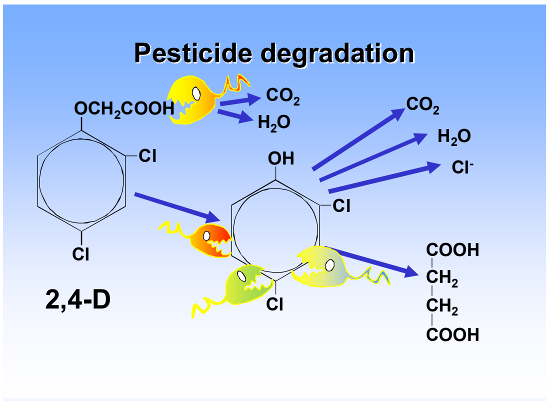
Although any of these mechanism can be a significant mechanism of pesticide loss for certain pesticides and for certain soils, overall the most important means is microbial degradation.

Pesticides are organic molecules and so they represent a source of food for soil microbes, especially the bacteria. Because every pesticide has a different molecular structure, not all bacteria are able to use them as food. But among the millions of bacteria in the soil, there will be some that can start to chew on the pesticide molecule. Because most pesticides are very complex molecules, it often takes several species of bacteria to degrade the molecule.

Normal application of pesticides adds a very small amount or organic carbon and nitrogen to the soil, especially compared to what is already present in the soil organic matter and crop and animal residues. Thus pesticides are really not significant overall as a food or energy source for soil microbes. In most cases they are simply degraded along with the more important food molecules that microbes are consuming.

Shown here is a highly simplified diagram of how 2,4-D is broken down in soil. The acetic acid group (vinegar) at the top of the ring is open to easy attack. Bacteria quickly chew it off and produce some carbon dioxide and water. The aromatic ring is much tougher to break, but bacteria with the right enzymes come along and break it open and start chewing up the carbon atoms that make up the ring, releasing harmless carbon dioxide, water, and chloride. The remaining simple 4 carbon molecule will also get chewed up until all that's left is carbon dioxide, water, and chloride.

Once an herbicide is applied to soil, there is usually a lag time of one to two weeks during which very little degradation occurs. During this time period the bacteria that feed on the herbicide are rapidly multiplying in response to the new food source. When their population gets sufficiently large, their feeding really begins to deplete the herbicide concentration in the soil. The rate of bacteria population buildup depends on things like soil temperature and moisture. If it is warm and moist, the lag time will be short, if it is very cold or very dry it will be much longer.



For good weed control with soil-applied or residual action herbicides, the herbicide concentration in soil has to stay high enough for long enough to suppress weed germination and growth. This critical soil concentration does not pertain to foliar applied herbicides such as 2,4-D. For soil applied herbicides we don't want the lag time to be too short. But we depend on soil bacteria to degrade the herbicides so we don't run into problems with carryover effects on the next crop, or with buildup of herbicides in soil. Thus we want herbicide concentration to drop below the maximum safe concentration by the next cropping season. Build up of herbicides in the soil could also lead to undesirable crop uptake, or movement to groundwater or surface water.

It is difficult to quickly summarize pesticide effects on soil organisms because of the huge number and variety of both soil organisms and pesticides. In addition, factors such as soil type, temperature, moisture, pH, pesticide concentration and duration of exposure all influence effects on non-target organisms.

In general most herbicides have minimal adverse effects on soil organisms. Some may affect algae, which would make sense since algae are plants.

Insecticides obviously can affect non-target soil insects, and some are known to be toxic to earthworms.

Fungicides and soil fumigants have adverse effects on a broad array of beneficial fungi, nematodes, and other soil fauna in addition to the target pathogenic fungi or nematode.

Earthworms are very important soil animals as we discussed earlier.

Overall, most herbicides are harmless to earthworms. The triazine class of herbicides appears to have moderate toxicity for earthworms. An indirect effect of herbicides and good weed control is a reduction in populations because of loss of plant cover and food supply for the earthworms.

Insecticides vary widely in their effects on earthworms. Keep in mind that there are numerous species of earthworms and they vary in their sensitivity to various chemicals.

In general the carbamate class of insecticides are highly toxic to earthworms.The organophosphate class of insecticides as a rule are of relatively low toxicity to earthworms.

The pesticides with the greatest toxicity for earthworms are carbamate fungicides and broad spectrum fumigants. Toxicity of fumigants is made worse by the fact there is little possibility for worms to avoid contact with the chemical.

There are things that can be done to reduce the effects of toxic pesticides

- reduce the frequency of application. Allow a few years for populations to come back up to normal levels before the next application. Annual applications of a toxic chemical for several consecutive years will take its toll.
- Avoid broadcast applications at times when worms are most actively feeding and tend to be near the soil surface.
- Band application greatly reduces contact with earthworms and so minimizes the effect on the overall population.

We have opened the black box of soil microbiology, at least a little bit. Lets quickly review some of the key things we saw in that black box.

- Soils are highly complex and diverse ecosystems
- The abundance of soil organisms is immense. They are characterized by large numbers of organisms and large biomass.
- There are many different kinds of organisms – thousands of species of bacteria in a single teaspoon of soil
- This wide array of organisms carries out many different functions in the soil.
- Diversity in a soil ecosystem gives it stability and resilience. It increases its capacity to function under adverse conditions.
- The relationships among soil organisms are very complicated and highly interdependent. Some are commensile, some parasitic, some symbiotic. Many of these relationships are highly beneficial for agricultural soils.
- Soil management and broader agricultural production practices can significantly affect the diversity and abundance of life in the soil ecosystem.

Management of Biotic and Abiotic Stresses in Sesame and Niger

A.R.G. Rangantha[1] and M.R. Deshmukh[2]

[1]Director (DWSR) and Project Coordinator (Sesame and Niger)
[2]Scientist, Sesame and Niger
JN Krishi Vishwa Vidhyalaya, Jabalpur-482004 (MP)

Sesame

In the recent past, the international demand and market for sesame has witnessed substantial growth. Sesame is one of the most ancient crops grown in India for several thousand of years. It is grown in more than 55 countries of the world. Asia contributes for more than 68% area and 67% production in world. The country ranks first in area (1870 thousand ha) under sesame and earns Rs. 1800 crore through sesame export. Sesame is quality edible oil, food, biomedicine and health care, all in one. The excellent nutritional, medicinal, cosmetic and cooking qualities of sesame oil made it queen of oils. The seeds are rich in quality proteins and essential amino acids, specially mithionine and tryptophan, which are essential for health and utilization of B complex. The seed is a rich source of linoleic acid, vitamins, niacin and minerals including calcium and phosphorus. Sesame seeds are used in the preparation of baby foods, which are considered as the best substitute for mother's milk to compensate the breast feeding. Sesame oil with 85% unsaturated fatty acids is highly stable and has reducing effect on cholesterol and prevents coronary heart diseases. It is grown in all seasons of the year and being a short duration crop, fits well in to various cropping systems.

I. Boitic stresses

A. Disease management

a) **Cultural practices:** Phytosanitary measures, crop rotation, date of planting, integrated fertilizer management, application of required micronutrients, desired plant population and removal of weeds etc. provide effective control of diseases.

Practice	Disease managed
Pathogen free site	All major diseases
Deep ploughing in summer	*Sclerotium rolfsii* , *Phytopthora, Rhizotonia* and *Fusarium*
Good drainage	Phytophthora blight, Fusarium root rot, vascular wilt, Macrophomina root rot/ stem rot
Manipulation in planting:	
(a) Shallow planting (2.5 cm)	Rhizoctonia root rot, Macrophomina stem and root rot
(a) Plant spacing	30x10 cm (3 lakh plants/ha) reduced Macrophomina stem/ root rot and Phyllody
(c) Early plating (Immediately after onset of monsoon)	Cercospora leaf spot, Alterneria leaf spot and Bacterial blight
(d) Late planting (About 3 weeks after onset of monsoon)	Macrophomina stem and root rot, Rhizoctonia root rot, Phytophthora blight and Phyllody

Crop Rotation	Phytophthora blight, Fusarium wilt and root rot, Macrophomina stem and root rot, Corynespora blight
Intercropping system	
(a) Sesame + Pearl millet (4:1)	Phytophthora blight and Cercospora leaf spot
(b) Sesame + Mothbean (1:1 or 2:1)	Macrophomina stem and root rot
(c) Sesame + Pigeonpea (1:1)	Phyllody
Mixed crop with Urid, Moong, Cowpea, Guar and Mothbean	Fusarium and Rhizoctonia root rot
Irrigation every two weeks (whenever necessary)	Macrophomina stem / root rot

Chemical control: Seed treatment with Thiram (3g/kg)/ Mancozeb (3g/kg)/ Bavistin (2g/kg)/ Captan (3g/kg)/ Thiram (2g/kg) + Bavistin (1g/kg) should be done before planting. Foliar fungal diseases can be checked by the spray of Mancozeb (0.3%), Zineb (0.3%), Copper oxychloride (0.2%). Soil treatment with Benlate or Rizolax-T. Powdery mildew can be controlled by spraying sulfex (0.3%) or Kerathane (0.1%).

Seed treatment with streptocycline (250-1000 ppm) is recommended for bacterial diseases. Hot water treatment by dipping the seed in water at 51^0C for 10 minutes followed by water having 0.025% Agrimycin 100 for 6-9 hours is also effective. The foliar infection can be checked by spraying steptocycline (500 ppm).

For the control of leaf curl virus the vector white fly needs to be controlled by spraying of oxydemeton methyl 10.025% Dimethoate or monocrotophos (0.05%) has been recommended to control *Orosius albicinctus* the vector of phyllody MLO. Tetracycline 500 ppm spray at flower initiation stage is also effective against phyllody.

Varietal resistance: The varieties/lines resistant to single and multiple diseases have been developed to minimize the losses due to diseases in different areas are given below.

Varieties/lines of sesame resistant/ tolerant to different diseases

Disease	Resistant varieties/lines
Wilt	JT-7, N-32, MB-12,
Macrophomina	AT-9, HT-16, RT-46, ST-58, Gwalior-6, ES-25, ES-105, ES-124,IS-156, IS-190, Line-144,
Stem/root rot	885, BAG-59, 21,65,9,5,11, RT-46, JTS-8, SI-249, SI-254-1
Phytophthora blight	75/1-1/2-1, M-3-1, M-3-2, No.-2-39, No.-66-193
Alternaria blight	No.2, No.4, J-77, E-8
Cerospora leaf spot	IS-4,14, 15, 21, 29 No.-4, No.-41A,No.-41B, No.-128, No-128A, L-36, RSB-1, HT-1,SI- 2373, SI-1501, SI-1032, X-79-6, TMV-6, S-1683, BIC-7-2, Sidhi-54, Rewa-114, Seoni Malwa, 65b58, 60/2/3-8B, 69B-392,73A-96B
Powdery mildew	CO-1, RS-129, BS-518-6G, X-74-24, SI-3170, 59-1-1, IS-401
Synchytrium gall	JT-66-276, SP-70-23
Bacterial leaf spot	Maporal, Ajimo Atar S-5, Morada, Almora white, C-24, C-87, C-96, M-31, NP-8, NP-23, Punjab-1, SSM-34, SSM-44, SSM-49, EC-4094, EC-13536, EC-14536, EC-20783, EC-20785, EC-20787,N-63-177-74-145, TC-325, T-58
Bacterial blight	T-58, Tozi-3, S-76F2-22, K-112
Phyllody tolerance	RT-46, RT-54, RT-103, RT-125, VRI-1

B Insect pest management

Cultural practices: After harvesting of kharif crop, the field should be ploughed to expose pupae for predation, soon after harvesting, straw and stubbles should be removed and utilized as animal feed or composted so that the carry over of the pests is avoided. Keep the crop free from weeds by regular weeding. Early sowing (in the Ist week of July) and use of early varieties like OMT-11-6-3 and JT-7 for 80-85 days, and the proper use of balanced doses of fertilizer to give a phillip to the crop growth make the crop to pass the vulnerable stage before Antigastra and gall fly build up the population above economic threshold level. Removal of Antigastra larvae from the leaf webs during the initial stages of plant growth. Clipping of galls, picking and burning the shaded buds of gall fly. Intercrop with cowpea, pigeon pea, peal millet, moong bean, urid bean and moth bean proved to be effective than sole crop for minimizing the damage by Antigastra and other insect pests.

Mechanical methods: Light traps are helpful to assess/monitor local populations of some pests for forecasting/warning systems and also as tools for their control. They are useful against leaf roller/capsule borer and hairy caterpillar. Collection and destruction of sphinx caterpillar. Collection and destruction of leaf rolls, shoots, infested capsule of Antigastra and gall fly infested buds. Collection and destruction of egg masses of S. oblique and early instars of caterpillars when they are in congregation. Birds eat the caterpillars when they find them and help to check them when they are numerous.

Tolerant varieties: Resistant lines lik IS-231-1, IS-158-2-84, SI-250,ES-12 and ES-22 for leaf roller/capsule borer and SI-1058, SI-1291, S. alatum, IS-65 and VS-81 for gall fly can be utilized as donars in breeding for resistance. Varieties tolerant for different pests are listed below:

Leaf roller/capsule borer: RT-46, RT-54, RT-103, RT-125, RT-127, JT-21 Usha, Swetha Til, Tapi, Krishna and N-32.

Gall fly: N-32,32 RT-46,Swetha Til, RT-103, RT-108, RT-125,OMT-26, RAUSS-17-4.

Leaf roller- capsule borer and gall fly: RT-46, RT-103,Swetha Til, RT-127, N-32.

Gall fly and mites: RT-127.

Hairy caterpillar: Tilottama and Rama for rabi/summer.

Leaf miner: TMV-3

Chemical Control: When pest-population reaches to E.T.L. (Economic threshold level), the choice of insecticides should be made with care which may kill the target species and be relatively safe to beneficial organisms like parasites and predators. Apply Phorate 10G @ 10 kg/ha as basal application. Spray with endosulfan 0.07% or quinalphos 0.05% or monocrotophos 0.05% or dimethoate 0.03% *viz*., first at 30 DAS (days after sowing) and second at 45 DAS will control *Antigastra* and *Asphondylia*. It resulted in the cost benefit ratio of 1:4.4. Endosulfan 4% or Carbaryl 15% or Phosalone 4% dust @ 25kg/ha is effective for the control of *A. styx* and other leaf eating pests. Two rounds of spray with neem oil or neem gold or neemicidin were found effective for the control of *Antigastra* at 30 and 45 DAS.

Biological control

Host: *Antigastra catalaunalis* Dup.: *Bracon gelchi* Ashm. Larval parasite; *Trathala flavo-orbitalis* (Cameron); Larval parasite (parasitism 8-12% from June-October); Predator: *Cantheconidia furcellata*.

Host: *Acherontia styx* Westwood : *Trichogramma* spp. Egg. Parasite active during August (93.4%); *Apanteles achorontiae* (on larval parasite); *Zygobothria* sp. Larval parasite during Ist week of September (95%).

Host: *Spilosoma oblique* Walker : *Trichogramma evanescens minutum* Riley-Egg parasite; *Apanteles obliqua* Wilkinson; Microbes: *Bacillus thuringiensis* var. *Kurstaki* (Dipel) 96% mortality of final star within 72 hrs of application.

Host *Asphondylia sesami* Felt : *Eurytoma dentipectus* Gohan; *E. nesiotes* sp. Crawford (Parasitising maggots)

Host: *Orosius albicinctus* Dist.: Predates: *Brumus sutugalis* (Early instar nymphs)

Weed management

Weeds are the major constraints in sesame production. Sesame is grown in all the seasons and therefore, the *floristic* composition of weeds vary depending upon the season and agro-ecological condition.

Mechanical and cultural: Minimum of two hand weedings, one at 15-20 DAS and another at 35-40 DAS keep the field weed free. Use of black polythene (250 mμ), as a mulch in between rows was effective in controlling weeds in inter-row spaces and increased the yield by 135%. Mechanical weeding by using hand hoe was also effective in controlling weeds in inter-row spaces. Growing of preceding crops with high smothering effect, selection of competitive varieties, stale seed bed technique, plant population, time and method of sowing, nutrient placement, intercropping with urdbean, mungbean, soybean, groundnut etc. are some of the cultural practices which can be used as a tool for weed management in sesame.

Chemical method: Hand weeding, though very effective, has own limitations for managing the weeds at desired stages due to large area, untimely rains, scarcity of labourers during critical period, increased wages and infavourable soil conditions, removing weeds within rows. Under such situations, herbicidal weed control has been found most effective and economical. Pre-plant incorporation of fluchloralin 0.75 kg/ha, pre-emergence application of pendimethalin 1.25 kg/ha or alachlor 1.5 kg/ha were found safe and effective in controlling weeds and increasing the sesame yield.

II Abiotic stresses

Prolonged drought, water logging, salt concentration, fluctuations in temperature and photo period are the important abiotic stresses often experienced during growth of sesame. Climate and environmental factors e. g. amount of rainfall and its distribution, temperature, radiation, photoperiod, humidity and soil factors e. g. type, depth, topography and soil fertility conditions are important for the growth of sesame.

Drought: Sesame is considered to be drought tolerant crop. After the seedling stage, sesame is capable to withstand a high degree of water stress than many other cultivated plants. Resistance of sesame to drought seem to be associated with its tropical origin and high root/ shoot ratio. However, during the plant establishment phase it is extremely susceptible to moisture stress. Once established, the crop grows almost entirely on stored soil moisture and with only occasional shower of rain in the early stage and good yield are obtained. The indehiscent types seem to be better suited to water stress than dehiscent type. Single stem type with deeper root system and high elongation rate than branching types are better suited for drought conditions.

Wild species*, Sesamum angustifoluim* is the highly drought resistant as it shows high percentage of fruit set (89%) during dry season. The adaptive features of this species are fleshy roots, small linear leaves a large number of stomata located only at the adaxial surface, hairiness and high capsule set in the dry season when other annuals in vicinity dry. This species has the potential of donating valuable genes for resistance to drought in to the cultivated *S. indicum.*

High temperature: Sesame normally requires fairly high temperature during its life cycle. Temperature for optimum growth from seedling to flowering and fruiting is in the range of 25-30°C. A temperature of 25-27°C encourages rapid germination, initial growth and flower formation. High temperatures particularly during night, promotes stem growth and leaf production. Temperatures above 40°C or above at flowering can seriously affect fertilization and number of capsules set. On the other hand, if temperature falls below 20°C for longer time, germination and seedling growth are delayed and these processes are inhibited at temperatures below 10°C. Varieties from moderate climate when grown under high temperature conditions, exhibit oozing symptoms followed by blackening of stem and branches due to fungal growth. RT-46, RT-125, RT-54 and RT-127 tolerate high temperature and are resistant to oozing complex. These varieties escape drought due to early maturity and can be grown in the drought prone areas.

Rainfall: Heavy and /or continuous rains at any time during crop growth will create water logging and increase the incidence of diseases and pests to cause heavy crop damage.

Water logging : The sesame crop is highly sensitive to water logging.

Salinity and alkalinity: Sesame is highly susceptible to salt concentration. Paradoxically, many soils on which sesame is grown are saline. A lot of variability in tolerance to salt water has been reported, there is ample scope for breeding sesame varieties suitable for areas of high salt concentrations. Variety TMV-1 has been found to be tolerant to 10,000 ppm sea water. Phosphorus concentration was found to change the salt tolerance in sesame. At low soil salinity levels, increasing P concentrations increased seed yield but at higher salinity levels yield decreased progressively as P increased. Thus P reduced the salt tolerance of plants at high soil salinity levels.

Soils with neutral reaction are preferred, although good results have been obtained on slightly acid and slightly alkaline soils. Sesame does not thrive well on acid soils. It will grown in soils of pH 5.5 to 8.0, but at higher pH soil structure becomes of increasing importance.

Management – Drought

- **Manipulation of sowing time:** Sesame is mostly grown in drought prone areas and cultivation is mainly rain dependent. Therefore, the crop should be sown at such a time which ensures utilization of maximum rainwater at the most crucial stage of flowering and capsule formation. Sowing of crop with the onset of monsoon in the areas of scanty rainfall has been found beneficial.
- **Seed hardening:** Seed priming with soaking of seed in water for 8hrs followed by drying before sowing was found to significantly improve the crop establishment.
- **Intercropping:** Moth bean and Urid bean when grown as intercrops with sesame, covers the soil surface and prevents it from direct exposure and evaporation due to sun. Ultimately the main crop will, also utilize the moisture thus conserved.
- **Mulching:** Mulching with organic wastes or polythene sheets in between rows, as per feasibility, may be useful to conserve the moisture in the situations of prolonged drought.
- **Clean cultivation:** Weeds compete with the crop for moisture, nutrients and sun light. Removal of weeds by hand hoeing and leaving them on soil surface to form mulch will also conserve moisture.
- **Tolerant varieties:** Tolerant and early maturing varieties are the best and low cost-non-monetary input technology for stress management. RT-46, RT-54, RT-127 are short duration, drought resistant varieties and can be cultivated to manage the drought.

Excessive moisture

- Studies on surface drainage indicated that broad raised bed and furrow method of sowing with 30 cm deep x 45 cm broad drainage channels intersecting at 8-10m depending upon the soil topography, resulted in significantly higher yield over the flat bed method sowing. The furrows in high rainfall areas do not allow water stagnation

NIGER

Niger, a little cared ecofriendly oilseed crop, is the life line of tribal agriculture and economy in India. India ranks first in area, production and export of niger in the world. Niger is primarily grown on the denuded soils in hilly and tribal pockets under input starved conditions. Niger crop grows without costly chemicals. Niger is less vulnerable to biotic and abiotic stresses as compared to other oilseeds. Niger has orthodox seed storage behavior and when properly dried can be stored up to 2 to 3 years under ordinary condition without losing its viability. Niger oil has good keeping quality, has 70% unsaturated fatty acids, free from toxins and the oil is considered good for health.

I. Biotic Stresses

Disease management: Niger crop suffers from relatively less number of diseases. However, Ozonium wilt (*Ozonium texanum* var. *Parasiticum* Thirum.), Collar rot (*Sclerotium rolfsii* Sacc.), Macrophomina rot and blight [*Macrophomina phaseolina (*Maubl.) Ashby], Damping off, root rot (*Rhizoctonia solani*), Cercospora leaf spot (*Cercospora guizoticola)*, Alternaria leaf spot (*Alternaria* sp.), Curvularia leaf spot (*Curvularia lunata*) Powdery mildew (*Sphaerotheca* sp.)Rust (*Puccinia guizotiae*), Bacterial leaf spot (*Xanthomonas campestris* pv. *guizotiae*), Cuscuta (*Cuscuta hyalina*) have been reported on niger.

Several seed borne fungi like *Alternaria* sp., *Aspergillus flavus*, *A. niger*, *Rhizopus nigracans, Cercospora guizoticola, M. phaseolina and R. batalicola* etc have been reported. Besides, bacteria like *Xanthomonas campestris* are also seed borne.

Cultural practices

Practice	Disease managed
Pathogen free site	All diseases
Deep ploughing in summer	Collar rot, root rot, wilt
Pathogen free seed	Seed borne diseases
Manipulation in planting	
(a) Shallow planting (2.5 cm)	*Rhizoctonia solani* and *R.bataticola*
(b) Planting spacing 30x10 cm (3 lakh plants/ha)	-do-
Irrigation to avoid stress condition	*Rhizoctonia bataticola*

Tolerant varieties

Variety	Tolerant to	
	Alternaria leaf spot	Cuscuta
IGP-76	+	-
Deomali	+	-
GA-11	+	-
ONS-8	+	+ (Moderately susceptible)

Chemical protection

Disease	Chemical	Mode of application
Root rots and wilt	Thiram (0.15%) + Captan (0.15%) in 1:1 + Urea (2%)	2-3 times soil drenching, in infected area and one meter around, along with the plant using sprayer without nozzle from the initiation of disease at 7 days interval
Leaf spots caused by Alternaria, Cercospora and Curvularia	Zineb (0.25%) or Mancozeb (0.25%) or Topsin-M (0.1%) or Bavistin (0.1%)	2 sprays as and when disease appear at 10 days interval
Bacterial leaf spot	Agrimycin 100 (250 ppm) or Streptocycline (500 ppm)	-do-
Powdery mildew	Sulfex (0.3%)	2 sprays starting from the initiation of disease at 10 days interval
Cuscuta	Basalin (1kg ai/ha)	Pre-sowing soil application
	Pronamide (kerb 50 W) @ 2kg	Pre-emergence soil application

Insect pests management

As Niger caterpillar (*Perigea capensis*), Cutworm (*Agrotis ipsilon*), Bihar hairy caterpillar (*Spilosoma obliqua*), Surface grasshopper (*Chrotogonus* sp), Aphid (*Uroleucon carthami*), Capsule fly (*Dioxyna sororcula*), Semilooper (*Achaea janata*), Green semilooper (*Plusia orichalcea*) and Green bug (*Nezara virdula*) are the insect pests reported.

Cultural methods: Clean cultivation; After harvesting of *kharif* crop the field should be ploughed to expose pupae for predation by birds and other enemies; Crop rotation and inter cropping.

Mechanical methods: Light traps are helpful to assess/monitor population of some lepidopterous insect pests like hairy caterpillars and cutworms for forecasting/warning system and effective in trapping their adults. Collection and destruction of egg masses and early instars of caterpillars when they are in congregation; Collection and destruction of larvae of hairy caterpillars and niger caterpillar.

Tolerant varieties: As regards the varietal response against most of the pests like Spilosoma oblique and *Perigea capensis*, it was noticed that early maturing varieties were attacked more as compared to late maturing ones. GA-10 and GA-5, being late maturing varieties, were attacked less by *S.obliqua* and *P.capensis*.

Chemical control: Spraying with dimethoate 0.03% or endosulfan 0.07% or dichlorovos 0.05% as and when required proved to be effective against insect pest of niger; Dusting with endosulfan 4% or phosalone 4% @ 20-25 kg/ha for effective control of D. oblique and other leaf feeding caterpillars.

Biological control

Host: *Spilosoma obligua*: *Trichogramma evanescens* minutum Rile-parasite; Apanteles oblique Wikinson. Microbes: *Bacillus thuringiensis* var *kurstaki* (Dipel) 96% mortality of final instar within 72 hr of application.

Host: *Perigea capenisis*, *Achaea janata*-: Nymphs and adults of *Creboter urbana* were found feeding on niger caterpillar and small larvae of semilooper (Mathur and Shrivastava, 1986). Therefore, these predators should be utilized for controlling larval pests.

Weed management

Weeds are the major constraints in realizing the optimum yield of niger. The crop is generally sown as broadcast with the result weeding becomes difficult and interculture operations are not possible. The important weeds in niger crop are Celosia argents, *Corchorus* spp, *Commelina benghalensis, C. communis, Ageratum conyzoides, Hibiscus* sp., *Eclipta alba,* etc. (among broad leaved), *Echinochioa colonum, E. crusgalli, Cynodon dactylon, Setaria glauca, Digitaria sanguinalis* etc. (among grasses) and *Cyperus rotundus*. Dodder (*Cuscuta* spp.), a parasitic weed is the major menace of niger in some parts of the country like Orissa, A. P. and Parts of M. P. (Tosh *et al.,* 1977).

Mechanical control: Hand weeding at 15 days after sowing (DAS) and if necessary, second weeding at 30 DAS (before top dressing of nitrogen) should be one. Taking short duration crops such as cowpea and frenchbean before niger may exhaust weed seed bank in the soil resulting in less weed population in niger. Inter cropping of cowpea, frenchbean, soybean, greengram and blackgram etc. in between the niger rows also suppress the weeds.

Chemical control: Paraquat is found to be effective as a spot treatment. Tosh *et al*., 1977 reported that chlorpropham as granular formulation at 4.0 kg/ha at 6 days after sowing (DAS) and pronamide at 2.0 kg/ha at 20 DAS selectively controlled *Cuscuta* infestation without any phytotoxic effect on niger. Pronamide is also found effective if used as pre emergence at 1.0-1.5 kg/ha or post emergence (20 DAS) at 2.0 kg/ha (Misra *et al*., 1981). Similarly pendimethalin (1.0-1.5 kg/ha) was found effective in controlling *Cuscuta* in niger (Venkata Ramana, 1995).

Pre emergence application of oxadiazon 0.75 kg/ha, pendimethalin 1.0 kg/ha was found effective in controlling weeds and increasing seed yield. When theses herbicides were integrated with hand weeding at 30 or 45 Das, seed yield levels were substantially increased.

***Cuscuta* management- Preventive practices:** Seed should be obtained from *Cuscuta* free areas or it should be thoroughly cleaned before sowing. *Cuscuta* seeds can be separated from niger seeds by sieving with 70-100 mesh sieve; Niger should not be taken up in the previously *Cuscuta* infested fields; Non contaminated implements should be used in the fresh field during field operation and sowing.

Mechanical control: Frequent inter row cultivation before the parasite attaches to the host plant is the usual method to control the *Cuscuta*. However, it is laborious and often not effective.

Cultural practices: Suitable crop rotation, inter cropping, time of seedling and growing of non host crops like cereals in the infested areas could help in reducing the spread of *Cuscuta* infestation. The shallow tillage in dry spell in rainy season hastens soil to dry up and the small emerging *Cuscuta* seedlings dry up.

II. Abiotic stresses

Niger is generally planted as a rainfed crop in *kharif* as well as *rabi* seasons. The important feature of the crop is that it gives satisfactory seed yield even under poor growing conditions.

Drought: The niger plant has a deep root system which endows it with high degree of drought resistance in deep soils under rainfed conditions. The plant has the potential to tolerate physical and physiological moisture stress of the soil and at the same time possess the ability to thrive on poor soil. A rainfall between 800 and 1300 mm is optimum, but a well-distributed rainfall of 600 mm will produce a good seed yield.

High rainfall and water logging: The growth of niger may be depressed with a rainfall over 2000 mm, but the plant can withstand high rainfall during the vegetative phase. On account of this, niger is most suitable crop for hill regions of high rainfall and humidity. Niger is capable of growing better in water logged conditions. Niger roots show exceptional resistance to water logging due to the existence of acrenchyma, which varies with the degree of soil saturation.

Temperature stress: Moderate temperature between 18 and 30°C suits well to the niger plant, but the rate of growth and flowering are adversely affected by temperatures above 30°C causing forced maturity. On the lower side, the temperatures below 9°C adversely affect the plant growth. Frost kills the plants, particularly at seedling stage but the older plants are least affected.

Salinity: The tolerance of the niger crop to high salinity, high boron and low oxygen levels have been documented. Increasing salinity from 0-4 mmhos/cm depressed seedling emergence by less than 10% and at 8 mmhos/cm, upto 50%.

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Role of Potassium in Abiotic and Biotic Stress Management

A.K. Dwivedi[1] and B.S. Dwivedi[2]

[1]Principal Scientist
Directorate of Research Services
[2]Scientist
Department of Agronomy
J.N. Krishi Vishwa Vidhyalaya, Jabalpur-482004 (M.P.)

Abstract

Abiotic and biotic stresses negatively influence survival, biomass production and finally the crop yield. It is a challenge to understand the basis of abiotic and biotic stress tolerance and to manipulate them. This review intends to focus on the role of potassium in abiotic and biotic stress management in crop production. Moisture deficit created by drought or withholding irrigation results in a significant reduction in plant water potential, osmotic potential, relative water content, photosynthetic rate, respiration, etc. Moreover, a marked reduction in various growth characters like, leaf area, weight or yield has been reported under abiotic and biotic stresses incidence of insect-pest and diseases. The application of potassium in general, mitigates the adverse effect of such stresses, which facilitate the conditions, that favours more or higher growth and yield levels of crop.

Introduction

Potassium is an alkali metal that occurs naturally in most of the soils. The total K content of the earth crust is about 2.3 to 2.5 per cent, but only a very small proportion of it becomes available to plants (Leigh and Jones, 1984). It is one of 18 elements that are essential for both plant and animal life (Brady and Weil, 2002). Plants require K proportionately in large quantities, hence, it is regarded as one of the three major plant food elements (Golakiya and Patel, 1988; Leigh and Jones, 1994; Dev, 1995). Higher yields of better quality depend greatly on the capacity and capability of the crop to resist or tolerate moisture and temperature abnormalities, diseases and other stresses during growing periods (Amtmann *et al*., 2004; Dev, 1995). Potassium is involved in many physiological processes such as photosynthesis (Vyas *et al*., 2001), photosynthetic translocation (Umar, 1997; Tiwari *et al*., 1998), protein and starch synthesis, water and energy relations (Rao and Rao, 2004), translocation of assimilates (Tomar, 1998) and activation of number of enzymes (Vyas *et al*., 2001; Sharma and Agrawal, 2002). Potassium also improves the water use efficiency (Singh et al., 1997; 1998) through its influence on maintenance of turgor potential (William, 1999). As most of the *kharif* and *rabi* crops are grown under rainfed conditions, crops experience water and temperature stresses of varying degrees and duration at various growth stages, thus, relevance of K nutrition under such stress conditions may assume great importance.

Potassium in Plant System

Potassium, an important macronutrient for plants, carries out vital functions in metabolism, growth and stress adaptations (Krauss, 2001; Krauss and Johnston, 2002). These functions can be classified into those that rely on high and relatively stable concentrations of K^+ in certain cellular compartments and those that rely on K^+ movement between different compartments, cells or tissues (Vyas *et al*., 2001). The first class of functions includes enzyme activation, stabilization of protein synthesis and neutralization of negative charges on proteins (Marschner, 1996). The second class, linked to its high mobility, is particularly evident where K^+ movement is the driving force for osmotic changes as, for example, in stomatal movement, light-driven and seismonastic movements of organs, or phloem transport (Amtmann *et al*., 2004). In other cases, K^+ movement provides a charge-balancing counter-flux i.e. essential for sustaining the movement of other ions (Singh and Singh, 1999). Thus, energy production through H+ ATPases relies on overall H+/K+ exchange (Tester and Blatt, 1989). Accumulation of K+ (together with an anion) in plant vacuoles creates the necessary osmotic potential for rapid cell extension (Singh and Singh, 1999; Warwick and Halloran, 1991).

Potassium deficiency leads to (i) growth arrest due to the lack of the major osmoticum (Singh *et al*., 1997 ; Warwick and Halloran,1991) , (ii) impaired nitrogen and sugar balance due to inhibition of protein synthesis, photosynthesis (William,1999) and long-distance transport (Bhaskar, *et al*.,2001) and (iii) increased susceptibility to pathogen probably due to increased levels of low molecular weight nitrogen and sugar compounds (Tiwari *et al*., 2001). In a natural environment, low-K conditions are often transient therefore, plants have developed mechanisms to adapt to short-term shortage of K supply.

Potassium is involved in numerous functions in the plant, such as in enzyme activation, cation/anion balance, stomatal movement, phloem loading, assimilate translocation and turgor regulation, etc. (Golakiya and Patel, 1988; Singh *et al*., 1999; Umar, 1997). Stomatal resistance decreases and photosynthesis increases with increasing K content of leaves (Peoples and Koch, 1979). In tobacco plants well supplied with K, 32% of the total N^{15} taken up within 5 hrs was incorporated into protein whereas, by 11% in K defi ient plants (Koch and Mengel, 1974). Potassium deficient leaf cells accumulate substantial quantities of low molecular weight organic compounds (Noguchi and Sagawara, 1966; Baruah and Saikia, 1989) because they act as an osmoticum in the absence of sufficient potassium.

Potassium and Stress Tolerance

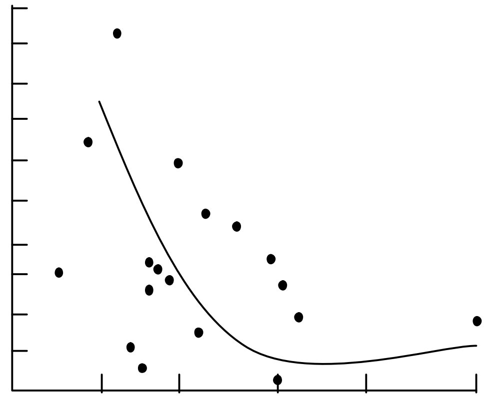
Abiotic and biotic stresses negatively influence survival (Agrawal *et al*., 2006) biomass production and crop yield (Amtmann *et al*., 2004; Dev, 1995; Tomar, 1998). Climatic extremes and unfavorable soil conditions are two major determinants affecting crop production (Singh *et al*., 2004). Potassium supply up to certain extent, can lessen their adverse effects on crop growth. The word abiotic means non-living and the components are those that do not have life, such as soil and climate / weather parameters. The biotic means living and components are those that have life, for example, plants, animals, microorganisms as well as some decomposers.

Abiotic Stresses

Soil moisture

The transport of K ion in soil medium towards plant roots takes place by mass flow and diffusion. On an average 10 per cent of total K^+ requirement of crops is transported by mass flow. In general diffusion is the main process of K^+ transport. According to Nye (1979) the diffusion of K^+ in the soil solution increases with soil moisture. Tortuousity i.e. the soil impedance increases with drying of soil. The diffusion coefficient for K^+ of about $1x10^{-7}$ cm^{-2} sec^{-1} at a soil water content of 23% decreases to $5x10^{-8}$ cm^{-2} sec^{-1} at 10% moisture content which is about $1.5x10^{-5}$ cm^2 sec^{-1} in pure water (Mengel and Kirkby, 1980). As water stress develops, K^+ helps in reducing the extent of crop growth loss through maintaining higher activity of enzyme nitrate reductase, which normally decreases under stress condition (Saxena, 1985). Potassium is also involved in the biosynthesis of proline and crop varieties with higher proline content are reported to have high yield stability as well as high productivity under moisture stress (Krishnasastry, 1985).

With variations in wet and dry conditions, the added K fertilizer may yield large responses in K responsive soils. Barber (1963; 1971) reported that lesser the rainfall for 12 weeks after planting, the greater the per cent yield increase of soybean from K additions (Fig.1). However, with low rainfall the roots tend to function more in the sub-soils and much lower in low K status (Nelson, 1978).



To provide 5 kg K/ha to the roots, the required K concentration in the soil solution in moist and dry soils varied. The drier the soil, the higher is the needed K concentration (Johnston *et al*., 1998). The K flux improves with the soil moisture (Fig. 2). On the other hand, a generous K supply can, to certain extend, compensate less diffusive K flux in drier soils.

With high rainfall and/or in waterlogged conditions the pore spaces in the soil get filled with water and oxygen content declines. This lowers respiration in plant roots and thus decline in nutrient absorption. However, by adding high amounts of K, the K need of the plant can be met even when root respiration is restricted (Skogley, 1976). Working on barley crop the adequate K had a reduced transpiration rate during stress (rate relative to 1.0 under non-stress) 5 minute after exposure to hot windy conditions. On the other hand, under severe K deficiency, the transpiration rate greatly increased. Greater water loss, thus, could limit the crop yield. Hot and dry winds are common occurrence in the plains and may be disastrous to crops.

Potassium fertilization can partially overcome the adverse conditions of poor aeration caused by waterlogging or compaction (Nye, 1979). The uptake of K is a process that requires energy provided by root respiration. If oxygen is lacking, root respiration is impaired and so is K uptake. As early as in 1963, Brown reported that poorly drained soils with low K resulted in poor yield as compared to the well drained soils. However, when K was increased to 150 kg/ha the yield increased even in poorly drained fields (Table 1).

Table 1. Yield of lucerne (ton/ha) under varying pH and drainage conditions

Soil drainage	pH 5.8		pH 6.5	
	37 kg K/ha	150 kg K/ha	37 kg K/ha	150 kg K/ha
Poorly drained	7.4	10.7	8.10	12.3
Well drained	9.2	10.7	9.8	11.9

Source: Brown, 1963

A number of physiological disorders are related to K levels in poorly aerated paddy soils. In such soils excessive ferrous (Fe^2+) or the presence of respiration inhibitors like hydrogen sulphide may inhibit K uptake and cause Fe toxicity, a disorder commonly known as "bronzing" (Dev,1995 ; Hardter,1997).

Soil salinity

Plant adaptations to saline conditions can depend on an increase in specific inorganic and organic solutes within the cell, which may contribute osmoregulation or to the ability to prevent the accumulation of salts within the cytoplasm (Warwick and Halloran, 1991; Singh and Singh, 1999) . The operation of either mechanism is important for tolerance and adaptations to salinity. Analysis of plant tissues for Na and K contents under salt stress condition has been suggested as one of the useful parameter to measure the varietal salt tolerance (Warwick and Halloran, 1991; Singh and Tiwari, 2006). In this regard, Singh and Singh (1999) tested four chickpea varieties including tolerant and susceptible for Na and K contents with increasing salt stress (Singh *et al*., 2004). It was observed that the values of K content in tolerant genotypes were significantly higher than those of susceptible genotypes (Singh *et al*., 2006).

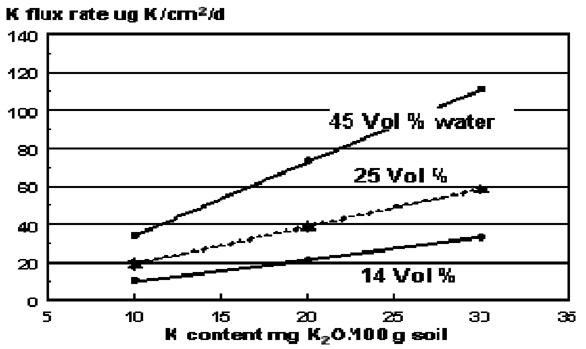


Fig. 2. K diffusive fluxes as affected by soil water content and K status of the soil (Source: Gath, 1992)

Temperature

Potassium can help plants to tolerate to both very high and very low temperatures (Grewal and Singh, 1980). The relationship between K nutrition and temperature is complicated by the interaction of soil and plant factor (Johnston *et al*., 1998). Frost damage has been reduced by maintaining of good level of K in the tissues of both annual and perennial crops (Grewal and Singh 1980; Shrinivasa Rao and Khera, 1995). The results from the findings of Grewal and Singh (1980) demonstrated that frost damage of the foliage of potato is inversely related to the K content of leaves.

Similarly, the pattern of K uptake increases with increasing temperature up to a maximum and very high temperature can be detrimental if the loss of energy through respiration becomes excessive. Alterations in the amount of shade influences the effect of factors, such as temperature and moisture condition on growth and yield and thereby, K requirements (Nelson, 1978; Dev, 1995; Rao, 2004).

Biophysical properties

The biophysical role of potassium, in turgor maintenance and expansive growth, particularly its role in stomatal regulation and its effects on water use and carbon dioxide assimilation processes are affected by K deficiency (Rao, 1999). However, moisture stress undoubtedly is known to reduce the turgidity of cells (Umar, 1997) and thereby, decreases stomatal conductance and photosynthesis (Singh *et al*., 1998). Potassium application helps in drought tolerance and enhanced maturity as well as juice quality in sugarcane. The application of potash @ 80kg K_2O/ha resulted in an increase in leaf area, diffusion resistance of stomata and thereby, reduced transpiration rate over without application (Tiwari *et al*., 1998). This could be due to adequate supply of the potassium. However, the stomata close rapidly under drought and minimize the transpiration rate (Umar, 1997). Role of K in stomatal regulation in *Brassica* under moisture stress had also been reported (Sharma *et al*., 1992).

It has also been observed that most of the tropical legumes experience frequent droughts of varying degree and durations during their growth periods. Potassium influences the water economy and crop growth through its effect on water utilization, by root growth reflecting maintenance of turgor, transpiration and stomatal behavior (Nelson, 1978) and consequently influencing dry matter production to greater extent (Cadisch *et al*., 1993). Singh *et al*. (1997) also observed relatively lower values of leaf osmotic potential under water stress. While, these increased upon watering, indicating the change in osmoregulation. Under stress condition, the decline in osmotic potential is mainly due to the accumulation of solute like K^+, proline and soluble carbohydrates. Moreover, the osmotic adjustment enables plants to deplete the soil water to a lower soil water potential level. Thus, facilitates a greater exploration of available soil moisture by roots (Singh *et al.*, 1997; Tiwari *et al.*, 1998; Willium, 1999).

Golakiya and Patel (1988) studied the effect of cyclic dry spells and potassium treatments on the yield and leaf diffusive resistance of groundnut. The repeated occurrence of stress conditions caused considerable reduction (up to 75%) in pod yield and the shortfall in production was still higher in the case of consecutive dry spells. Potassium application of 60 kg K_2O/ha enhanced the level of production over control (no water stress) and could also restore the loss in pod yield to a noticeable extent. A marked increase in the diffusive resistance of leaves with K fertilization supports the contention that potassium plays an important physiological role in counteracting adverse conditions caused by drought.

Photosynthesis is the process through which the energy of solar radiation is directly converted in to sugar, starch and other organic components (William, 1999). Though, K is not an integral part of chlorophyll molecule, but it influences photosynthesis to a greater extent. Photosynthesis rate drastically decreases under water deficit because of both stomatal and non-stomatal factors (Umar, 1997; Singh *et al.*, 2004). The reduction in photosynthetic rate is also due to decreased leaf water potential and RWC under water stress, which leads to decrease in stomatal conductance. The rate of photosynthesis is enhanced with supply of K in rooting medium because K helps in maintaining the rate by improving RWC and leaf water potential through osmotic adjustment under stress (Singh *et al.*, 1997). It has also been reported that accumulation of optimum K in guard cells provides the adequate amounts of solute necessary in developing proper leaf water potential gradient required for movement into guard cells for stomatal opening necessary for photosynthesis. The amount of solar energy transformed into dry matter production, thus will be greater even in moisture stress condition under adequate K supply (Cadisch *et al.*, 1993).

Effect of K levels (25, 50,100 and 200 ppm) on water relations, CO_2 assimilation, enzyme activation and plant performance under soil moisture deficit in cluster bean (Vyas *et al.*, 2001) have shown that the plant water potential and RWC declined due to water stress at all K levels . However, the decline was less in plants growth at 200 ppm K level as compared to plants grown at low K levels. Wyrwa *et al.* (1998) observed that in K depleted soils under drought condition, the triticale yield got decreased by more than 50% whereas, application of 100 kg K_2O/ha increased the yield to a level which was only about 17% less than the yield of plants well supplied with water (Fig. 3).

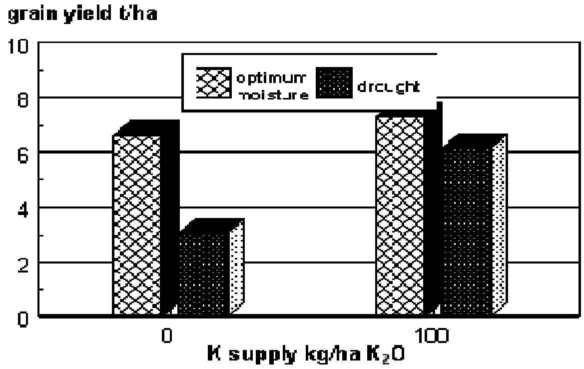


Fig. 3. Effect of potassium supply on yield of triticale as affected by drought

(Source: Wyrwa *et al.*, 1998)

The yield improvement due to K application in number of crops suggests that under low moisture K application may result in yield improvement only when K availability is limiting. The evidences indicate that application of K mitigates the adverse effect of water stress by favorably influencing internal tissue moisture, photosynthetic rates and nitrogen metabolism.

Biotic Stresses

Insect, pest and disease incidence

Crops are constantly subjected to several fungal, bacterial and viral deceases. It has been observed that disease incidence, in general increases with the increase in Nitrogen level (susceptibility) that results in an increase in reducing and non-reducing sugar contents, but invariably decreases with potassium applications (Velazhahan and Ramabadran, 1992). Amongst fungal diseases especially the sheath rot caused by *Sarocladium oryzae* in rice has assumed much importance in recent years by causing heavy yield losses (Bhaskar *et al.*, 2001). They reported that the sheath rot disease incident in rice increases with increase in N levels from 0 to 300 kg N/ha while, the phenol content in leaf sheath was found to increase with K application as compare to N levels. Further, it was observed that higher the phenol content, lower was the sheath rot incident probably due to growth of inhibiting pathogens.

Potassium has been shown to reduce the severity of several plant diseases. For example, Baruah and Saikia, (1989) reported that at low levels of potash the stem rot disease infestation in rice was relatively much greater ranging from 38.5 to 42.5 per cent, in comparison to optimum K levels. Potassium inhibits the accumulation of soluble carbohydrates as well as nitrogenous compounds in the tissues, thus helping to counteract a situation that favours fungal growth when K level is deficient. Similarly, lignifications of vascular bundles could be responsible for greater susceptibility in plant for pathogen attack and survivals (Jayraman and Balasubramanian, 1988). Potassium, more than any other element, is known to reduce plant susceptibility to diseases by influencing biochemical processes and tissue structures. Due to the interaction of factors, such as environmental conditions, susceptibility of the plant or variety to disease, disease incidence and level of other nutrients, the effects of K can be variable. In a recent review it has been reported that high levels of K nutrition reduced the severity of more than 20 bacterial diseases, more than 100 fungal diseases and 10 diseases caused by viruses and nematodes (Marschner, 1995; Marschner *et al.*, 1996). Potassium deficiency usually results in the accumulation of soluble N compounds and sugars in plants, which are a suitable food source for parasites. Whereas adequate K results in stronger tissue and thicker cell walls which are more resistant to disease penetration, while N has the opposite effect.

The concentration of soluble assimilates in a plant cell is an important factor for the development of invading pathogens especially for obligate parasites such as mildew or rust. This group of pathogens requires living plant cells to complete their life cycle. Thus, the host cell must survive the invasion by the parasite if the latter is to survive. Ample N supply helps in longevity of cells, high turnover of assimilates and high content of low molecular weight compounds. Facultative parasites, in contrast, require weak plants to be infested and killed to survive. Vigorous plant growth stimulated by ample N would suppress infestation by this group of pathogens. This may explain differences in the expression of plant diseases in relation to the nutrition of the host (Krauss, 2000) summarizes (Fig. 4) the effects of N and K on the severity of the infestation by both obligate and facultative parasites.

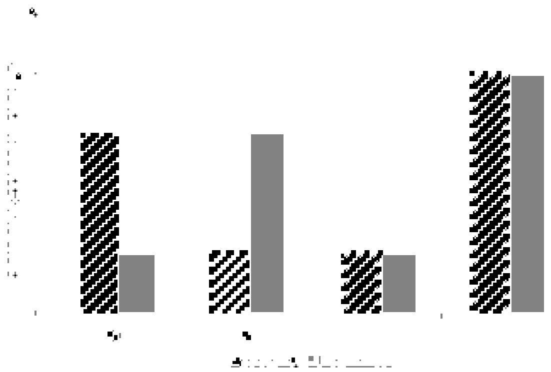


Fig. 4: Effect of N and K on expression of diseases caused by obligate and facultative parasites (Source: Marschner, 1995)

As a general observation, plants excessively supplied with N have soft tissue with little resistance to penetration by fungal hyphae or sucking and chewing insects (Krauss, 2000). On-farm trials in India with soybean showed considerable less incidences with girdle beetle, semilooper and aphids when supplied with adequate potash (Fig. 5).

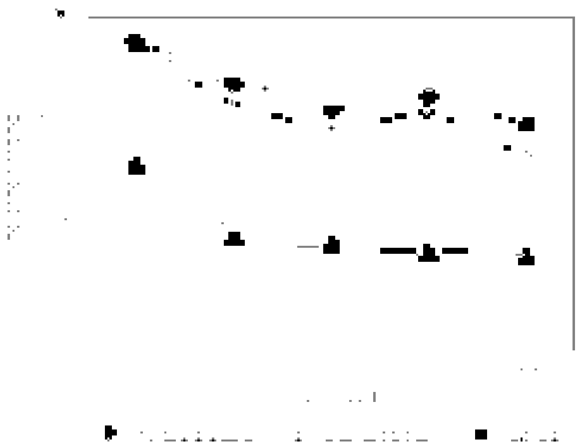


Fig.5: Pest incidence in soybean as affected by potash supply (Source: Krauss, 2000)

Similarly, excessive growth due to an unbalanced N supply can also create microclimatic conditions favorable for fungal diseases. Lodging of cereals as commonly observed at over supply with nitrogen and inadequate potash is a good example, humidity remains longer in lodged crops giving ideal conditions for germination of fungi spores.

Insufficient K also causes a pale leaf colour that is particularly attractive to aphids, which not only compete for assimilate but transmit viruses at the same time. Wilting, commonly observed with K deficiency, is another attraction to insects. Cracks, fissures and lesions that develop at K deficiency on the surface of leaves and fruits provide easy access, especially for facultative parasites.

The ratio between nitrogen and potassium plays obviously a particular role in the host/pathogen relationship. Perrenoud (1990) reviewed almost 2450 literature references on this subject and concluded that the use of potassium (K) decreased the incidence of fungal diseases in 70% of the cases. The corresponding decrease of other pests was bacteria 69%, insects and mites 63% and viruses 41%. Simultaneously, K increased the yield of plants infested with fungal diseases by 42%, with bacteria by 57%, with insects and mites by 36%, and with viruses by 78% (Fig. 6).

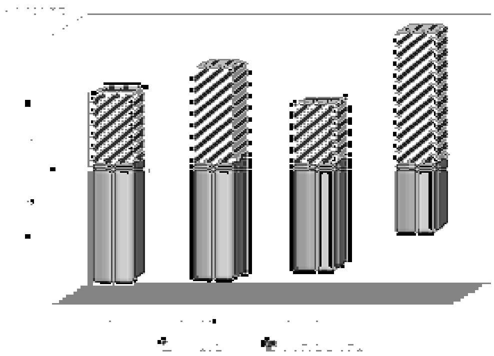


Fig.6: Effect of potassium on yield increase and pest incidences

(Source: Perrenoud, 1990)

The effect of K on crop specific host/pathogen relationships for rice in Asia has recently been summarized by Hardter (1997). For example, stem rot, *Helminthosporium sigmoideum*, generally occurs at high nitrogen supply in soils poor in K. With improved K supply, the incidence decreases and yields increase. A similar inverse relationship between disease incidence and plant nutrition with K has been reported for brown leaf spot in rice (*Helminthosporium oryzae*), rice blast (*Piricularia oryzae*) or sheath blight of rice (*Thanatephorus cucumeris*). A curative effect from applying K is also seen for bacterial diseases in rice like bacterial leaf blight, *Xanthomonas oryzae*, although highly susceptible varieties hardly responded to K in contrast to varieties with a moderate degree of resistance. The number of whitebacked plant hopper, *Sogatella furcifera,* could be substantially reduced with K in the resistant rice variety IR 2035 but K had almost no effect with the susceptible variety TN-1.

The enhanced rates of K application can induce or improve insect resistance by the following mechanisms. Accumulation of defensive phenolic compounds and their derivatives found to be toxic to insects. Thus, making the plants less palatable to insects and thereby causing non-preference (Perrenoud, 1990; Hardter, 1997).

Probable explanations for the beneficial effect of K on the host pathogen relationship focus on the following mechanisms. At insufficient K and/or excessive nitrogen, low molecular soluble assimilates like amino acids, amide and sugars accumulate in the plant cells. Correspondingly, Noguchi and Sugawara (1966) found in leaf sheaths of rice that the content of soluble N increased from 0.18 at adequate K to 0.45% at NP only. Similarly, soluble sugar increased from 1.52% to 2.43% at NP. The concentration of soluble assimilates in a plant cell is an important factor for the development of invading pathogens such as obligate parasites to complete their life cycle.

Conclusion

In India, moisture and temperature stresses are the most important abiotic stresses for crop productivity and yield potentials. Soil moisture alters physiological processes; root elongation, turgidity and rate of regeneration; stomatal conductance; photosynthesis and rate of crop development and maturity. It has been observed that crop responses to fertilizer K additions are often the greatest when water is either deficient or excessive. Potassium stimulates the degree and extent of root proliferation, root branching, etc. The greater root proliferation usually gives plants better access to sub soil moisture. Adequate K decreases the rate of transpiration through affecting the stomatal conductance.

Potassium usually speeds the rate of development and maturity, altering the deleterious effects of stress at critical growth stages. Under conditions where rainfall patterns are highly cyclical, drought effects can be reduced by advancing the date of pollination when most crops are highly sensitive to moisture stress.

Pulses especially chickpea experiences temperature stress under rainfed condition as this crop is taken after *kharif* crops. The crop experiences low temperature at initial stage of growth, results in poor and slow vegetative growth while, high temperature at the end of cropping sequence leads to forced maturity resulting low crop production. Potassium application helps plants to tolerate both the high and low temperatures.

Amongst abiotic stresses, soil salinity is a major constraint that affects plant growth and yield. Extra expenditure of energy for osmotic adjustments or in repair mechanism under salinity stress causes growth reduction. Potassium content in salt tolerant genotypes has been reported to be significantly higher than those of susceptible genotypes. Addition of K in salt-affected soils improves crop yields including vegetable crops.

Potassium application inhibits the accumulation pf soluble carbohydrates as well as nitrogenous compounds in the tissues. This helps to counteract a situation that favours fungal growth when K levels are deficient. Similarly lignifications of vascular bundles could be responsible for greater susceptibility in plant for pathogen attack and survivals. Insufficient K also causes pale yellow colour to leaves that attracts aphids, wilting in crops, commonly observed in K deficient soils. Cracks, fissures and lesions that develop under K deficiency on surface of leaves and fruits provide easy access for facultative parasites.

Available literature on K shows that K application decreases incidence of fungal diseases by 70 % of the cases, bacteria by 69%, insect and mites 63% and viruses 41%. Simultaneously, increase the yield of plants infested with fungal diseases by 42% with bacteria 57% with insect and mites by 36%and with viruses by 78%.

It has established that phenol content in leaves increases with increase in K application resulting in low disease incidence (leaf sheath rot and stem rot in rice). Potassium content in shoots of tolerant genotypes of various crops has been reported to be significantly higher than those of susceptible genotypes. Plants under moisture stress have low photosynthetic rate. The decrease in solar energy harvest efficiency due to moisture could be enhanced with K application

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Integrated Plant Nutrient Supply and Management Strategies for Improving Soil Health, Abiotic Stress and Enhancing Crop Productivity in Irrigated and Rainfed Agro-Ecosystems

Anand Swarup

Professor & Head
Division of Soil Science & Agricultural Chemistry
Indian Agricultural Research Institute, New Delhi 110 012

Abstract

Improving and maintaining soil health for enhancing and sustaining agricultural production is of utmost importance for India's food and nutritional security. Climate change and the resultant aberrant weather situations are increasing the vulnerability of rainfed farming. Rainfed agriculture in the semi-arid tropical (SAT) regions of India face the twin problems of 'water thirst' and 'plant nutrient hunger'. Due to moisture scarcity these lands are incapable of supporting double cropping. Consequently, the soil organic matter turnover and fertilizer use efficiency is very low. After the harvest of the economic component only negligible amount of residues/stubbles remain in the soil. High temperature mediated rapid decomposition of organic materials reduces the organic matte level to a marginally low level. This results in massive soil structure, poor fertility and hard setting tendencies. On the other hand, most of the farmers in these regions are marginal to small, and are below the economic threshold level, thus unable to purchase fertilizers. However, in order to sustain the productivity of dryland crops, it is extremely important to off-set the nutrient depletions through appropriate nutrient management practices. Addition of organic materials in light textured limited rainfall soil areas should receive priority in managing soil fertility. The results from long-term fertilizer experiments conducted in different agro-ecological regions involving diversified cropping systems and soil types have shown that imbalance fertilizer use particularly nitrogen alone had a deleterious effect on soil productivity and health and the damaging effects in the absence of P and K fertilizer varied in the order: Alfisols>Vertisols>Inceptisols. In a period of less than 10 years crop productivity in N alone plots came to almost zero in Alfisols. Integrating organic manure (FYM @ 10-15 Mg $ha^{-}1$) with 100% recommended NPK fertilizer doses not only sustained high productivity of crops but also maintained soil fertility in most of the cropping systems. The results further revealed that soil type is one of the most important factor affecting fertilizer use efficiency and crop yields. Therefore, sustained efforts are needed to improve and maintain this most important natural resource base – the soil through judicious integration of mineral fertilizers, organic and green manures, crop residues and bio-fertilizers so that it nourishes continuous cropping without being irreversibly damaged in the process.Development of site-specific integrated plant nutrient supply (IPNS) and management strategy is therefore, a viable option for enhancing nutrient use efficiency and sustaining the productivity of cropping systems. The basic concept underlying IPNS is the maintenance or adjustment of soil fertility and plant nutrient supply to an optimum level for sustaining the desired crop productivity through optimization of benefits from all possible sources of plant nutrients in an integrated manner. IPNS is an approach ecologically, socially and economically viable and environmentally un-hazardous.

Introduction

In the scenario of impending climate change, increasing soil temperature is inevitable. An experiment was conducted to examine the impact of abiotic stress (heat at 48 C for 24 h) on the abundance of microbial groups (bacteria, fungi, *Actinomycetes*, *Pseudomonas*, *Azotobacter* and ammonia oxidising bacteria) in soils under long-term application of fertilizers with and without farmyard manure, and to assess the resistance and resilience of dehydrogenase activity and microbial groups against abiotic stress, and their relationships. The results have revealed that abiotic stress has significantly reduced the dehydrogenase activity and abundance of different microbial groups (Fig. 1 and 2). The amplitude of reduction varied 20 to 80%. The negative impact of heat stress on the dehydrogenase activity and microbial groups was highest in soil treated with only N (100% N). Among the soil organisms, resistance and resilience of fungi and *Actinomycetes* were higher than those of bacteria, *Pseudomonas*, *Azotobacter* and ammonia oxidising bacteria. Ammonia oxidising bacteria were found to be most sensitive with minimum resistance index (0.03-0.16) against heat stress. Correlation studies indicated that resistance index of dehydrogenase activity was not associated with initial level of microbial groups. However, for resilience (*i.e.,* recovery) of dehydrogenase activity there had been significant association with individual microbial groups, except with *Azotobacter*. It was clear that among the treatments, application of NPK + farmyard manure was most effective in enhancing the resistance and resilience of soil biological functions against heat stress.

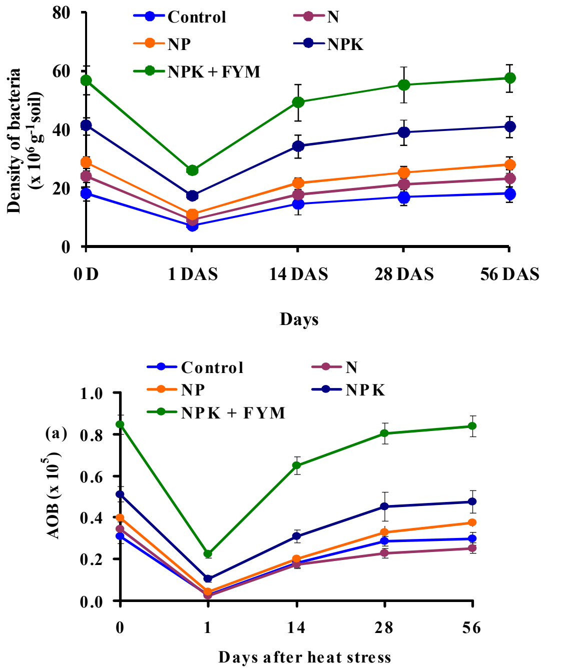

Fig 1. Dehdrogenase activity and Population of bacteria in soil after heat stress. Bars indicate standard errors of mean. 0D and DAS indicate, 'fresh soil' after sampling and 'days after stress,' respectively.

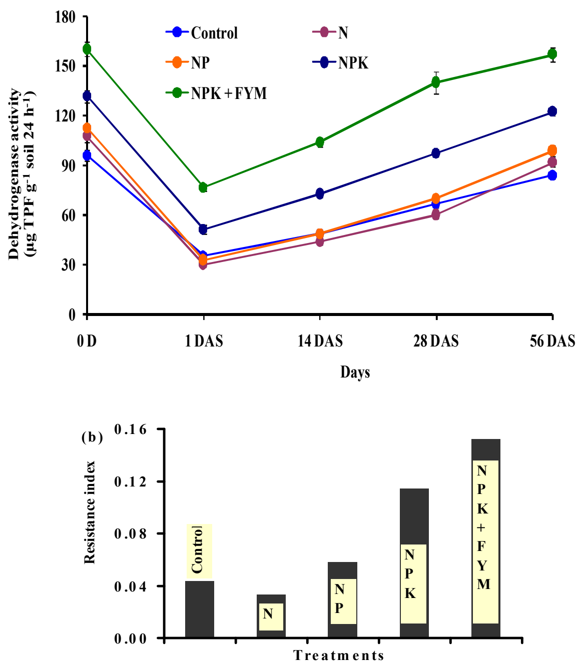

Fig. 2. Abundance, resistance and resilience of ammonia oxidizing bacteria against heat stress

Improving and maintaining soil fertility for enhancing nutrient use efficiency and sustaining agricultural production is of utmost importance for India's food and nutritional security. Though India is a food surplus nation at present with more than 200 Mt food grains production per annum, it will require about 8-10 Mt additional food grains each year if the trend in rising population persists. This challenge can be met by greater and more efficient use of fertilizers particularly N,P and K and organic sources. With globalization, Indian agriculture is passing through a critical phase. It is confounded with increasing crop production, sustainability and long-term environmental quality issues. Answers to these questions can be sought by the long-term experiments which are valuable repositories of information regarding the sustainability of intensive agriculture. Many factors influence the complex chemical, physical and biological processes which govern soil fertility and productivity. Changes in fertility caused by imbalanced fertilizer use, acidification, alkalinity and declining soil organic matter (SOM) may take several years to appear. These properties in turn can be influenced by external factors such as atmospheric pollution, global climate changes or land use management practices. Long-term experiments provide the best possible means of studying changes in soil properties, nutrient dynamics and processes and identifying emerging trends in nutrient imbalances and deficiencies and to formulate future strategies for maintaining soil health. In fact, agricultural scientists have recognized the long-term sites as invaluable tools in the study of agro-ecosystem dynamics. But, the renewed emphasis on such studies has arisen from the growing notion that "certain soil processes are long-term in nature and must be studied as such". In view of growing importance of long-term experiments for addressing current and future agricultural and environmental issues Dawe et al (2000), Powlson et al (1998), Swarup (2001), Swarup and Wanjari (2000) and Swarup et al (1998, 2000) made extensive efforts to review and document available data on (i) yield trend analysis, soil properties and key sustainable indicators such as organic carbon and pH under long-term experiments which can not be measured from short- term studies and (ii) identified regional fertility constraints and opportunities to increase agricultural productivity through integrated plant nutrient supply (Swarup and Gaunt 1998; Swarup, 2004). These experiments have provided very valuable data which are highly relevant for farmers, scientists and policy makers. The outcome from these experiments is discussed herewith.

Effects of Long-term Fertilizer Use on Crop Productivity

1. The responses to fertilizers were in the order of NPK>NP>N but the degree of response to individual nutrients varied with the locations. The rate of response declined in some cases sharply even after a few years whereas at some others the decline was gradual. The decline was more when high yields were obtained continuously for a number of years with high dose of NPK fertilizers, causing a severe drain from the soil of other essential plant nutrients which became limiting factors for crop production (Table 1).

2. Continuous use of N alone resulted in decline in yield at all the centers except at Coimbatore, Ludhiana and Pantnagar and had deleterious effect on long- term fertility and sustainability, indicating that other major and micro nutrients were becoming limiting factors and adequate response to N could not be obtained unless those factors limiting yield were taken care of. The decline in yield with N alone was most spectacular at Palampur, Ranchi and Bangalore. Incidentally, these are also the acid soils where there were severe deficiencies of both P and K.

3. Locations having Vertisols or Vertic Ustropept type of soils such as at Jabalpur and Coimbatore, P deficiency is so severe that without its application crop yields were extremely poor and the benefits of N and K application were not realized at all.

4. Super- imposition of treatments at Pantnagar showed beneficial effects of S, Zn and FYM application. Response to Zn is clearly evident at Ludhiana also. Thus the addition of Zn and S becomes essential after a few cycles of intensive cropping at most of the locations. Thus next to N,P and K, the deficiencies of Zn and S are also becoming the major yield limiting factors in most of intensive cropping systems and appropriate changes in fertilizer use policy are needed for sustaining high productivity.

5. Up to a number of years the responses to the treatment NPK +10/15t FYM/ha were as good as NPK at 100/150% alone but continuous use of these treatments after some years started showing less responses to NPK alone than to NPK+FYM treatment over the years. This indicates that some micro-nutrients or secondary nutrients like Zn and S were becoming yield limiting factors. These nutrients are provided by FYM besides supplying additional quantities of NPK and it has beneficial effect on the physical properties and biological condition of soil. It has to be recognized that 15 t FYM of an average quality can add annually 75-100 kg N, 50-75 kg P_2O_5 and 170-200 kg K_2O per hectare, Farmyard manure helped in sustaining the yield over the years at all the locations and the results were spectacular in Alfisols at Palampur, Bangalore and Ranchi; in Mollisol at Pantnagar and in Vertisol at Jabalpur.

6. The effect of NPK+FYM treatment was most conspicuous on maize than on wheat in the maize-wheat system at Palampur and Ludhiana. In these cases the improvement of physical condition of the soil and additional nutrient supply effect (N, P, K, Zn and S) could have produced synergistic effects also.

7. The scheduling of P, K, Zn and S application to the more responsive crop in the sequence should receive attention. As for instance, in a rice-wheat system application of P to wheat and that of K, Zn and S to rice is more beneficial. Similarly in maize-wheat cropping system, Zn, S and FYM applications are more beneficial to maize than to wheat. However, the residual effect of FYM was more conspicuous in wheat at Palampur.

8. The residual and cumulative effect of FYM was also reflected in the enhanced production of subsequent crops. The effect of NPK (100% optimal) + farmyard manure (15 t/ha) on crop yields in acid soils (Ranchi and Palampur) was comparable to or often superior to that of NPK + lime indicating that to a certain extent the benefits of liming were met by the FYM which also has a buffering effect on soil acidity correction, as confirmed by changes in pH status of Palampur and Ranchi soils. For attaining high yield potential liming has to be accompanied with optimal doze of NPK. Recommended dose of NPK sustained high productivity of cassava than FYM alone treatment in an acid Ultisol at Trivandrum. NPK + FYM sustained high productivity of soybean and wheat over NPK or N+FYM treatment at Almora.

9. The results of the experiments at different locations have clearly brought out that

- Yield declines when imbalanced fertilization continued for long periods.Yield stagnates or declines when input levels are kept constant and/or sub-optimal.
- There are evidences of a downward shift in the entire fertilizer response function at all the levels of fertilizer applications which

means lesser increases due to application of same dose of plant nutrients. In other words there is a need for application of heavier doses of fertilizer to obtain same yield.

- Application of FYM over and above 100% of the recommended NPK invariably sustains high productivity over the years.
- Continuous cropping without adequate inputs decreases indigenous soil N, P and K supply.
- In case of acid soils, application of N alone aggrevates the problem of acidity. Application of lime helps in correcting acidity, but for attaining high yield potential liming has to be accompanied with optimal doze of NPK(Table 2). Similarly, application of gypsum based on gypsum requirement of soil is extremely important in attaining high yields and maximizing nutrient use efficiency in alkali soils of the Indo-Gangetic Plains and improving organic carbon status of the soil(Table 3).

Long-term fertilizer experiments conducted over 25 years in different agro-ecoregions of India involving a number of cropping systems and soil types (Inceptisol, Vertisol, Mollisol and Alfisol) have shown a decline in SOC as a result of continuous application of fertilizer N alone (Swarup 1998). Balanced use of NPK fertilizer either maintained or slightly enhanced the SOC over the initial values. Application of farmyard manure (FYM) and green manure improved SOC which was associated with increased crop productivity. Considering the nutrient removal by crops and supply through different sources under intensive cropping systems, it is seen that removal is far greater than the supply. It is, therefore, extremely important to maintain SOC at a reasonably stable level, both in quality and quantity, by means of suitable addition of organic materials or crop residues. Maintenance of soil organic carbon is an important tool for crop productivity and sustainability. Other important benefits of SOC in low-input agro-ecosystems are retention and storage of nutrients, increased buffering capacity, better soil aggregation, improved moisture retention, increased cation exchange capacity. The addition of organic carbon improves soil structure, texture and tilth, activates a very large portion of inherent microorganisms and reduces the toxic effects of pesticides.

Table 1. Average grain yield of crops (tha^{-1}) over the years in long-term experiments on yield stability and productivity

Centre	Crops	Control	N	NP	NPK 100%	NPK 150%	NPK+FYM 100%	NPK-S/ +S/lime	NPK+Zn
				INCEPTISOLS					
Barrackpore	Rice	1.6	3.5		4.0	4.4	4.2	3.1	3.5
(1972-97)	Wheat	0.8	2.1	2.3	2.4	3.0	2.5	2.4	2.4
Bhubaneswar	Rice	1.6	2.1	2.2	2.8	3.0	3.5	2.4	2.8
(1973-94)	Rice	1.4	2.1	2.8	3.0	3.3	3.7	3.0	3.1
Coimbatore (1972-95)	Finger-Millet	0.7	1.0	2.8	2.8	3.0	3.3	2.8	2.8
	Maize	0.6	0.8	2.7	2.9	3.1	3.4	2.9	3.0
Delhi	Maize	1.2	1.6	1.8	2.1	2.4	2.3	2.1	2.2
(1994-96)	Wheat	2.2	3.5	3.9	4.3	4.9	4.6	4.8	4.8
Hyderabad	Rice	1.1	2.6	3.4	3.6	4.3	4.7	2.8	3.0
(1972-95)	Rice	1.0	1.8	2.2	2.6	3.3	3.4	2.3	2.5
Ludhiana	Maize	0.4	1.4	1.8	2.3	2.4	3.2	2.4	2.7
(1972-95)	Wheat	1.0	2.7	4.1	4.8	4.9	4.9	4.9	4.9
				VERTISOL					
Jabalpur	Soybean	1.0	1.2	2.0	2.2	2.2	2.3	2.0	2.0
(1972-96)	Wheat	1.1	1.4	4.0	4.3	4.5	4.7	4.3	4.0
				MOLLISOL					
Pantnagar	Rice	3.4	5.0	5.0	5.4	5.4	6.2	5.7	5.2
(1972-96)	Wheat	1.6	3.8	3.8	3.9	4.2	4.6	4.2	3.8
				ALIFISOLS					
Palampur	Maize	0.3	0.6	2.0	3.2	4.0	4.6	4.0	3.6
(1973-97)	Wheat	0.3	0.4	1.8	2.5	3.0	3.3	3.1	2.5
Ranchi	Soybean	0.8	0.4	1.0	1.6	1.5	1.9	1.9	-
(1973-97)	Wheat	0.9	0.5	2.4	2.8	2.9	3.1	3.0	-
Bangalore (1986-95)	Finger-Millet	0.6	0.9	1.4	4.0	4.8	4.6	3.9	4.0
	Maize	0.4	0.7	1.0	2.3	2.5	2.7	2.3	2.2

Source: Swarup, A (1998)

Table 2. Changes in soil properties in a permanent manurial experiment at Ranchi after 28 years of maize – wheat cropping sequence

Treatment	pH	Organic carbon (%)	Grain Yield (t ha^{-1})	
			Maize	Wheat
Control	6.1	0.54	0.50	0.76
N	3.3	0.56	0.11	0.12
NP	3.4	0.61	0.55	1.20
NPK	3.5	0.64	0.80	1.70
NPK+Lime	6.7	0.61	4.16	4.10
FYM	6.4	0.93	2.80	2.50
Initial	6.0	0.53	-	-

Source: Sarkar, A.K. (1998)

Table 3. Effect of long-term sesbania green manuring on sustainability of rice-wheat and soil properties in a gypsum amended sodic soil

Treatment	Average grain yield (t ha^{-1})		Soil properties after 1992 (Olsen's P)		
	Rice (85-91)	Wheat (85-92)	OC (g/kg)	(Kg/ha)	pH
Fallow-rice-wheat	5.4	2.7	2.3	13.5	8.8
Green manure-rice-wheat	6.8	3.6	3.8	36.7	8.5
CD(P=0.05)	0.5	0.5	0.3	4.5	-

Source: Swarup, A (1998)

Enhancing Nutrient Use Efficiency for Maximizing and Sustaining Crop Production

Efficient management of nutrients constitutes one of the most important factors to achieve agronomic and environmental targets of intensive crop production systems. Agricultural intensification requires increased uptake of nutrients by crops. The depletion of nutrient reserves from the soil is often a hidden form of land degradation. (Swarup and Ganeshamurthy, 1998; Swarup et al. 2000). On the contrary, excessive application of nutrients or inefficient management leads to environmental problems, especially if large quantities of nutrients are lost from the soil plant system into water or air. Enhancing and sustaining crop production by improving plant nutrient management together with a better use of other production factors is thus a major challenge. The Green Revolution in the sixties led to self-sufficiency in food production but still we require about 8-9 Mt tons additional food grains each year if the trend in rising population persists. Although fertilizer use has already increased tremendously, still Indian Agriculture is being budgeted at an annual deficit of about 8-10 Mt. Accomplishment of the enhanced rate of productivity requires that soil fertility be either enhanced or at least sustained at the present level. Recently, concerns have been raised regarding consequences of fertilizer use, more particularly of N fertilizers. This makes some sense as fertilizer recovery efficiency of N seldom exceeds 50 percent. A major portion of applied fertilizer is lost from soil plant system by leaching, run off, denitrification and volatilization and pollutes the soil, water and air.

Overmining of Nutrients

Intensive cropping invariably results in heavy withdrawal of nutrients from soils and its success largely depends upon the judicious application of inputs commensurate with the nutrient uptake. The nutrient uptake values

Table 4. Nutrient uptake in long-term fertilizer experiments under intensive cropping systems in India

Cropping	Soil type	Yield(t ha^{-1})	Nutrient uptake (kgha^{-1}yr^{-1}) N	P	K	Total
Maize-wheat-cowpea (F)	Inceptisols	6.8 – 0.6 6.	240	45	250	535
Rice-wheat-jute fibre	Inceptisols	6.5 – 1.5	250	50	275	575
Maize-wheat-cowpea (F)	Mollisols	9.5 – 1.9	260	65	295	620
Rice-rice	Inceptisols	6.2	150	40	175	365
Soybean –wheat	Vertisols	6.3	285	44	225	554
Soybean –wheat	Alfisols	4.2	220	35	170	425
Fingermillet –maize	Alfisols	6.5	210	42	215	467
Fingermillet –maize	Inceptisols	6.5	245	40	270	555
Groundnut-wheat	Alfisols	2.9	106	18	65	189
Sorghum-Sunflower ybrids	Vertisols	2.9	89	42	117	248

Source: Swarup (2006)

generally provide a reliable estimate of the nutrient requirements under varying agro-ecological regions which would form the basis for the development of a sound fertilizer recommendation strategy for realizing higher productivity and maintaining soil fertility. The average uptake of major nutrients by the crops at 100 % NPK treatments of selected intensive cropping systems are presented in Table 4.

The uptake of any nutrient is a function of yield and nutrient concentration in the plant. It is apparent that nutrient removal (NPK) can be as high as 620 $kgha^{-1}yr^{-1}$. In general, the exhaustive cropping systems in respect of nutrient removals are rice-wheat, rice-rice, maize-wheat and soybean-wheat. A look at differences between the nutrients applied and the nutrient uptake with optimal 100 % NPK dose indicated a positive balance of N and P and negative in respect of K on almost all the soils with minor differences occurring in respect of cropping systems. At the national level it is estimated that annually 34-35 Mt of nutrients are removed from the soil, whereas only 24-25 Mt are supplied from fertilizers and organic sources thus leaving a negative balance of about 10 Mt. The continuous nutrient imbalance can become staggering when we consider the future needs for food. Thus food security is very much related to fertilizer use. For feeding a population of 1.4 billions by 2025, India will need to produce 311 Mt food grains. For producing this much food India will need at least 45 Mt plant nutrients, out of which at least 35 Mt should come from chemical fertilizer sources containing 5.6-8.8 Mt P_2O_5 + 2.3 to 4.7 Mt K_2O and the rest nitrogenous fertilizers. At least 10 Mt nutrients should come from organic manures, crop residues and bio-fertilizers.

Fertilizer Use Efficiency

Fertilizer use efficiency refers to the proportion of applied nutrients recovered by the crop. It is commonly expressed as a percentage of fertilizer used by the crop or alternatively in terms of crop yield per unit of fertilizer (e.g. kg grain per kg of applied nutrient). Fertilizer use efficiencies very widely and usually decrease as fertilizer rates increase. Nitrogen efficiency based on grain yield, rarely exceeds 50 to 60 % and can be as low as 20 %. First year fertilizer efficiencies are normally 10 to 30 % for P and 20 to 60 % for K, although efficiencies can be greater over the long-term because of the residual properties of these immobile nutrients. Continuous use of N alone produced the greatest yield decline at a majority of sites. Responses to N declined with the passage of time, while responses to P and K improved due to increased soil P and K deficiency (Table 5,Swarup 2002). Fertilizer N,P and K use efficiency of crops improved considerably with balanced NPK fertilization Application of FYM in conjunction with 100% NPK further enhanced their use efficiency (Table6) A recent review of worldwide data on N use efficiency for cereal crops from researcher managed experimental plots reported that single year fertilizer N recovery efficiencies averaged 65% for corn, 57% for wheat and 46% for rice (Ladha et al., 2005). Nitrogen recovery in crops grown by farmers rarely exceed 50% and is often much lower. A review of best available information suggests that the average N recovery efficiency for fields managed by farmers ranges from about 20 to 30% under rainfed conditions and 30 to 40% under irrigated conditions. N recovery averaged 31% for irrigated rice grown by Asian farmers and 40% for rice under field specific management. In India, N recovery averaged 18% for wheat grown under poor weather conditions, but 49% under good weather conditions. The best management practice (BMP) for achieving optimum nutrient use efficiency is applying nitrogen (nutrient) at right rate, at right time and in the right place.

Table 5. Nutrient response ratio (kg grain/kg nutrient) in long-term fertilizer experiments: 1973-77 vs 1992-96

Location, soil and crops	Nitrogen		Phosphorus		Potassium	
	1973-77	1992-96	1973-77	1992-96	1973-77	1992-96
Palampur (Alfisol)						
Maize	14.6	1.6	13.9	20.6	2.4	20.0
Wheat	4.3	3.1	13.4	21.2	3.6	13.2
Ranchi (Alfisol)						
Soybean	10.4	8.1	6.1	10.6	4.1	20.6
Wheat	7.8	1.4	29.9	38.2	1.0	15.9
Coimbatore (Inceptisol)						
Finger millet	3.1	5.4	35.3	43.9	11.4	13.4
Maize	1.7	1.3	32.7	28.6	1.3	14.5
Bhubaneshwar (Inceptisol)						
Rice (kharif)	6.7	2.6	1.05	5.5	6.9	8.2
Rice (rabi)	11.2	3.2	1.8	14.1	2.7	5.5
Jabalpur (Vertisol)						
Soybean	26.0	8.4	7.9	7.7	2.9	13.7
Wheat	7.0	0.5	20.2	41.1	8.4	6.0

Source : (Swarup,A 2002)

Table 6. Apparent N, P and K use efficiency (100%) of crop under various treatments at Ludhiana

Crops	No. of crops	100% N	100%	100% NPK	100% NPK + FYM
N use efficiency					
Maize	25	16.2	30.6	32.0	45.2
Wheat	25	32.2	51.4	64.0	68.2
P use efficiency					
Maize	25	10.0	17.6	28.4	
Wheat	25	21.0	30.4	34.2	
K use efficiency					
Maize	25	-	43.0	59.0	
Wheat	25	-	93.0	108.0	

Source: (Brar and Pasricha ,1998)

Alleviation of nitrogen stress caused by waterlogging in salt affected soils

Saturation and/or temporary flooding conditions often occur for short periods during the growing season of crops like wheat, barley, mustard pearlmillet, maize, sorghum and sunflower which are not adapted to wetland conditions. Such an occurrence is very common in alkali soils of the Indo-Gangetic plains. Nitrogen deficiency triggered by saturation was an important cause of low yields. Decrease in oxygen diffusion rates (ODR) of soils and in the uptake of P,K and Zn by the crop also occurred.These detrimental effects were overcome by supplementing extra dose of nitrogen at the time of first and second irrigation (top dressing) which alleviated N deficiency and enhanced the uptake of P,K and Zn by the crop (Swarup and Sharma 1993). Increasing the rate of N from 80 to 120 and 140 kg/ha under saturated conditions restored the green colour of the plants and significantly improved yield and N yuptake (Table 7).

Table 7. Effect of water stagnation and topdressed N on wheat yield

Treatment	N (kg/ha) top dressed			Yield (t/ha)		Total N uptake (kg/ha)	
	Basal	1st irrigation	2nd irrigation	Grain	Straw	Grain + straw	Apparent N recovery (%)
T1 Drained	40	40	40	3.29	0.58	87.8	-
T2 Undrained	40	40	40	1.79	0.45	40.9	-
T3 Undrained 40	50	50	1.90	0.48	46.1	26.0	
T4 Undrained 40	60	60	2.67	0.50	66.5	64.0	
T5 Undrained 40	70	70	3.74	0.55	97.3	91.3	
LSD (P=0.05) -	-	-	0.68	0.04	-	-	

Source(Swarup and Yaduvanshi 2004)

Environmental Consequences

Fertilizer N, P and K after their application in soil undergo transformation in physical, chemical and biological processes. For example, dynamics of N in the soil-plant-atmosphere system includes various soil processes (mineralization, immobilization, urea hydrolysis nitrification, volatilization, denitrification and N movement in soil), the processes pertaining to above ground plant growth, and nitrogen uptake by crops. Soil type is one of the most important factors in affecting fertilizer use efficiency and soil productivity (Kumar et al. 1995; Swarup 2002).

Phosphorus after its application in soil is either removed by crop or gets immobilized into various insoluble forms (Fe and Al-phosphate and Ca-phosphate in alkaline soils) and gets fixed in soil clays or organic matter. The use efficiency of P does not exceed 20 percent. Significant amount of P is lost from the soil through surface run off and erosion resulting in eutrophication of water bodies.

Potassium is the most abundant plant nutrient in soil having illitic type of clay mineral. It is more mobile than phosphate and is susceptible to loss by leaching, run off and erosion. The K use efficiency is about 70 %. Loss of K is a waste but carries no environmental concern. The major environmental consequences related to fertilizer use are: (i) nitrate pollution of ground water, (ii) eutrophication , (iii) ammonia volatilization, (iv) acid rain, (v) green house affect, (vi) damage to crops and soil organisms, and (vii) trace element and heavy metals contamination (Swarup 2006).

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Managing Macro Nutrients in Acidic Soils through Inorganic and Organic Sources for Higher Nutrient Use Efficiency and Crop Productivity

Surendra Singh

Professor & Head
Department of Soil Science and Agricultural Chemistry
Institute of Agricultural Sciences
Banaras Hindu University, Varanasi 221005 (U.P.)

Introduction

The common soil-related constraints in acid soils are acidity, coarse texture, low base saturation and low cation exchange capacity accompanied by poor fertility status, low water and nutrient retention capacities. Adequate plant nutrient supply holds the key for improving the food grain production and sustaining livelihood. The supply of nutrients in the form of organic helps in retaining more moisture and there by increases water and nutrient use efficiency. Integrated use of fertilizers, organic and biological sources of plant nutrients and their different management practices have a tremendous potential not only in sustaining agricultural productivity and soil health but also in meeting of higher nutrient use efficiency for different crops and cropping systems

Nitrogen (N), phosphorus (P) and potassium (K) are primary plant nutrients (PPN), because they are taken up by plants in large amounts and must be supplied almost every crop season in adequate amounts. They are also the key elements involved in photosynthesis, the biochemical process responsible for the food production essential for all plant and animal life on the planet earth. Nitrogen is a constituent of chlorophyll, the energy trapping food sysnthesizing molecule in plants, phosphorus is involved in energy transfer and potassium is involved in opening/closing of the leaf stomata.

Calcium (Ca), magnesium (Mg) and sulphur (S) are referred to as secondary nutrients. Calcium is a constituent of cell wall and essential for stability of cell membranes in the plants and magnesium is a structural component of chlorophyll. Thus, is indispensable for photosynthesis by plants. Sulphur is required for synthesis of S containing amino-acids and proteins, activity of protolytic enzymes and increased oil content in oil bearing plants.

The significance of secondary nutrients in agriculture production has been increasingly recognized in recent years. Acid soils are developed under high rainfall conditions and their specific nature pose several problems for successful crop production. Secondary nutrients are the key nutrients responsible for low productivity of crops in acid soils of the country. Red and lateritic soils of the country are in general low in productivity. Such low productivity is attributed to a number of factors of which nutritional disorders are most important.

Management of primary nutrients

Efficient nutrient management demands understanding the pathways of nutrient losses through gaseous loss, leaching loss, erosion and runoff losses and developing technologies to minimize these losses. Among the nutrients, nitrogen is the most mobile and likely to be lost easily from the soil – plant system. Many water soluble nutrients are lost through runoff during intense rainfall and nutrients sorbed on the surface of soil particles-clays and silt and soil organic matter are lost when the top soil is eroded by water or wind.

These losses of nutrients must be controlled by developing appropriate site specific technologies. Inclusion of legumes in the cropping system improves the fertilizer nitrogen use efficiency. A ratio of 4:2:1 of N: P_20_5: K_20 is generally considered to be ideal for achieving maximum use efficiency in each nutrient. Split application of N synchronizing with the crop demand improves its use efficiency. Application of N in 4 splits could significantly improve the grain yields of crops. Deep placement of fertilizer in the moist zone improve their use efficiency. Placement of nitrogenous fertilizers reduces the volatilization loss where as placement of phosphatic fertilizers reduces the fixation. The management practices like deep tillage, summer ploughing, conservation tillage and mulching which conserve moisture in the root zone improve the response of the crop plants to applied nutrients. Liming of acid soils improves the phosphorus use efficiency.

Management of secondary nutrients:

All the liming materials have value for supplying calcium and calcium and magnesium, rising the pH and making aluminium, manganese and iron less toxic The choice of which one to buy is determined by the cost in relation to its purity, the ease of handling, their availability in the speed with which the lime reacts. Calcium carbonate, often occurring as a mixed compound with Mg is the most common liming source. Pure crystalline $CaCo_3$ is called calcite or calcitic limestone and has neutralizing value of 100%. Lime stone with Ca and Mg in equimolar proportions is referred to as dolomite lime stone. The neutralizing value of dolomitic limestone can vary less than 60% to over 100%. Lime stone rocks contain primarily calcium carbonate and magnesium carbonate plus an insoluble residue (clay and sand). Finely ground limestone is an effective material for correcting or preventing Ca deficiencies as well as for reducing soil acidity. A number of industrial by-product like basicslag, limesluges, phosphogypsum and pressmud etc. are rich sources of calcium and could serve as cheap liming materials in some areas. Use of single super phosphate, triple super phosphate, gypsum, phosphogypsum, rockphosphate and Basicslag may also be useful for arresting calcium deficiency. Liming materials containing Mg (dolomite and basic slag) are usually regarded as a better source for crops in acid soils. Most commonly used material to supply Mg are Mg SO_4 and dolomite.

The magnitude of Ca and Mg deficiency will vary according to degree of soil acidity and base saturation. Deficiency of Ca is expected where Ca saturation is less than 25% or less than 1.5 m.e exchangeable Ca/100 g soil especially, in humid region soils. Usually soils containing less than 1 m.e. exchangeable Mg/100g soil or less than 4-15% of CEC occupied by Mg are considered deficient. The S deficiency is generally observed in light textured, low organic matter containing soils which are prone to leaching. The extensive use of non - sulphur fertilizer further accentuates the deficiency of this element in soils.

On the basis of response to lime, crops like pigeonpea, soybean and cotton have been classified as high responsive, chickpea, lentil, peas, groundnut and sorghum as medium responsive and small millets, rice, potato etc as low or non responsive. Liming of acidic and red lateritic soil not only ameliorate soil acidity related problems but also supply lot of calcium to crops grown there. Lime application @ 1/10, 1/15 and 1/20 of lime requirement (LR) applied in rhizosphere at sowing time was compared with LR dose applied as broadcasting only once as in the beginning. The mean yield of Urad, Soybean, Groundnut, lentil and Gram with $1/20^{th}$ LR dose of lime was at par with that of 1 LR dose.

Magnesium is likely to be deficient in acid soil and liming may accentuate this deficiency. Response of magnesium to groundnut, wheat, soybean and potato in acidic soils of Jharkhand was higher with application of 30 kg Mg/ha through magnesium sulphate. The magnitude of response of S differ widely among the crops and their cultivars, soil types and degree of S deficiency. Beneficial effect of S application on increasing yield of several cereal, oilseed, pulse and cash crops has been reported in S deficient soils of the country by several workers. Response of oilseeds and pulses to sulphur application has been reported extensively from Jharkhand. In acidic soils of Jharkhand, S application from 24 to 60 kg /ha increases yields of oilseeds and pulses appreciably. Yield response due to S application ranged between 26.3 to 40, 17 to 26 and 29.7 to 63 per cent in oil seeds, pulses and vegetable crops. There is an active involvement of S in protein synthesis and oil production. Sulphur is a constituent of amino acid like methionine, cystine and cysteine which are building blocks of protein. Sulphur application not only enhances the grain yield but also improve the quality of pulse crop.The increase in protein content was reported in chick pea, green gram, black gram, peigon pea and lentil.

Integrated Plant Nutrient Management (IPNM)
Integration of organic sources with fertilizers
FYM

The substitution of fertilizer N requirement to 50% by FYM has given yield levels nearly similar to those obtained with complete fertilization. The application of FYM not only increase the nitrogen use efficiency of urea, but also increases the fertility status of the soil Combined use of organic manures and fertilizers is the ideal way to sustain soil productivity. Panda and Sahoo (1989) summarizing the results of rice based crop sequence on Alfisol in Orissa clearly brought out the beneficial effect of organic manure in enhancing nutrient use efficiency. Results obtained so far point to the conclusion that 50 per cent of the nutrient requirements can be supplemented by organic sources like FYM. Organic sources provide additional benefits by improving soil physical condition. Hadimani et al (1982) observed in a six year study on an Alfisol increase in organic matter content of soil to 0.9 per cent from the initial value of 0.55 per cent. In a long- term experiment on the Alfisol of Bangalore, highest finger millet yields were maintained where FYM and fertilizers were used in an integrated manner.The benefits of use of earthworm casting to prepare compost from the waste materials such as city wastes, rural wastes , kitchen wastes, sewage sludge and farm wastes have been highlighted by several workers. (Lee and Wani 1988; Kale *et al*. 1990). Application of vermicompost in combination of inorganic fertilizer (1:1) ratio in terms of N equivalence was found very effective in case of sunflower grown in Alfisol at Hyderabad (Neelaveni, 1998).

Greenmanure

Greenmanure is one of the most effective and environmentally sound methods of organic manuring that offers an opportunity to cut down the use of chemical fertilizers. Greenmanuring as an inter cropping practice could find place in red soils. Greengram grown in the inner space of upland rice and cowpea before transplanting of medium land rice turned 6 weeks later showed a benefit equivalent to 30 kg N ha^{-1} in rainfed acidic red loam soils of Jharkhand.The practice of applying green leaves and lopping of N fixing trees has produced higher yields in many situations than applying the same rate of fertilizer N. A 5- year study on an Alfisol at Bhubneswar, Orissa showed that 30 kg N through inorganic 30 kg organics (gliricida, water hyacinth or FYM) gave higher yields of finger millet compared to 60 kg N+40 kg P_2O_5+ K_2O ha^{-1} through fertilizers.

Crop residues

In Alfisols of Bangalore, it was observed that incorporation of crop residues in soil having low organic matter content led to improvement in the fertility status and soil physical properties. The maize yield over a 5 year period increased by 25 per cent with maize residue at 4 t ha^{-1} per year. In an another study conducted on Alfisols at Hyderabad, on-farm residue management was compared with other bulky organic manures like cattle manure and compost over seven years with perl millet and cowpea as test crop. The crop residue enhanced the yield of perl millet. Yield of cowpea increased with all types of manures. The incorporation of residues made significant improvement in soil structure, stability of aggregate and hydraulic conductivity. Vekateswarlu (1984) also showed that residue incorporation improved stability of aggregates in both loam and sandy loam Alfisols. At Akola, crop residues application increased sorghum grain yield by 20 per cent in Sorghum + Pigeon pea intercropping system. Hundekar et al (1999) reported significant increase in Rabi Sorghum yield due to added six different crop residues with 100% RDF in Vertisols. An excellent example of crop residues with fertilizers on Rabi sorghum productivity at Solapur.

The use of residues left can further be fortified by the process of composting and vermicomposting. In several studies it has been revealed that all levels of organic matter improved the yield attributing characters along with grain, straw and biological yield over no organic manure. And vermicompost are helpful to recoup the soil health, which can be deteriorated due to indiscriminate use of chemical fertilizers over the years.

Integration of inorganic sources with fertilizers

Amelioration of soil acidity is indispensable to increase the fertilizer use efficiency of crops and crops sequences. For economic and efficient use of fertilizers, liming is important to increase base saturation and inactive Al^{3+}, Fe^{2+} and Mn^{3+} in soil solution. For efficient N fixation and thereby in creasing P availability, liming is important. Review of plant research (Sarkar et al 1989) shows that for stability in crop production of Alfisols, fertilization with liming is crucial. The total of NPK and micronutrients by wheat –soybean crop sequence on acid Alfisols of Ranchi indicates that there is need to apply lime along with fertilizers to mitigate deficiencies of plant nutrients in rainfed acid soils of Jharkhand. The response of lime along with NPK application to different crops in India are reported by several worker. The response of liming was 23.6 per cent higher in pea when it was used along with recommended dose of NPK fertilizers Sarkar et al (2004).

Sulphur is now accepted as the fourth major plant nutrient along with N,P and K. Inclusion of S is essential along with application of NPK fertilizers for obtaining higher crop productivity. Sulphur deficiencies are being reported more and more in acid rainfed areas of Jharkhand (Singh et al 2000). Field experiments niger, groundnut, mustard lentil, blackgram and soybean with S along with recommended dose of N, Pand K fertilizers were conducted in S deficient acidic rainfed soils of Jharkhand. The sources of S were gypsum, phosphogypsum and low grade pyrites. Results reveal that application of gypsum and phosphogypsum were superior for basal application compared to low grade pyrites in these soils. Significant remarkable increase these crop yields and quality was obtained due to S added through gypsum and phosphogypsum. Gypsum was the most effective S source in groundnut due to presence of Ca which helps in pod formation. Pyrites application is advocated as broadcast 3-4 weeks before sowing the crop in order to provide time for oxidation and conversion to plant available sulphate form.

Integration use of biofertilizers, leguminous crop with fertilizers:

Rhizobium inoculation has now become a practice for introduced legume crops. In acid soil, a lot of work has been conducted on agronomic use of *Azotobactor* and *Azospirillum*. During the crops tested sorghum, pearl millet and finger millet appeared to be consistently responsive its inoculation at more than one location (Tilak and Subba Rao 1987). *Azospirillum* seed inoculation has been reported to increase 20-30 kg N ha^{-1}. Desal and Konde (1984) from field trials in Maharastra observed that grain and dry matter yields of sorghum were increased by seed inoculation with *Azotobacter chroocooccum* and *Azospirillum* brasilense. Use of *Azotobacter* and BGA has been tested for rice in acidic up and medium land soils (Singh *et al.,* 2002; Singh et al 2008). Results reveal a significant increase in grain yield of upland rice due to *Azotobacter* inoculation.

Capitalization of legume effect is one of the important strategies of tapping additional nitrogen through biological N fixation. The contribution of legumes in cropping systems towards the yield and soil fertility have been reviewed by Singh and Das (1984,1986) and Reddy et al (1988).The effect of preceding crops on the succeeding non legumes crops have been studied at a numbers of locations. The legume was either as a monsoon or a post – monsoon crop. Short duration fodder legumes like cowpea, cluster bean, moth bean and soybean were found to be enrich the soil fertility. Das et al (1990) in five year rotation of castor with sorghum, sorghum + pigeonpea and green gram + pigeonpea in an Alfisol of Hyderabad observed that green gram + pigeonpea intercrop system had a positive balance of 97 kg ha^{-1} total nitrogen in soil. Comprehensive study on the contribution of legume crop in cropping system has also been made recently by Katyal and Das (1993).

Conclusions

Acidic soils are invariably poor in fertility status of macro nutrients. There is need for integrated use of organic and inorganic inputs through synergistic combination in a holistic manner to improve nutrient use efficiency and crop productivity in acidic soils. The nutrient use efficiency in acid soils should be improved through optimizing the nutrient levels with conjunctive use of liming also. The major sources of plant nutrients are chemical fertilizers, organic sources, greenmanures, biofertilizers, leguminous crops, crop residues and agro industries based materials. No single source can meet the increasing nutrients needs of crops. There is also need to more thrust on use of locally available organic and inorganic sources of macro nutrients and biofertilizers in order to reduce requirement of chemical fertilizers so that nutritional requirement of crops is met at a low cost.

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Experimental Designs for Field Experimentation

H.L. Sharma

Professor & Head
Department of Mathematics and Statistics
JN Krishi Vishwa Vidhyalaya, Jabalpur-482004 (MP)

Data are the fundamentals of statistics. They can be generated through two ways:

(i) Sample surveys (ii) Field experimentation

Design of experiment is very much useful in field experimentation to test the significant differences among the treatment means. Some of the terminology which are utilized in design of experiment are given below:

- Experiment
- Treatment
- Experimental unit
- Experimental error
- Precision
- Layout

Experiment

Experiment is a means of getting an answer to the question that the experimenter has in mind. This may be to decide which of several pain–relieving drugs that are available in the market is the most effective or whether they are equally effective. An experiment may be planned to compare the Chinese method of cultivation with the standard method used in India. In planning an experiment we clearly state our objective and formulate the hypotheses we want to test.

Treatment

The different procedure under comparison in an experiment are the different treatments. e.g. in an agricultural experiment, the different varieties of a crop or the manures will be the treatments. In a dietary or medical experiment, the different diets or medicines etc. are the treatments.

Experimental unit

An experimental unit is the material to which the treatment is applied and on which the variable under study is measured. In an agricultural field experiment, the plot of land, and not the individual plant, will be the experimental unit; in feeding experiment of cows, the whole cow is the experimental unit; in human experiments in which the treatment affects the individual, the individual will be the experimental unit.

Experimental error

A fundamental phenomena in replicated experiments is the variation in the measurement made on different experimental units even when they get the same treatment. A part of this variation is systematic and can be explained, whereas the remainder is to be taken of the random type .The unexplained random part of the variation is termed the experimental error .This is a technical term and does mean a mistake, but includes all types of extraneous variation due to –

- inherent variability in the experimental units
- error associated with the measurements made and
- Lack of representativeness of sample to the population under study.

Precision

The precision of an experiment is measured by the reciprocal of the variance of the mean:

$$\frac{1}{\operatorname{var} iance\ (mean)} = \frac{n}{\sigma^2}$$

as n i.e. replication number increases, precision also increases. Another means of increasing precision is to control σ^2, smaller the value of σ^2, the greater the precision.

Layout

The term layout refers to the placement of treatment to the experimental unit according to the condition of design.

Basic principle of field experimentation

There are three basic principles:

- **Randomization**

For an objective comparison, it is necessary that the treatments be allotted randomly to different experimental units. Statistical procedures employed in making inferences about treatment holds good only when the treatment are allocated randomly to the various experimental units . The purpose of randomness is to ensure that the source of variation not controlled in the experiment operate randomly so that the average effect of any group of units is zero. In other words randomization ensures that different treatments on the average are subjected to equal environmental effect.

- **Replication**

The repetition of treatments by applying them to more than one experimental units is known as replication. It results in more reliable estimate of the treatment means than is possible with a single observation. In any experimental situation, replication is necessary in order to get an estimate of experimental error variation caused due to uncontrollable factors. As it is, this variation, against which the variability due treatments is compared. If we repeat a single treatment a number of times the mean of the treatment will be subjected to standard error = $\sigma/\sqrt{r}$ where σ is the nature error variability.

- **Local Control**

The reduction in the experimental error can be achieved by making use of the fact that adjacent areas in the field are relatively more homogeneous than those widely separated. The entire experimental material, if it is heterogeneous, may be divided into different groups or blocks by taking homogeneous units together and the treatment may be allocated randomly to different units in each group by putting a restriction that each treatment is applied to one and only one units of the block such that no treatment is repeated in any group and no treatment is absent from any group.

This procedure of blocking or grouping is termed as local control.

- The aim of the local control is to reduce the error by suitably modifying the allocation of treatments to the experimental units.

Basic designs

- Completely Randomized Design
- Randomized Complete Block Design
- Latin Square Design

Completely randomized design

The simplest design using the two principles i.e. .replication and randomization is the completely randomized design (CRD). In this whole of the experimental material assumed to be homogeneous is divided into a number of experimental units depending upon the number of treatments and their replication. The treatments are then allotted randomly to the units /plots. This design is useful for laboratory, green house and pot experiments. Missing plots or unequal replication do not create any difficulty in the analysis of this design .If we have three treatment A ,B ,and C with 5, 3 and 4 replication then the total experimental material is divided into 12 experimental units .Then random allotment of treatment A ,B,C can be done to 5 , 3 and 4 experimental units as shown below.

Table

A	B	A	B
A	A	C	C
C	B	C	A

Model –

$Y_{ij} = \mu + \tau_i + e_{ij}$ (i = 1, 2 …..t, j = 1 ,2 ….r)

Where, yij denotes the observation of jth replicate for the ith treatment

μ is the general mean effect ,

ti is the effect due to ith treatment and

eij is the random error

Randomized complete block design

When the experimental material is not entirely homogeneous, the completely randomized design can not be used. So here we divide the whole material into homogeneous groups/blocks of experimental units by adopting the principle of local control. Here the homogeneous groups called blocks are formed perpendicular to the fertility gradient. The randomization of the treatments is done independently in each block. Let there be 5 treatments A, B, C, D and E and each replicated three times .The experimental area may be divided into three blocks B1, B2, B3 as shown below and then each block is divided into 5 plots.

B_1	A	C	D	B	E
B_2	D	C	E	A	B
B_3	A	A	C	D	B

The design is used frequently in agricultural field experiments.

Model: $Y_{ij} = \mu+t_i+b_j+e_{ij}$; (i = 1, 2 …t, j = 1 ,2 .r)

Where, yij denotes the observation of jth replicate for the i th treatment

μ is the general mean effect ,

ti is the effect due to ith treatment and

bj is the effect of jth blocks

eij is the random error .

Latin square design

The randomized block design is intended to reduce error in respect of one factor by forming homogeneous block or groups. Often there is a variation among animals in respect to more than one factor variation in respect of two factors can sometimes be controlled simultaneously by an arrangement known as Latin square .In this design, the number of replications must be equal to the number of treatment. The txt unit is grouped in "t' rows and 't' column according to the variation in two factors. Similarly in field experiments, soil heterogeneity is eliminated in two ways by grouping the units into rows and columns. If the fertility gradient is in the direction of east to west, then the grouping will be done in the direction of North to South. The treatments are allotted such that each treatment 'occurs once and only once in each row and in each column.

The following are the examples of a Latin Square Design

A	B	C
B	C	A
C	A	B

B	C	A	D
D	A	C	B
A	D	B	C
C	B	D	A

The first is a Latin square of order 3 in a standard form. The second of order 4 has been derived from a standard Latin square by permutation of rows and columns.

Model - $Yij = \mu + ri + cj + tk + eijk$

($i = 1, 2 \ldots t, j = 1, 2 \ldots t, k=1,2\ldots t$)

where yijk denotes the observation on the kth treatment jth column and in ith row,

μ is the general mean effect ,

ri is the effect due to ith row ,

cj is the effect due to jth Column the i th treatment

tk is the effect due to kth treatment and

bj is the effect of jth blocks

eijk is the random error which is assumed to be independently and normally distributed with mean zero and constant variance (σ^2)

Factorial Experiments

- Experiment where the effects of more than one factor, say variety manure, etc. are considered together are called factorial experiments, while experiment with one factor, say only variety or manure , may be called simple experiments. Consider a simple case of a factorial experiment. The yield of a crop depends on the particular manure applied .We may have two simple experiments, one for the variety and one for the manure. First experiment will give information on whether the different varieties of crop are equally effective or there are some varieties which will give higher yields than rest, similar type of information may be obtained from the second simple experiment about the manures. Though the experiment with varieties will be performed in the presence of a particular manure (not all the manure) and the experiment will be performed with a particular variety (not all the varieties), they will not give us any information about the dependence or independence of the effect of the varieties on those of the manures. If there are p different varieties then we shall say that there are p level of the factor 'varieties'. Similarly, the second factor 'manure' may have q level, i.e. there may be different manures or different doses of the same manure .Then this factorial experiment will be called a pxq experiment.

Types of factorial experiment

➢ **Symmetrical factorial:** where the levels of each factor are the same in the experiment

❑ Example- 2^2, 2^3, 2^4 …2n are symmetrical factorial experiments of factors two, three, four ,……. n, each it two levels .The experiments 3^2, 3^3, 3^4 …3n are also symmetrical factorial consisting of 2, 3, ……., n, factors each at three levels . Here in both type of experiments, the levels of the factors are the same. In first, it is 2 and in second, it is 3.

➢ **Asymmetrical factorial:** where the levels of each factor are the different in the experiment.

❑ In general, if there are n factors each with s levels than it is known as S^n factorial (symmetrical) experiments. If the factors consists of different levels i. e A has 2 levels and B has 3 levels, then it is known as 2x3 asymmetrical factorial experiment and if there is another factor which is at four levels, then it called 2x3x4 factorial experiment.

One factor at three levels

The three levels of factor a may be denoted by a_0, a_1, a_2, with equal intervals. In dealing with factors at two levels we have not mentioned the matter of equality of interval because there is only one interval in that case. Levels with unequal intervals can also be analyzed, the situation for one factor at three levels, a_0, etc., also denoting the response at that level is shown below. We observe the following:

Increment form 0 to 1: $a_1 – a_0$

Increment from 1 to 2: $a_2 –a_1$

Sum of increments: $(a_2-a_1) + (a_1-a_0) = a_2-a_0$

Difference between increments:

$$(a_2-a_1) – (a_1-a_0) = a_2-2a_1 +a_0$$

The first contrast, a_2-a_0, measures the linear effect of the factor. The second contrast, a_2-$2a_1$+a_0, measures the deviation from linearity, because if the three points in are collinear, this quantity equals zero. The method of subdividing the ssq with two degrees of freedom.

Two factors, each at three levels

When there are tow factors, each at three levels, there will be nine treatment combinations, an example of which is given in .The ssq between blocks (with 3 df), the ssq between treatments (with 8 df), and the ssq for error (with 24 df) may be calculated the usual way. In fact, these preliminary results may be found in, with blocks and treatments interchanged and rearranged.

The seven contrasts

For factors at two levels, the symbolic expressions and expansions for the various contrasts have been greatly simplified by replacing a1 and a0 by a and 1, etc.

Unfortunately, there is no equally simple notation for factors at three levels. We may, however, adopt a half-simplified system, writing a_2,a_1,a_0,as a_2, a, 1. Even this half-simplified notation will save us a lot of writing labor.

Now the sum of squares for the three row totals (300, 228, 192) may be subdivided into two single components, as was done in Sec.

These four contrasts may be written symbolically

$$A_1 = (a_2 - 1) (b_2 + b + 1)$$

$$A_2 = (a_2 – 2a + 1) (b_2 + b + 1)$$

$$B_1 = (a_2 + a + 1) (b_2 - 1)$$

$$B_2 = (a_2 + a + 1) (b_2 - 2b + 1)$$

Where factors like (a_2 + a + 1) and (b_2 + b +1) simply mean marginal totals. The remaining four expressions for different types of interactions are

$$A_1B_1 = (a_2 - 1) (b_2 - 1)$$

$$A_1B_2 = (a_2 - 1) (b_2 – 2b + 1)$$

$$A_2B_2 = (a_2 – 2a + 1) (b_2 – 2b + 1)$$

These eight expressions, when expanded, will form a set of orthogonal contrasts, each with a single degree of freedom. Instead of lining the nine treatment combinations into a single file. Note that the coefficients for the interactions are actually products of corresponding coefficients of the main effects involved.

The 2x3 factorial

When one factor (say,a) is administered at two levels (a_1,a_2) and another factor (say,b) at three levels with equal intervals (b_0,b_1,b_2), we say breakdown of treatment effects of a 2x3 factorial (based on hypothetical data)

	a_2			a_1			Effect Z	Divisor Dxr	ssq Z^2/Dr
	b_2	b_1	b_0	b_2	b_1	b_0			
	144	138	108	162	90	78			
A	+1	+1	+1	-1	-1	-1	60	6x6	100
B_1	+1	0	-1	+1	0	-1	120	4x6	600
B_2	+1	-2	+1	+1	-2	+1	36	12x6	18
AB_1	+1	0	-1	-1	0	+1	-48	4x6	96
AB_2	+1	-2	+1	-1	+2	-1	-84	12x6	98
Total treatment ssq									912

Is a 2 x 3 factorial experiment. It is the simplest example of factors with mixed level. The analysis hardly needs explanation, because we merely combine the techniques of the preceding two chapters. The five contrasts among the six treatment combinations are, symbolically,

$$A = (a_2 – a_1) (b_2 + b_1 + b_0)$$

$$B_1 = (a_2 + a_1) (b_2 – b_0)$$

$$B_2 = (a_2 + a_1) (b_2 – 2b_1 +b_0)$$

$$AB_1 = (a_2 – a_1) (b_2 – b_0)$$

$$AB_2 = (a_2 – a_1) (b_2 – 2b_1 + b_0)$$

The above table gives the coefficients of the treatment combinations after these symbolic expressions have been expanded; this is a numerical workout from a 6 X6 Latin-square data. It is seen that the sum of the five-component ssq is 912, as was found in above Table. Each component may then be tested against s^2 = 14.2 with 20df.

Zero level and dummy treatments

When the lowest level of application of the factors is actually zero (that is, no application at all as an absolute control) and the factors involved are different kinds of material such as different derivatives of a basic chemical compound, different preparations of a vaccine or antiserum, different varieties or strains of organisms, different forms of an active ingredient, etc., then the three treatment "combinations' at the zero level are all identical, receiving no active ingredients at all. For convenience, let us change the notations slightly and denote the three different drugs by a, b, c (aspirin, Bufferin, Coricidin; or Ajax, Babo, Comet, if you like) each administered at three levels – 0 (none given), 1 (10grains per day), 2 (20 grains per day). The nine combinations are then as tabulated here. But the three combinations at the zero level (a_0, b_0, c_0) really represent the same condition (placebo): the patient receives no drug of any king. There are actually only seven (not nine) distinct treatments.

The factorial may also be regarded as a 2x3 plus an extra control, instead of the superficial 3x3. The investigator may, of course, conduct an experiment with just seven treatments, each replicated a certain number of time. In such a case, the number of observations at the zero level is only one-third of that at the other two levels and the quantitative effect of the drugs will not be as accurately determined as when there is an equal number of replications at levels. In many instances, it is desirable to preserve the superficial 3x3 structure with equal number of placebos and treatments at 1 and 2 levels. Then the treatments a0,b0,c0 are called dummy treatments. They are assigned at random to patients as if they were different. The analysis of the treatment effects, however, requires a sight modification.

Confounding

Confounding in experimental design is then to denote an arrangement of the treatment combinations in the block in which less important treatment effects purposively confounded with the block. This non- orthogonality is not a defect of the design; it is deliberately introduced in order to get better estimates and tests on the important treatment combinations.

➢ **Types of confounding**

❖ Complete confounding

❖ Partial confounding

❖ **Complete confounding**

In complete confounding, we confound the same interaction in all the replications and thus, we don't have the information regarding get information that interaction from all the replication where as unconfounding effects can be estimates and tested as any complete block design.

❖ **Partial confounding**

In partial confounding the different interaction is confounded in different replications. That is, if one effect is confounded in first replicate, then other effective will be confounded in second, in third and so on.

Systems of confounding in a 2^n experiments:

Let us suppose that we have 5 factors A, B, C, D and E each at 2 levels, giving 32 combinations.

- treatment combinations in all .We wish to use blocks of 8 experimental units .The experiment will consist of 4 blocks of 8 units and there will be 3 effects or interactions confounded with blocks .
- If we confound the interaction BCD, the treatment the combinations fall into two groups, each groups consisting of 2 of the blocks namely:
- (α) : (1), bc , bd, cd ,a, abc , abd,acd, e, bce, bde, cde,ae,abce,abde,acde.
- (β): b, c, d, bcd, ab, ac ,ad, abcd, be, ce, de, bcde, abe, ace, ade , abcde.
- If we also confound, say, CDE, we divided the treatment combinations and again into 2 groups.
- (γ):(1),cd,ce,de,a,acd,ace,ade,b,bcd,bce,bd e,ab,abcd,abce,abde.
- (δ):c,d,e,cde,ac,ad,ae,acde,bc,bd,be,bcde,a bc,abd,abe, abcde.

If each of the comparisons (α) vs. (β) and (γ) vs. (δ) are to be block comparisons, the blocks must contain the common treatment combinations of the followings:

(1) Treatment common in (α) and (γ)

(2) Treatment common in (α) and (δ)

(3) Treatment common in (β) and (γ)

(4) Treatment common in (β) and (δ)

The four blocks will be represented as given below

(1)	(2)	(3)	(4)
(1)	e	b	c
cd	cde	bcd	d
a	ae	ad	ac
acd	acde	abcd	bd
bce	bc	ce	ae
bde	bd	de	bcde
abce	abc	ace	abe
abde	abd	ade	abcde

Split plot experiment

In field experimentation, sometimes we need the large experimental area to the test the treatment .In fact, when we go for testing the different methods of ploughing or irrigation. In this situation, it is difficult to manage both treatments in a small area. These treatments are called the whole plot treatments or main plots. It is possible to test another treatment by splitting the main plot into subplots which does not require large plots. It may be possible that for subplot treatment expense may be slightly high. We introduce the second treatment in split plot by splitting the whole plots. We test the treatments which are in sub plots more efficiently rather than whole plots.

Model : Yi j k=μ+r i+m j+e i j+s k+(ms) j k + e i j k

where, Yijk is the observation on the k t h sub plot the jth main plot in the ith replication.

μ is the general mean effect

ri is the ith replication effect

mj is the main plot treatment effect

eij is the error first or main plot errors which are N(O,σ2e)

sk is the kth sub plot treatment

(ms)j k is the interaction effect due to main and sub plot treatment

eijk is the error second or sub plot error which are N(O,σ2e).

Strip plot experiment

- Another kind of split plot experiment is the strip plot experiment. It is also known as split block experiment because the blocks are spitted row wise and column wise to accommodate the two sets of treatments .This experiment is usually performed where both treatments require large plot size .This is generally happened in agronomic experiments in which both experimental factors are not easily applied to small areas like split plot .

- For example: The factors are tillage and water management.

- In this experiment each block is divided row wise as per the first set of treatments and column wise as per the second. The column wise treatments are laid out either in RCBD or LSD. The randomization process is the same as that for the standardized design. The layout plan of 1 replicate is be as shown in the following figure.

Replication 1

	A_o	A_2	A_3	A_1
B_1				
B_2				
B_0				
B_4				
B_3				

where A and B are the level of first and second set of treatments .In this experiment at least two replications are required. Such experiment provided relatively low accuracy on both main effects with relatively high accuracy on the interaction.

Response surface

If in an agricultural experiment, yield is influenced by several factors like height of the plant, length of ear head, temperature, relative humidity, etc., which are all quantitative variables then the yield (or response) is a function of the levels of these variables and is denoted by

$$Y_j = \varphi(X_{1j}, X_{2j}, \ldots X_{kj}) + E_j$$

Where j=1,2,…, n represent the j-th observation in the factorial experiment and X_{ij} denotes the level of i-th factor of the j-th observation and $E_j^{\prime}s$ are experimental errors which are assumed to be independent and follow normal distribution with mean zero and variance σ_k^2. The function 'φ' is called response surface. If φ is known then it is easy to predict (or forecast) the value for knowing the different levels of factors. Further the combination of levels of factors can be arrived at to attain the optimum and maximum response once the function is known.

In the absence of knowledge of the function it can be assumed that the experimental region can be represented by a polynomial of first or second degree. The designs used for fitting the first degree and second degree polynomials are called first order and second order designs respectively. The fitting of second order polynomial is illustrated here with an example.

Example: An experiment was conducted with nitrogen at four levels (40, 60, 80, 100 kg/acre) along with phosphorus at three levels (15, 30, 45 kg/acre) in a lay-out of randomized block design having three replications for paddy. The hypothetical yields are presented in the following Table 16.70.

Treatment	*1*	*2*	*3*	*Total*
n_0p_0	8	10	9	27
n_0p_1	10	14	12	36
n_0p_2	11	9	10	30
n_1p_0	13	12	15	40
n_1p_1	15	14	13	42
n_1p_2	18	16	19	53
n_2p_0	14	12	10	36
n_2p_1	20	22	22	64
n_2p_2	24	26	25	75
n_3p_0	16	15	18	49
n_3p_1	22	20	23	65
n_3p_2	28	27	29	84
	199	**197**	**205**	**601**

Fit the response surface for the above data.

The two way table of nitrogen and phosphorus with plot yield totals of three replications is given in table.

Table: Phosphorus

Nitrogen	*15*	*30*	*45*	*Total*
40	27	36	30	93
60	40	42	53	135
80	36	64	75	175
100	49	65	84	198

The Factorial analysis is presented in the ANOVA table.

Source	d. f.	S.S.	M.S.	F_{cal}
Replications	2	2.89	1.45	
Treatments	11			
N	3	711.42	237.14	117.40**
P	2	343.06	171.53	84.92**
NP	6	177.83	29.64	14.67**
Error	22	44.44	2.02	
Total	35	1279.64		

** Significant at 1 percent level.

To examine the trend in yield for different levels of nitrogen and phosphorus, the linear, quadratic components for phosphorus; linear, quadratic and cubic components for nitrogen as well as for NP Interaction were computed as follows. The coefficients of orthogonal polynomials for linear and quadratic components for phosphorus levels (-1,0,1) and (1,-2,1)respectively, the coefficients for nitrogen levels for linear, quadratic and cubic components are (-3,-1,+1,+3), (+1,-1,-1,+1), (-1,+3,-3,+1) respectively.

Table

	40	*60*	*80*	*100*	*total*
P_L (Linear)	3	13	39	35	90
P_Q (quadratic)	-15	9	-17	3	-20

$$P_L.S.S. = \frac{(90)^2}{3 \times 4 \times 2} = 337.50, \quad P_Q.S.S. = \frac{(-20)^2}{3 \times 4 \times 6} = 5.56$$

It can be verified that

$$P_L.S.S + P_Q.S.S. = P.S.S.$$

Similarly the linear, quadratic and cubic components for nitrogen are computed as follows.

Table: phosphorus levels

	15	*30*	*45*	*Total*
N_L (linear)	62	109	184	355
N_Q (quadratic)	0	-5	-14	-19
N_C (cubic)	34	-37	-12	-15

$$N_L.S.S. = \frac{(355)^2}{3 \times 3 \times 20} = 700.14$$

$$N_Q.S.S. = \frac{(-19)^2}{3 \times 3 \times 4} = 10.03$$

$$N_C.S.S. = \frac{(-15)^2}{3 \times 3 \times 20} = 1.25$$

The interactions of P_L with N_L, N_Q, N_C and P_Q with N_L, N_Q, N_C would be computed as follows.

$$P_LN_L = -3(3) - 1(13) + 1(39) + 3(35) = 122$$

$$P_LN_Q = +1(3) - 1(13) - 1(39) + 1(35) = -14$$

$$P_LN_C = -1(3) + 3(13) - 3(39) + 1(35) = -46$$

$$P_LN_L.S.S. = \frac{(122)^2}{3 \times 3 \times 20} = 124.03$$

$$P_LN_Q.S.S. = \frac{(-14)^2}{3 \times 2 \times 4} = 8.17$$

$$P_LN_C.S.S. = \frac{(46)^2}{3 \times 2 \times 20} = 17.63$$

$$P_QN_L = -3(-15) - 1(9) + 1(-17) + 3(3) = 28$$

$$P_QN_Q = +1(-15) - 1(9) - 1(-17) + 1(13) = -4$$

$$P_QN_C = -1(-15) + 3(9) - 3(-17) + 1(3) = 96$$

$$P_QN_L.S.S. = \frac{(28)^2}{3 \times 6 \times 20} = 2.18$$

$$P_QN_Q.S.S. = \frac{(-4)^2}{3 \times 6 \times 4} = 0.22$$

$$P_QN_C.S.S. = \frac{(96)^2}{3 \times 6 \times 20} = 25.60$$

The analysis of variance table given in table 16.71 is now rewritten as presented in table 16.74.

Source	d. f.	S.S.	M.S.	F_{cal}
Replications	2	2.89	1.45	
N	3	711.42		
N_L	1	700.14	700.14	346.60**
N_Q	1	10.03	10.03	4.97
N_C	1	1.25	1.25	
P	2	343.06		
P_L	1	337.50	337.50	167.08**
P_Q	1	5.56	5.56	
NP	6			
N_LP_L	1	124.03	124.03	61.40**
N_LP_Q	1	2.18	2.18	
N_QP_L	1	8.17	8.17	
N_QP_Q	1	0.22	0.22	
N_CP_L	1	17.63	17.63	8.73**
N_CP_Q	1	25.60	25.60	12.67
Error	22	44.44	2.02	
Total	35	1279.64		

** Significant at 1 per cent level.

From Table it can be observed that the yeild is significantly effected by linear and quadratic trend of nitrogen , linear trend of phosphorus, linear trend of nitrogen with linear trend of phosphorus, cubic trend of nitrogen with linear trend of phosphorus, cubic trend of nitrogen with quadratic trend of phosphorus.

The response surface is the mathematical relation taking yield as the dependent variable and the above mentioned factors as independent variables. Let the relation between yield and $N_L, N_Q, P_L, N_LP_L, N_CP_L$ and N_CP_Q by ,

$$\hat{Y} = \bar{Y} + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5 + b_6X_6$$

Where $\hat{Y}$ is the estimated value of yield and

$$X_1 = N_L, X_2 = N_Q, X_3 = P_L, X_4 = N_LP_L, X_5 = N_CP_L, X_6 = N_CP_Q$$

And $b_i's$ are regression coefficients.

In order to find out the regression coefficients ($b_i's$) the coefficients of orthogonal polynomials will be used as given in the Table 16.75 since $b_i = \frac{\Sigma X_iY}{\Sigma X_i^2}$.

Nitrogen levels	Phosphorus levels	Yield Total (Y)	N_L=1(N-70)	N_Q	P_L	N_L	N_CP_L	NC_{PQ}
40	15	27	-3	+1	-1	+3		
	30	36	-3	+1	0	0		
	45	30	-3	+1	1	-3		
60	15	40	-1	-1	-1	+1		
	30	42	-1	-1	0	0		
	45	53	-1	-1	1	-1		
80	15	36	+1	-1	-1	-1		
	30	64	+1	-1	0	0		
	45	75	+1	-1	1			
100	15	49	+3	+1	-1			
	30	65	+3	+1	0			
	45	84	+3	+1	1			
$\sum X_iY$ $\sum X_i^2$		601	355 60	-19 12	90 8	122 40	-46 40	96 120
b_i 5.9167	11.2500	-1.1500	0.800					
	-1.5833	3.0500						

The response surface between yield and X_is' is given by

$$\hat{Y} = 50.0833 + 5.9167X_1 - 1.5833X_2 + 11.2500X_3 + 3.0500X_4 - 1.1500X_5 + 0.8000X_6$$

The same relation between yield and $N_L, N_Q, P_L, N_LP_L, N_CP_L$ and N_CP_Q is rewritten as

$$\hat{Y} = 50.0833 + 5.9167N_L - 1.5833N_Q + 11.2500P_L + 3.0500N_LP_L - 1.1500N_CP_L + 0.8000N_CP_Q$$

The estimated yields can be obtained for the given levels of nitrogen and phosphorus.

For example, the estimated yield, when the level of nitrogen is 80 and the level of phosphorus is 45, is obtained by substituting in the fitted equation for $N_L = +1, N_Q = -1, P_L = +1, N_LP_L = +1, N_CP_L = -3$ and $N_CP_Q = -3$ i.e.

$$\hat{Y} = 50.0833 + 5.9167(+1) - 1.5833(-1) + 11.2500(+1) + 3.0500(+1) - 1.1500(+1) + 0.8000(-3) = 74.5333. kg.$$

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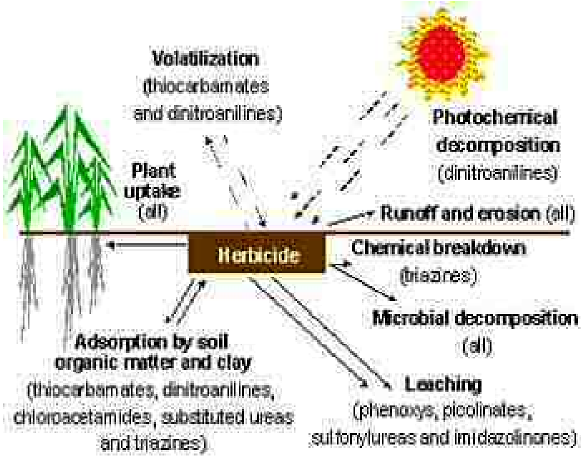
Managing Herbicide Persistence in Soil

K.K. Barman

Principal Scientist

Directorate of Weed Science Research
Jabalpur (M.P.)-482004

For effective control of weeds, herbicides must remain in soil in an active and available form until their purpose is accomplished. However, herbicidal activity is desirable only up to the time herbicides have achieved their desirable purpose. The length of time that an herbicide remains active in the treated soil is called persistence or soil residual life. Herbicide persistence is an important property of soil-applied herbicides, and some post emergence herbicides that allows for extended weed control. When the herbicide remains unaltered in the soil during the crop season of application, it is advantageous. If an herbicide persists in the soil for longer time and is present when a rotational (and susceptible) crop is planted, the persistence causes herbicide carryover and is undesirable. Persistence is the integrated result of all herbicide-loss pathways that act upon the parent compound when it is in



the soil environment. Figure 1 summarizes these features.

Fig. 1: Fate of applied herbicides

Factors affecting persistence

The persistence of herbicides in soil is regulated by herbicidal properties, soil characteristics, climatic conditions and management practices.

A. Herbicidal properties

Acid or base strength. This measure refers to whether the pesticide has basic, acidic or nonionizable properties. This determines its ability to exist in the soil water or be retained onto soil solids. Thus, the acid or base strength of both the herbicide and the soil determines potential herbicide movement and plant uptake. In general, herbicides whose pH is close to the pH of the soil are strongly retained and are not subject to runoff, erosion and/or leaching. In contrast, herbicides whose pH is not close to that of the soil are less strongly retained and are subject to runoff, erosion and/or leaching. Also, they are more available for plant uptake than strongly retained herbicides.

Table 1: Summary of the relative behavior of herbicides in soil

Herbicides	Water Solubility	Volatility	Soil Retention	Persistence
Dinitroanilines	very low	moderate-high	moderate-high	short-moderate
Thiocarbamates	low-moderate	high-very high	low-moderate	very short-short
Chloroacetamides	moderate	low-moderate	low	very short-moderate
Substituted ureas	very low-low	very low-moderate	low-high	short-moderate
Phenoxys/benzoics / picolinates	low-high	very low-moderate	very low-low	very short-short (pH dependent)
Sulfonylureas	very low-high (pH dependent)	very low-low	very low-low (pH dependent)	short-long
Imidazolinones	moderate-high (pH dependent)	very low	very low-low (pH dependent)	short-long
Organic phosphorus	very high	very low	very high	N/A
Triazines	low-moderate (pH dependent)	very low-low	low-high (pH dependent)	very short-moderate
Dipyridiniums	very high	very low	very high	N/A

Water solubility. This measure refers to how readily the herbicide dissolves in water. This determines the extent to which an herbicide is in the solution phase (plant available) or the solid phase. Water solubility plays a major role in determining the fate of herbicides in water, soil and air. An herbicide that is water soluble will not be retained by the soil.

Volatility. Volatility refers to the tendency of the herbicide molecule to become a vapor. The vapor pressure (VP) at 25^{o}C is an index of this characteristic. Herbicides with high vapor pressures are likely to escape from the soil and volatilize into the atmosphere. Dinitroaniline herbicides are lost in the environment by surface volatilization.

Soil retention. Soil retention is an index of the binding capacity of the herbicide molecule to soil organic matter and clay. In general, herbicides with high soil retention are strongly bound to soil and are not subject to leaching. Those not exhibiting high soil retention are not strongly bound and are subject to leaching.

B. Climatic condition

The climatic conditions dictate the soil temperature and moisture conditions. The primary herbicide-loss pathways in soil are microbial breakdown and chemical breakdown, primarily driven by reactions with water. The effects of soil temperature and moisture on herbicide degradation are straightforward in that degradation mechanisms involving microorganisms operate best at optimal conditions for biological growth. Provided the soil is moist, the rate of herbicide degradation increases with soil temperature. The interactive effect of soil moisture and soil temperature is shown in table 2. Alternate wet and dry periods give greater persistence and adequate weed control over a longer period (Eagle 1983). Chemical reactions and volatilization typically are enhanced with increased temperature.

Table 2: Influence of temperature and moisture on herbicide degradation in a sandy loam soil

Herbicide	Half life for degradation (days)							
	Field capacity				25% of field capacity			
	20° C	15° C	10° C	5° C	20° C	15° C	10° C	5° C
Propyzamide	35	59	98	164	90	152	252	422
Metribuzin	36	56	88	138	97	150	237	370
Linuron	74	90	110	134	142	173	210	257

Source: Walker (1983)

C. Soil type

Microbial activity is greater in soils with higher organic matter content; adsorption of most pesticides also increases with an increase in organic matter content. Thus a fertile soil, rich in organic matter, may promote faster degradation of a herbicide but also have less available to degrade, based on its greater adsorption sites. However, in general the faster rate of herbicide loss is observed with the increase in organic matter content. Leela (1987) reported that alachlor was active upto 40 days in some mineral soils but upto 20 days in organic soil. Persistence increased with the increase in clay content. Jayakumar *et al.* (1990) found that pendimethalin at recommended doses for weed control in crops persisted more in black soil than alluvial and red soils.

Soil pH may have direct effect if the stability of the chemical is pH dependant, and it may have indirect effects through changes in microbial population or changes in adsorption of herbicide in soil. The herbicides simazine and atrazine are hydrolysed in solution under acid conditions and their degradation in soil is more rapid at lower soil pH. High soil pH associated with calcitic soils, overliming, or proximity to limestone gravel lanes may reduce herbicide degradation and increase carryover. This effect may be important for triazines and some sulfonylureas. Degradation of metribuzine (Ladlie *et al*. 1976) and napropamide (Walker *et al*. 1984) was less in soil with decreasing pH.

D. Management practices

Most often herbicides applied on the surface of dry soil are subjected to volatilization and photodecomposition losses. To increase the persistence of the volatile herbicides, e.g. thiocarbamates and dinitroanilines, incorporating them in the surface soil is desirable. Contrary to the general perception, evidences are there to show that with repeated annual applications of certain herbicides to the same soil there is a build-up of micro-organisms adapted to breakdown the herbicide resulting in more rapid degradation than in freshly treated soil. Although first observed with phenoxyalkanoic herbicides it has also been found with amide and thiocarbamate herbicides (Hance 1987, Fryer *et al*. 1980, Racke and Coates 1990), although not all members of a group may be affected. Accelerated breakdown of a soil acting herbicide may significantly reduce its persistence to less than a desired period of time and thus its effectiveness.

Avoiding Herbicide Carryover

Following pre-cautions are to be taken to avoid herbicide carryover problems.

1. Application of correct rate of herbicide as per specific soil type and weed problem. Required dose a herbicide may vary depending upon the soil type. Hence, always read the label before applying any herbicide. Besides that, accurate acreage determination, accurate chemical measurement, proper sprayer calibration, and uniform application are essential.
2. The prescribed method and time of application to be followed. Incorporation dilutes herbicides; however, herbicides will more likely remain longer if incorporated than if surface-applied without incorporation. Incorporating the herbicide makes it less susceptible to loss by volatilization and photodegradation. In addition, an incorporated herbicide is immediately exposed to soil particles and may be tied up temporarily through adsorption and later released. Decreased volatilization and photodegradation losses and increased adsorption favour possibility of carryover of relatively persistent herbicides.

Postemergence and late soil applications have greater potential than earlier applications for being present the following season.

3. The amount of tillage affects herbicide persistence. Minimum-till and no-till, which leave crop residue on the soil surface, also tend to leave a greater concentration of herbicide near the surface zone. Persistent herbicides present in this concentrated zone may affect susceptible crops. Tillage encourages herbicide decomposition indirectly through increased microbial and chemical breakdown.

4. Herbicide combinations may reduce the risk of carryover problems. By tank-mixing two or more herbicides, one may reduce the application rates of those products that can potentially cause problems and at the same time broaden the weed-control spectrum.

5. Herbicides may interact with one another or with other pesticides and may enhance crop injury when applied in the same year or in consecutive years. For example, a soybean crop may tolerate a certain level of atrazine carryover. However, if another photosynthetic inhibitor, such as metribuzin, is applied to soybeans after atrazine-treated corn, injury is more likely.

Detection of residue problem and selection of suitable cultivar

One can get his soil analysed in a recognized laboratory to detect the herbicide residue. However, it may not be cost effective in light of his concern. The bioassay can help predict potential crop injury. The test is inexpensive and can be done with a few simple supplies. A bioassay does not measure the amount of herbicide residue present in the soil, but it may indicate whether or not enough residue is present to injure a sensitive crop. A farmer can easily find out if there is any residue problem in his field, in respect to the crops/varieties intended to sown in the forth-coming season, by taking the following steps:

a. Soil collection and preparation

With the indoor bioassay, proper sampling of soil is the first step. The accuracy of a bioassay depends on sampling technique and depth and area of soil sampled. Soil samples should be collected and the test conducted about one month before seeding time.

i. Before planting/seeding time, collect representative soil samples from the field suspected of having herbicide residues. Collect samples also from those areas believed to be free of herbicide residue for use as a “check” soil. Keep the suspected and check soil samples in separate places to avoid possible contamination.

ii. Collect soil samples at the depth of cultivation, usually 15 cm. If no tillage is practiced, samples from top 0 to 8 cm soil layer are to be collected, as most residual herbicides are bound in the upper 5 cm layer of soil.

iii. Take separate samples from high spots and low spots, including areas where sprayer overlap could have resulted in an overdose particularly if the overlap is still visible in standing stubbles.

iv. Using a spade, trowel or soil sampler, take several samples from the suspected area and mix them. Collect enough soil, about 2-3 kg, to fill required numbers of (10 cm diameter) pots.

v. Store the samples in cool conditions. If the soil is wet, spread it out to air dry until they can be worked readily. Do not over dry. After drying, crush clods to pea-sized particles.

b. Performing bioassay

Take two sets of required numbers of small pots (10 cm diameter). In one set, take the contaminated soil and in other set take non-contaminated soil (see Fig. 2). Depending upon the size of seeds, sow 5-10 viable seeds of the crop to be evaluated to both sets of pots. Water the pots to raise the soil moisture content at approximately the field capacity level. Maintain the soil moisture uniformly in all pots during the experimental period by frequently irrigating the pots. Keep the pots in a net house or growth chamber. After a few days, take an observation on germination percentage and thin out the relatively weaker plants to allow 2-3 healthy plants per pot to grow for about 15-20 days. Harvest the shoots and take observation on shoot length. Take the contents of the pot into a sieve and wash out the soil with running water. Collect roots and measure root length. Oven dry the shoots and roots separately at 60-65^{o}C and record their dry weight. If the growth parameter values as recorded from pots that contained the contaminated soil are significantly lower (say less than 80%) than those recorded from the pots with non-contaminated soil, it may be concluded that the crop or the variety in question is not suitable for sowing in the given field.

Fig.2. A typical bioassay being performed on several species to detect herbicide residues in soil and also to select a suitable crop if the residue is present in the soil. (Front row: Herbicide-contaminated soil; Back row: Check soil)

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Organic Farming: A Natural Resource Conservation System for Sustainable Agriculture

L.N. Verma

Former Director
National Biofertilizer Development Centre and Retd.Principal Scientist
Department of Soil Science & Agricultural Chemistry
J.N. Krishi Vishwa Vidyalaya, Jabalpur -482004 (M.P.)

The traditional agriculture practiced by our forefathers was essentially an organic agriculture. The addition of animal excrement, stinking garbage, rotting corpse on cultivated soil was common practice as for back as of *Ramayan* age (interpreted by C. Rajagopalachari). *Holy Quran* (590AD) mentions of return of at least one third of what you take out from soil implying recycling or addition of post- harvest residue. Considering the use of organic matter, the use of mineral salts as fertilizer material to promote plant growth is of recent origin, just 100- 120 years old and that of chemical pesticide to control the incidence of pests and diseases of crops arising more often due to imbalance use of chemical fertilizers and neglect of use of organic matter is hardly started about 50 years back.

The Green Revolution has been a landmark in transformation of Indian agriculture most of the contribution to the success have been due to the use of high yielding variety of planting material, fertilizers, plant protection and irrigation system. Establishment of agricultural universities and adoption of research results obtained from these universities by farmers through the extension network of State Department of Agriculture paved the way for substantial increase in food production leading the nation to self sufficiency and even surplus for export. The success of the Green Revolution made the nation jubilant.

Table 1. Compound annual growth rate in yield of important crops in India

Crops	1980-81 to 1989-90	1990-91 to 1999-2000
Rice	3.19	1.27
Wheat	3.10	2.11
Maize	2.09	1.69
Total Cereals	2.90	1.58
Total Pulses	1.61	0.96
Total Food grains	2.74	1.52
Total Oilseeds	2.43	1.25
Sugarcane	1.27	0.95
Cotton	4.10	-0.61
Total Non-food grains	2.31	1.04
All Principal crops	2.56	1.31

In the recent decades despite of commendable progress made earlier deceleration of crop yield has become a matter of serious concern. The growth rate of rice has gone down form 3.19 in 1980- 90 to merely 1.27 in 1991- 2000. The decreasing growth rate of other crops may be seen in Table- 1.

High Agrochem Low Response:

Consumption of chemical fertilizers have increased seven folds and of pesticides by 375 folds while the resulting food production had just doubled during the first 20 years of launch of Green Revolution (Ramanathan, 2006). Increased use of chemicals under intensive cultivation has disturbed the harmony existing among soil, plant and microbial population (Ghosh, 1999). The fertilizer (Kg ha $^{-1}$) use in Korea is 357, Japan 247, Netherland 172, Bangladesh 158, Germany 153, India 89, China 71, USA 47 and Australia 5 (Fertilizer Statistics 2003-04). The use of pesticides (Kg ha $^{-1}$) in USA, Japan, Korea, China, India are 1.50, 1.80, 16.60, 2.25 and 0.38 respectively. It is reported that the incidence of insects, pests and diseases is more acute and serious due to imbalance use of fertilizers, so the use of pesticides during last a few decades has become most essential agro-input to increase and sustain crop yields. Agro-chemicals are very expensive input in conventional farming and with the decrease in yield per unit use of agro chemical, the farmers have suffered loss and their financial system has become unsustainable. The farmers cultivating cotton and paddy in Maharashtra, Andhra Pradesh, Kerala and Karnataka have gone under heavy debt, are financially broke and are tending to end their life, which is most unfortunate, disheartening and alarming.

Ailing Nutrition:

Basically everything absorbed by the plants from the soil, water and air becomes part of the plant. All 17 essential elements absorbed by plants become part of food chain. Sources of these elements and substances are agro-chemicals (pesticides, fungicides weedicides, and fertilizer), air pollutants (sulphur dioxide, nitrogen oxide that cause acid rain), shelf life enhancer and elements that become soluble in cooking wares and food containers. Scientific evidences indicate that along with the content of food, particles of pesticides, sprayed or used over crops leave undissolved and harmful elements which are transferred to human and other living bodies through grains, vegetables, fruits and grasses cause a number of diseases, ailments and harmful effects on our health (Bhattacharyya, 2005). India stands first in the list of quantity of pesticides consumed through food. It is 362.5 mgd^{-1} person^{-1} pesticides and 356.3 mgd^{-1} person^{-1} for non vegetarian and vegetarians food respectively, while in USA it is only 7.6 mgd^{-1} person^{-1} (Table -2). According to WHO, 14000 people end their life every year in the third world countries due to pesticide poisoning. Its immediate effect has appeared in environment and ecosystem also. Large scale death of birds, snakes, peacocks, crabs and aquatic animals is reported every year. The pesticide residue persistence in agricultural produce, food commodities, animal products, irrigation water are matter of serious concern as their presence is more than maximum residue limit of Prevention of Food Adulteration Act 1954.

Table 2. Quantity of pesticides consumed through food

Country	Pesticides consumed through (mgd^{-1} person^{-1})
USA	7.6
United European countries	12.0
Canada	13.3
Australia	20.0
Germany	149.0
Europe	156.0
India- Vegetarians	356.3
Non- vegetarians	362.5

Source: Selvaraj *et al*. (2005)

Over the years in the recent decades, despite commendable progress made earlier, deceleration of growth and crop yield from Green Revolution technologies have surfaced and caused serious concern and chain of several problems. The cause of such serious concern was due to the indiscriminate, unscientific uncontrolled use of not only agro-chemicals like fertilizers, pesticides, fungicides, weedicides, growth promoters etc. but also other natural resources like water, aimed, paradoxically to increase the yield of crops and multiply the profit. Effects of unscientific use of agrochemicals under Green Revolution are given in Table-3.

Table 3: Effect of unscientific use of chemical inputs under green revolution and the end result

S. No.		Effect/End Result
1.	Sustainability of yield	- Definite deceleration of crop yields over years - Crop failure and losses
2.	Soil degradation	- Nutrients exhaustion, deficiencies and imbalances - Physio-chemical and biological properties affected - Salinity, sodicity and acidity - Reduced fertility and productivity - Soil health deterioration - Accumulation of toxic substances and heavy metals
3.	Ground water	- Depletion and poor quality - Extra cost and energy to lift - Sea water ingress in coastal areas
4.	Ecology	- Imbalance in soil flora and fauna and destruction - Elimination of biodiversity and destruction of biological balance - Elimination of natural enemies of pests viz. parasites and predators - Resistance in pests to chemicals
5.	Environment	- Pollution of soil, water and air - Accumulation of toxic heavy metals and non-biodegradable substances from inputs
6.	Social and economic problems	- Serious health hazards - Permanent or partial disability of farm workers - High inputs - Profitability declines - Loss increases - Export constraints affecting national economy - Rural economy ruined due to over-dependence of outside inputs like seed, fertilizers and plant protection chemicals.

Source: Ramanathan (2006)

Conservation of Natural Resources

From the last 100- 150 year there has been a paradigm shifts in agriculture system as natural agriculture to agrochemical agriculture to integrated agriculture to organic agriculture. Such shifts are visible in resource conserving technologies as well due to globalization and urbanization. The age old paradigm based on massive inversion of soil with plough has changed to a new paradigm of conservation agriculture. Some major shifts observed include -

1. Conventional tilled wheat ---- zero tillage / reduced tillage wheat.
2. Puddle transplanted rice —-- direct dry seeded rice (zero- tillage rice)

3. Multiseedling transplanting rice —--- monoseedling rice per heel.
4. Residue burning/residue incorporation —--- residue retention (mulching)
5. Monocultures —--- diversified agriculture.
6. Sole crops —--- intercrops in bed planting.

Therefore, under such paradigm shift, conservation of natural resources, eco friendly production technologies and integrated crop management practices are required to be emphasized to a great extent necessitating the concept of organic forming as modern technology, methodology and philosophy for adoption and sustainability.

Organic Farming: Definition and Scope

Traditional agriculture, sustainable agriculture, *jaivik krishi* are used as synonym to organic agriculture. This is misnomer. Some thinks that use of organic manures and natural methods of plant protection in place of synthetic fertilizers and pesticides is organic farming. This partly includes the required input and therefore not true in real sense. The most accepted definition of organic forming is, "The term organic is best thought of as referring not to the type of inputs used, but to the concept of the farm as an organism, in which all the components – the soil minerals, organic matter, microorganism, insects, plants, animals and humans- interact to create coherent, self regulating and stable whole. Reliance on external inputs, whether chemical or organic, is reduced as far as possible. Organic farming is (w) holistic production system (Bhattacharyya 2005)".

In literature organic- sustainable agriculture is described either in negative term- no dependence on synthetic fertilizers, pesticides and antibiotics or in terms of substitute practices (use of manures, crop rotation, and minimum tillage). Such specification neglect attitudes, goals, values and redesign components of organic – sustainable agriculture (Verma 2002) organic sustainable agriculture is a philosophy has its roots in set of value that reflect a state of environment, of awareness of ecological and social realities and the ability of the individual to take effective action. It includes the design and management procedures which work with natural processes for conserving all resources, promote agro ecosystem resilience and self regulation, and minimize waste and environmental impact while improving farm profitability (Mac Rae, et al. 1990).

International Federation of Organic Agriculture Movement (IFOAM) established in 1972, is a key milestone in organic farming in current period has considered local soil fertility as a very to successful production and supports the development of self supporting systems on local and regional level. IFOAM covers all aspects of operating farms that promote environmentally, culturally and economically sound production of food, fiber, herbs, and fuel wood. Organic farming is a science and art of producing crops and live-stocks. Thus organic farming may be comprehensively as environment friendly ecological production system that promotes and enhances biodiversity, biological cycles and biological activities. It emphasizes on minimum use of off-farm inputs and management practices that restore maintain and enhance ecological harmony.

Features of Organic Farming:

Organic farming system is required to have the following salient features:

1. production technology under agriculture, animal husbandry, poultry farming and aquaculture etc.
2. to do away with all synthetic or artificial inputs including chemicals as fertilizers, pesticides, weedicides and plant and animal hormones.
3. the inputs from seed to seed, calf to calf and egg to egg should only be from natural sources and processes.
4. at post harvest stage, food processing should ensure non-use of any chemicals, synthetics and preservatives, colouring or flavouring agents. and
5. increased use of on-farm inputs and minimum use of off-farm inputs.

Principle of Organic Farming:

IFOAM has underlined the detailed principle attached to the organic farming, which in short is to

1. maintains long term fertility of soils.
2. avoid all forms of pollution that may result from agricultural techniques.
3. produce food stuff of high nutritional quantity in sufficient quality.
4. reduce the use of fossil energy in agricultural practice to a minimum.
5. maintain genetic diversity of agricultural system of plant, wild life habitats.
6. give live-stock conditions of life that confirm to their physiological need.
7. the healthy use and proper care of water, water resources and all life therein.

8. encourage and enhance biological cycles with in the farming system, increasing microorganism, soil fauna and flora, plants and animals.
9. use as far as possible, renewable resources in the on-farm organized agricultural system.
10. use materials and substances which can be reused or recycled either on farm or else where.
11. produce non food products out of renewable resources which are fully biodegradable. and
12. allow everyone involved in organic production and processing a quality of life that conforms to Human Rights Charter to cover their basic needs and obtain an adequate return and satisfaction from this work; including a safe working environment.

Possibility and Adoption of Organic Farming:

Fertilizers and pesticides are considered most important contributor towards bringing the nation to self sufficient in food requirement and agricultural scientist, policy makers and as whole every body believes that to get away with chemical inputs will bring the nation back to yield level not sufficient to meet the requirement of ever growing population.

The bases of the doubts on successful organic farming are scientific in nature. There is a need of 17 essential elements and plant absorbs nutrients in inorganic forms the nitrogen as NO_3^- , NH_4^+, phosphorus as HPO_4^{-2}, $H_2PO_4^-$ potassium as K^+, irrespective of source whether it is from chemical fertilizers or organic manures, plants can not differentiate the source. Nutrients applied in organic form are converted into inorganic form before absorbed by plant. Since plant takes nutrients in inorganic form therefore it is logical to apply nutrients in inorganic form i.e. chemical fertilizers, secondary the organic farming requires huge quantity of organic fertilizer which is difficult to obtain. Organic fertilizer contains heavy metal (cow manures contain 0.80 cadmium, 58 chromium, 16 lead, 29 nickel and 62 copper in ppm on dry wt. basis) and are pollutant to water body (Chhonkar 2003).

There is no scientific report to justify that organically produced food has equal or superior nutritional quality. It seems that it is not logical to protect crops from devastating pests and diseases without using chemical pesticides and lastly that organic farming may not be economical. Dr. Norman Borlaugh, Nobel laureate, the father of Green Revolution is of the view that organic agriculture can not increase agricultural productivity. However, the difficulty in maintaining the sustainability of crop yield, deterioration of soil health and increasing environmental pollution there, the consensus has reached to go for integration of inorganic and organic agriculture is ideal.

Answers to the above doubts and questions by organic activators are very simple. History of fertilizers is hardly 100-160 years. They are not convinced with the logic that the use of fertilizers is essential for cell growth, protein formation etc, as many trees *banyan, jamun, ashoka* tree etc. growing on domestic locality, annual and seasonal plants and perennial trees growing on road side, hill side desert, forest are surviving with huge biomes years after years without use of any chemical fertilizers. Incidence of pests and diseases are more frequent and intense in crop receiving chemical fertilizers and the compound annual growth rate in yield of important crops in India is declining gradually even after use of chemicals.

The efficiency of a fertizer is not more than 45 % and there is no residual effect. Efficiency of fertilizer nitrogen is 30-45%, phosphorus is 15-20% potassium is 70-80%, zinc is 2-5% and copper is hardly 1-2%. It means farmer applies nitrogen fertilizer worth of Rs. 100; only fertilizer worth of Rs. 40-45 is used up by the crop and rest go waste.

Contribution of chemical fixation of nitrogen is only 15.3% while that of biological fixation nitrogen in 67.3% of the total amount of nitrogen added to soil. Indiscriminate use of inorganic fertilizer has not only deteriorated the chemical properties (deficiency of macro and micro nutrients) but also physical (water holding capacity and structure) and biological properties (low microbial count, hormones, antibiotics and biomass).

The charges made that cost of cultivation of organically grown product is more than the fertilizer grown product is not true. The cost of chemical fertilizers and pesticides are at subsidized rate for which tax payer pay the bill. On the other hand organically grown products are in high demand and fetches premium price over chemically grown products, which compensate the loss due to initial decreased yield during conversion from inorganic farming. Long term experiments conducted world over including ICRISAT Hyderabad, India has proved that organic farming system yields almost the same as under irrigated conditions and more under marginal lands rain fed and drought condition as compared to conventional farming. An indo-Swiss research team collected and compared agronomic data form 60 organic and 60 conventional farms from Madhya Pradesh and Andhra Pradesh for c period of two years and found average cotton yields in organic fields were 4-6 % higher. The results show that organic cotton farming has the potential to be an economically sound business proposition even for small and marginal farmers.

Biopesticides like *Trichoderma viridi*, *Bacillus thurengiensis* (BT), NPV, GV, etc, botanical pesticide (*neem*) biocontrol agents (*Trichogramma, Cryptolaemus, chrysoperla* etc) are available and capable of controlling pests and diseases as recorded in the study under Integrated Pest Management Programme. Pesticides are non selective and are also toxic to beneficial insects.

The World of Organic Farming:

According to latest statistics published by International Federation for Organic Agriculture Movement (IFOAM) at Biofach 2007, on the subject "organic farming world wide", almost 31 million ha are currently managed organically by at least 633891 farms. This constitutes 07% of the agricultural land of the countries covered by survey. Oceania holds 39% of the world organic land, followed by Europe 23%, Latin America 19%. There has been major growth of organic land in North America and Europe. Both have added over half

Table 4. Standards for organic food and farming used as basis for the certification work by all India Federation of Organic Farming (AIFOF) 1995

Recommended	Permitted	Restricted	Prohibited
Rotation Management			
Balance between fertility building & exploitative cropping, different root system, legumes, similar pest and disease susceptibility must be separated	Rotations falling short of these guide lines but utilizing legumes, green manure and catch crops	Onions, mustard, cabbage, cauliflower and potatoes	Continuous cropping of onions, mustard, cabbage, cauliflower potatoes in the same plot in successive years
Manure Management			
Organic, FYM and composted crop wastes, aerated slurry or urine	Organic FYM, biogas plant slurry	Brought in farm manures, and waste after composting from unknown source, mushroom compost, municipal compost, sewage sludge	Brought-in-compost that are not composted
Supplementary Nutrients			
Heavy metals not to exceed in mg kg-1 Soil Manures Hg 1 2 Pb 100 250 Cd 2 10 Nil 50 100 Cr 150 1000 Cu 50 400 Zn 150 1000	Rock phosphate, feldspar, dolomite, gypsum lime-stone, calcium, seaweed, basic slag, rock potash, wood ash, meat, bone, horn, meals, fish meals	Dried blood, wool waste, hop-waste, leather meal, potassium sulphate, borax	Fresh blood, mineral fertilizers including urea, super-phosphate diammonium phosphate, muriate of potash, slaked lime, quick lime
Weed Management			
Balanced rotation, composting, slurry, aeration, presowing cultivation, appropriate sowing dates, pre-germination, propogation, transplanting, higher seed rates, variety selection, raised beds, biodegradable mulches	Pre and post emergence thermal operations, plastic mulches	Long term use of plastic mulches	All chemicals, hormones, herbicides within the crop, pathways
Pest and Disease Management			
Balanced rotation, predator encouraging ecology, comparison planting, mixed cropping, resistant varieties, strategic planting dates, balanced nutrient supply	Mechanical control traps, barrier and sound sprays, homeopathic and biodynamic preparations, bicarbonate of soda. soft soap, steam sterilization biological control	Pyrethrum, derris, quassia, borscans and burgundy mixture, sulphur	All biocides including nicotine, formaldehyde and phenols for soil sterilization, methyl bromide and other chemicals for soil sterilization, metal dehyde, mercurial seed dressing
Grass Silage Management			
Freshly cut grasses as feed	Molasses as silage additive	Bacterial silage additive with AIFOF permission	Other silage additives
Transport and Storage			
Vehicles, containers and equipment for harvesting and transport must be clean and free from non organic crop residues and contaminants, pesticides	Vacuum cleaning, steam cleaning, high pressure water cleaning	Pyrethrum, sulphur, diatomaceous earth in stores only, bait for rodent control	Post harvest pesticides, sprout inhibitors, fungicidal sprays, dip or powders, chemical fumigants

Adopted From AIFOF (1995)

Total certification bodies accredited by NPOP GOI in 2008.

Among States Orissa, Jammu and Kashmir, Rajasthan, Maharashtra and Kerala are major certified States and accounts for 60% of the total certified area in the country. Chhattisgarh has a area of only 293.16 ha while Madhya Pradesh contributes 16,581.37 ha.

million ha each during 2005-06. Currently the countries with the highest area is Australia- 11.8 followed by Argentina- 3.1, China-2.3, US-1.6 and India 0.17 million ha. (Certified organic 2006) Besides this India has also about 2-3 million ha certified wild forest collection area. Although organic agriculture is now present in most part of the globe, demands remain concentrated in Europe and North America. The two regions are experiencing undersupply because production is not meeting demand. (World of organic agriculture 2007).

Organic Farming in India:

Organic farming in India was initiated by sir Albert Howard, a British agronomist in Indore (M.P.) with Development of Indore method of aerobic compost, (Howard 1929) followed by Banglore method anaerobic compost (Acharya 1934) and NADEP compost (ND Pandri Pande Yeotmal 1980). In the year 2000 planning commission Govt. of India formed a steering group on agriculture who identified organic farming as national challenge and suggested organic farming in North East Region, rain fed areas and in those areas which are receiving low or negligible quantity of agrochemicals. Following this decision National Agricultural Policy (2000) recommended promotion of traditional knowledge of agriculture related to organic farming and it's scientific up gradation.

The Department of Agriculture and Co-operation, Ministry of Agriculture constituted a task force which recommended promotion of organic farming. The ministry of commerce launched the national organic programme in April 2000. Agricultural and processed food products export development authority (APEDA) has taken up the implementation of national programme for organic production (NPOP). Under the NPOP, documents like national standards, accreditation criteria, accreditation procedure, inspection and certification procedures have been prepared and approved by National Steering Committee (NSC) (Bhattacharyya and Chakraborty 2005).

The Department of Agriculture and Co-operation, Ministry of Agriculture launched a new central sector scheme "National Project on Organic Farming" (NPOF) from 1st October 2004 with initial outlay of Rs. 57.05 crore which has raised to Rs. 150.00 crore in XI five year plan. NPOF has now six Regional Centers of Organic Farming located at Jabalpur (MP), Nagpur (MS), Banglore (Karnataka), Bhubaneshwar (Orissa), Hissar (Haryana) and Imphal (Manipur). NPOF has been successful in establishing the concept and usefulness of organic forming but has also dispelled many myths. Now with more than 200 Service Providers appointed by NPOF, at least 2.5 to 3.0 lakh farmers are growing in about 1.5 lakh ha of land the certified organic food. (Organic Farming News Letter 2007).

Standards and Certification of Organic Products:

Organic Farming Products are different then the Conventional Farming Products. All agricultural products are considered conventional agricultural products unless the product has gone through the certain tests and obtained a certificate from Govt. of India approved Certifying and Regulatory Agencies.

Certain organically grown commodities may sell at premium price particularly vegetables, fruits, some grains and beans. The premium prices are 10-15% more than conventionally produced material. In organic farms certain certified inputs have been recommended for adoption so that the products may attain the certification standards. These standards serve to differentiate the products and help to achieve premium price. Certification guide lines recommended by All India Federation of Organic Farming are detailed in Table-4.

Package of Practices for Organic Farming:-

There is a need to develop specific package of practices for growing different crops in certain area. It may define land preparation, selection of variety, organic fertilization, biological control of pest-diseases and weeds, harvest, storage, transport and marketing. The package of practice so developed is required to be approved by certifying agency. Some countries have developed package of practices for some crops, this may not be adapted as such because of variation in soil, water availability, weather, climate and demand of the product.

Organic packages of practices developed by Maharashtra Organic Farming Federation (MOFF) for three crops; cotton, wheat and red gram has been published under title Organic Package of Practices for Maharashtra: cotton, wheat and gram (MOFF 2007). Similar package of practices for crops possibly can be grown in identified region in Chhattisgarh needs to be developed and approved so as to Help the farmers to sell their products at premium price. Economic sustainability of farmers is provided by good markets for their organic produces.

Table 5. List of Certification Agencies

S. No.	Certification agency
1	BVQI (India) Pvt. Ltd Marwah Centre, Krishanlal Marwah Marg. Andheri (East). Mumbai
2	Ecocert SA, Sector-3, S-6/3 & 4, Naksharawadi, Aurangabad
3	Indian Organic Certification agency, (INDOCERT) Thottumugham Aluva, Coachin
4	IMO Control Pvt. Ltd. 1314, Double Road, Indiranagar 2nd Stage, Banglore
5	International Resources for Fairer Trade, Unit No.7, Parsi Pandhayat Road, Andheri (E), Mumbai
6	Lacon Quality Certification Pvt. Ltd. Chenathra, Theepany, Thruvalla, Kerala
7	Natural Organic Certification Association, 5th Lane, Shikshak Nagar, Kothrud, Pune
8	OneCert Asia Agri Certification Pvt. Ltd. Agrasen farm, Vatika Road, Jaipur
9	SGS India Pvt. Ltd. 250 Udyog Vihar, Phase-IV, Gurgaon
10	Skal Internatonal (India), No.191, Ist Main Road, Mahalaxmi Layout, Banglore
11	Uttaranchal State Organic Certification Agency, 12/II Vasant Vihar, Dehradun

In Chhattisgarh, rainfed tribal region comprises more than 60% of the area where negligible or no chemicals are used, subsistent agriculture is being practiced for a long period. These areas are organic area by default. Use of biofertilizers, biodynamic preparations, vermicompost, *Amritpani*, crop residues, animal dung, green manure and biopesticides must be encouraged at war footing on on-form production closed system.

Economic sustainability of farmers is once secured by good market for the organic produces, the farmer is ensured of better returns from organic farming, large number of them will adopt his and they will work towards good productivity and higher returns. The estimated market potential estimate is given for eight metro cities: Chennai, Hydrabad, Banglore, Mumbai, Ahmedabad, Pune, Delhi and Calcutta in Table 6. The market potential for organic foods in 2006 in top 8 metros in the country is at Rs. 562 crores taking into consideration 10-20% organic premium. The overall market potential is estimated to be around Rs 1452 crores Table 7. Across all cities and regions the most preferred category is fresh vegetables, followed by fruits as organic. The next is milk and dairy products. Table-8 arranges the 20 different food categories in the order of preference (Menon 2007) major organic products exported from India is given in Table-8.

Table 6. Potential estimated* for organic foods in top 8 metros in India (at retail level 2005-06 prices – considering organic premium 10-20%)

Study	In Rupees million (Figures rounded off)	
markets	Accessible potential* *	Market potential
Chennai	840	1500
Hyderabad	330	740
Bangalore	690	1280
Mumbai	1480	5860
Ahmedabad	300	780
Pune	280	580
Delhi	1120	2230
Calcutta	570	1540
TOP 8 METROS	5620	14520

*Bssed on our primary survey **Through Modem retail format

Source: India certified organic 2007

Table 7. Market potential for different organic food products in top 8 metros

(At retail level 2005-06 prices – considering organic premium 10-20%)

Study products	Accessible potential		Market potential	
	Rs million	%	Rs million	%
Vegetables	1030	18	3220	22
Fruits	710	13	2460	17
Milk	520	9	1660	11
Dairy Product	500	9	1110	8
Bakery Products	480	9	1860	13
Oils	320	6	590	4
Rice	270	5	460	3
Ready to eat	260	5	360	2
Wheat- *Atta*	250	5	4700	3
Snacks	220	4	560	4
Frozen foods	220	4	300	2
Dals	180	3	320	2
Health Drinks	170	3	340	2
Canned foods	170	3	230	2
Tea	120	2	230	2
Coffee	100	2	170	1
Condiments	50	1	120	1
Spices	40	1	80	1
Sugar	2.8	0	4.8	0
Baby Food	0.1	0	0.30	0
TOTAL	**5620**	**100**	**14520**	**100**

Source: India Certified organic 2007

Table 8. Major organic products exported from India during last four years (Quantity in MT and value in lakh)

Product	2005-06		2004-05		2003-04		2002-03	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Honey	2117.3	3904.8	3814	2318.80	526.0	686.0	122.0	164.0
Tea	1875.0	3841.5	1876	4788.63	1996.6	2886.9	1531.3	4071.0
Spices	543.9	374.6	350	516.66	625.0	394.1	79.0	141.7
Coffee	167.2	136.1	162	146.63	97.2	82.0	46.2	46.4
Rice	1630.1	893.2	1070	164.59	578.0	118.0	962.0	378.0
Others	1619	3666	1072	1598	2465	3098	1421	1395
TOTAL	7953	12816	8344	9533	6288	7265	4161	6196

Source: Agricultural Processed Foods Export Development Authority (APEDA), New Delhi

Market value and production of commodities from organic farming system in India as reported by Agricultural Processed Foods. Export Development Authority (AEDA) New Delhi and major organic products exported from India during the year 2005-06 is given in Table-9.

Table 9: Status of organic production during 2005-06: Production and market value

S. No.	Details	Certified organic	In-conversion organic
1	Number of farmers	25684	7803
2	Total crop production (in MT)	34760	85878
3	Export (in MT)	15037	2461
4	Domestic sales (quantity in MT)	225770	14025
5	Export value (in Rs. Lakh)	51629	NA
	Domestic sale value (in Rs. Lakh)	24430	NA

Major organic products exported from India during the year 2005-06

(Provisional)

Products	Production (MT)	Export Quantity (MT)	Value (in Lakhs)
Honey	3746.8	2117.3	3904.8
Tea	14831.4	1875.0	3841.5
Spices	12010.6	543.9	374.6
Coffee	4183.0	167.2	136.1
Rice	8326.9	1630.15	893.2
Others	62072	1619	3666
TOTAL	**105171**	**7953**	**12816**

Source: Agricultural Processed Foods Export Development Authority (APEDA), New Delhi

Market value and production of commodities from organic farming system in India as reported by Agricultural Processed Foods. Export Development Authority (AEDA) New Delhi and major organic products exported from India during the year 2005-06 is given in Table-9.

A tiny State of Sikkim in the Himalya Region has converted two State farms into centers of excellence for organic farming and have converted 100 villages into biovillage. From Andhra Pradesh a success story of growing rice organically by Ponumatsa Peddi Raju is well described and from Punjab, Shri Harjant Singh Siddhu Raitha kalam village, Bhatinda has been recognized as successful farmer in converting 15 ha area under organic farming in 3 years. Now Punjab State Government has a plan to increase the area to 10% land under organic farming and is ten years time one third of the total agricultural land under commercial and organic farming to enhance the income of farmers of the State.

Organic Farmers Association of Assam which has been working for the promotion of organic farming since 2002, has registered farmers to the tune of 1638. Their farms have been certified as organic farming by SKAL International Certifying Agency. Very recently Nagaland vide notification no. AGR/MC-I/2002 dated 18th March 2007 announced that “in order to make Nagaland a total organic state, the Governor of Nagaland is pleased to adopt and notify the Nagaland State policy for organic cultivation as per the provisions”.

Equivalence of Indian Organic Standards:

All organic farming products have to go through the following four hurdles – certification and regulatory mechanism, organic standards, market network and technology package. After USA, now European Union has also granted equivalence to the National Programme on Organic Production (NPOP) of India indicating that organic farming products generating from India can be exported to USA and all countries under European Union.

Globally India in on fast track to top slot in organic cotton farming by 2006-07. There are 30,000 organic cotton growers in the country, majority, of them are in Maharashtra and Gujrat. Production of organic cotton in 2006 is pegged at 10,000 tonnes and expected to touch 14,000 tonnes next year. At present India ranks among the top five organic cotton producing country. Because of increasing cost of agro-chemical inputs without concomitant increase in the value of the produce, the farmers practicing conventional farming have been not able to repay the debts have started to convert their holdings from conventional farming to organic farming system. The organic farming system has already been put to test by thousands of farmers in Maharashtra, Karnataka, Tamilnadu, Andhra Pradesh, MP., Uttaranchal and Orissa.

Conclusion:

Suitable soil, fresh water, climate, vegetation, nutrients and energy are the basic natural resources needed for agricultural production. These natural resources are not only shrinking rapidly but also deteriorating very fast due to the pressure to meet the food, fiber and fuel requirement of ever increasing population. After independence of the country national growth of agriculture food production has surpassed the population growth of the country. The out break of population has been three times while food production has reached four times from 1947 to 2002. Now India is in position not only to feed its population but also to export food grains.

In the past more attention was on cereal production but for making balanced diet (food) intake livestock, horticulture, poultry, fishery, and legume production are required to be also taken seriously. The added problem is that these products are to be taken from diminishing and deteriorating per capita arable land and irrigation water resources and expending biotic and abiotic stresses. Agriculture development is not possible on deteriorating natural resources; conservation and efficient use of natural resources have become a primary consideration to meet the future challenges of food and environment security. Now under such resources stress conduction, the need for more food and other agricultural commodities can possibly be met through higher yields per unit of land, water, energy and time. The important consideration to be serious about is that in process of meeting the challenge of food security, health of natural resources is not ignored.

In future, highly intensive agriculture is required to meet the growing demands; it would call for more efficient management of inputs like seed, water, plant nutrient and protection system and labour. Resource management has a direct bearing on society and economics and therefore it is expected that future planning and activities have to originate from and should address the social and economic needs of the farmers. Organic farming since aims at exclusion of off-farm inputs: seed, soil, plant nutrients, water and plant protection and an inclusion and dependence on closed on-form system, there could probably be no other way better in securing health of natural resources. For success of the organic farming, there has been a pseudo fear of declining productivity; some long term experiments in Switzerland, USA and India (ICRISAT Patancheru A.P. India) have proved that low cast on farm resource based management system can yield optimum and comparable productivity. Two third areas are under rainfed agriculture. Even if all water resources are geared up and irrigational potential is exploited fully half of the net cultivated area of the country will remain unirrigated. Under such conditions efficiency of inputs is not fully utilized in conventional farming. Rupella *et al*. (2006) in their survey observed that most of the organic farming practioners shifted to organic farming not because of premium price of the organic produce but the reduced expenditure on inputs and similar yields to their neighbor conventional farmers.

Every farmer is a researcher and every field is a laboratory. Location specific adoption of farming technology has to be modified by the organic farming practioner. A simple example is of an experience of farmer in Gurdaspur district of Punjab who saved 50% irrigation water and harvested increased yield of sugarcane up to 8409 acre^{-1} worth Rs one lakh by planting sugarcane in ridges and trenches (Tribune 21st Oct. 2006).

To introduce and popularize chemical fertilizers and pesticide in the country, it took more than fifty years and government central and state furrowed enormous funds for the cause. The fertilizers, certain pesticide and seeds/ planting materials are still sold on subsidised rate. An abrupt and total shift to organic farming from conventional farming system is neither desirable nor possible. The shifting may be done in phases like inclusion of additional percentage of holding every year and hundred percents in 3 to 5 years depending on sustainability. It is too early to negate and doubt the popularization of organic farming system as organic production is coming from the farmer's movement and consumer's choice which can not be ignored. A central sector project, the National Centre of organic farming at Ghaziabad with six Regional Centers at Jabalpur, Nagpur, Hissar, Bhubaneshwar, Banglore and Imphal have been established, are acting as facilitator for promoting Organic Agriculture. A few of the research and development priority needs for early and hastened shifting to organic farming are to be addressed are development of location specific package of practices, low cost certification process, separate standard and certification processes for domestic market and export market, formation of co-operative sector to help in marketing of the products of tribal farmers and provision of adequate subsidy and encouragement to the farmers practicing organic farming.

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Importance of Weed Management in Food Security

P.K. Singh

Principal Scientist
Directorate of Weed Science Research
Jabalpur (M.P.)
e-mail: drsinghpk@gmail.com

Introduction

Agriculture is the mainstay of Indian economy because of its high share in employment and livelihood creation. This sector supports more than half a billion people providing employment to 52 per cent of the workforce. It is also an important source of raw material and demand for many industrial products, particularly fertilizers, pesticides, agricultural implements and a variety of consumer goods. However, the share of agriculture in the gross domestic product has registered a steady decline from 38 per cent in 1980-81 to 17.5 per cent in 2007-08, which is quite alarming. But, high dependency of majority of poor makes this sector all the more important. As of today, India has about 17 % of the world's population living on 4.2% of the world's water resources and 2.3% of the global land. A large proportion of India's geographical area is under cultivation, being 51%, as compared to mere 11% of the world average. However, the present cropping intensity of 137% has registered an increase of about 26% since 1950-51.

India has made impressive strides on the agricultural front during the last six decades. The foodgrain production increased by about 4.5 times from a meager 50.8 million tonnes in 1950-51 to an estimated harvest of about 227 million tons in 2007-08. This increase was achieved despite the fact that the net sown area has plateaued around 140 m ha since 1970s till date. Similarly, there was not much increase in the net irrigated area also which is about 58 m ha at present. Thus, virtually all of the increase in the foodgrain production resulted from yield gains rather than expansion of cultivated area.

Though, the average annual growth rate of foodgrain production since 1950-51 to 2006-07 was 2.5 per cent compared to the growth of population which averaged at 2.1 per cent, it however, decelerated to 1.2 per cent during 1990-2007 which was lower than the annual rate of growth of population, averaging 1.9 per cent. To meet the growing needs of the food security, 2.0 percent growth in food grain production is considered essential. Increased agricultural productivity and rapid industrial growth in the recent years have contributed to a significant reduction in poverty level. Despite the impressive growth and development, India is still home to the largest number of poor people of the world. With about 250 million below the poverty line, India accounts for about one-fifth of the world's poor.

As per the projections of IFPRI, Washington there is a likelihood of shortfall of 41 per cent in the food grain production in the country by 2020. With the medium fertility assumption of 1.6 per cent, we ought to produce 300 million tones of foodgrains in 2020. The country has high population pressure on land and other resources to meet its food and development needs. Low and stagnant yield per unit area across almost all crops has become a regular feature of Indian agriculture. Besides, the natural resource base of land, water and bio-diversity is under severe pressure. The massive increase in population and substantial income growth, demand an extra about 2.5 mt of foodgrains annually. In this backdrop, the required increase in food production can be realized only through vertical increases in productivity, as the possibilities of horizontal increase i.e., expansion of area are minimal. The vertical increase has got tremendous scope which can be achieved with better genotypes and providing farmer-friendly input technology. One such technology which has a potential to yield substantial increase in the production of foodgrains is proper weed management as weeds alone are known to account for to nearly one third of the losses caused by various biotic stresses. In some situations the uncontrolled weeds can even lead to complete crop failure. The efforts to control weeds many a time, also contribute towards the increased cost of cultivation of crops. A recent study undertaken at this Centre suggests that proper weed management technologies if adapted can result in an additional production of 103 million tonnes of foodgrains, 15 mt of pulses, 10 mt of oilseeds and 52 mt of commercial crops, per annum, which in few cases are even equivalent to the existing annual production. The losses due to weeds in foodgrains and oilseeds are almost half of the current production level while an equal amount are lost in pulses.

Table1. Potential yield losses due to weeds

Category	Losses due to weeds per annum	Current production (2009-10)	Gap in demand by 2020
	million tonnes		
Food grains	103	231	35
Pulses	15	15	7
Oilseeds	10	30	8
Commercial crops	52	262	-
Total	180	538	-

Therefore, greater awareness about the losses caused by the weeds and the need for improved weed management technologies are very vital to meet the growing demand for foodgrains, pulses, oilseeds and other crops by the ever increasing population. There is tremendous scope to increase the agricultural productivity by adapting the improved weed management technologies that have been developed in the country by Directorate of Weed Science Research, Jabalpur as well as its 22 Cooperating Centres working at different SAUs under the All India Coordinated Research Project on Weed Control (AICRP-WC). Despite the enormous magnitude of the losses due to weeds, policy makers have not yet felt the significance of weed management as happened in case of varietal breeding and other inputs such as irrigation, fertilizers and seeds.

Weed Management

What is a weed?

Weeds are plants that are undesirable to human activity at a particular time and place, and therefore, weeds will always be associated with human endeavours. Weeds are the plants growing in places where they are not desired. They interfere with our activities be it a crop field, play ground, or a pond. Weeds are no separate group of plants. Man invented the weeds. Plants have been termed as weeds considering their negative value in a given situation. The definition given by Weed Science Society of America (WSSA) hence appears apt "Any plant that is objectionable or interferes with activities and welfare of man". This is given with the perspective that any plant or vegetation could be included as a weed in the future so long as the plant fits into the above definition. Unlike other pests, weeds are ubiquitous and affect almost all the crops.

What weeds cause?

In agriculture, weeds cause huge reductions in crop yields, increase cost of cultivation, reduce input efficiency, interfere with agricultural operations, impair quality, act as alternate hosts for several insect pests, diseases and nematodes. Weeds compete with crop plants for various inputs/resources like water, nutrients, sunlight etc.

In addition to agriculture, weeds also affect and interfere in the management of all the terrestrial and aquatic resources. They endanger the native biodiversity by choking and deliberate takeover of the native plants and also by corrupting and invading open lands, road sides and recreational areas like public parks. They also affect the aquatic resources by interfering in fisheries/aquaculture, navigation and irrigation water management besides reducing the aesthetic and recreational value of water bodies. Weeds do not spare even animals and stealing land, homes and food from animals by invading the grazing areas. They cause health hazards like skin allergy, asthma, nasal diseases etc., to both humans and cattle. Weeds also interfere with maintenance and inspection of various defence, electrical, railway and airport installations besides being a potential fire hazard. Besides weeds also are a nuisance in forestry reducing their productivity. Out of the total 826 weed species reported in the country, 80 are considered as very serious and 198 as serious weeds. The importance of their management seldom requires any mention especially under the present day high input farming systems.

Origin of DWSR:

Considering the problem of weeds in crop fields and the need for weed research in India, it was decided to set up a nodal centre for basic and applied research in Weed Science in the VII Five Year Plan. Thus, the present Directorate of Weed Science Research, Jabalpur came into being in April, 1989. In fact, it is the only Institution in the entire world at present, dealing exclusively with the problems posed by weeds in a comprehensive manner using multidisciplinary approach.

The mandate of the Directorate is as follows:

- To undertake basic and applied researches for developing efficient weed management strategies in different agro-ecological zones;
- To provide leadership and co-ordinate the network research with State Agricultural Universities for generating location-specific technologies for weed management in different crops, cropping and farming systems;
- To act as a repository of information in weed science;
- To act as a centre for training on research methodologies in the areas of weed science and weed management;

- To collaborate with national and international agencies in achieving the above mentioned goal; and
- To provide consultancy on matters related to weed science

The Directorate, since its inception has significantly contributed in the areas of identifying major weeds in different crops and cropping systems of the country, development of national database of weeds, evaluation of new herbicides and making herbicide recommendations, monitoring of herbicide residues in food chain and environment, identifying weed competitive crop cultivars, weed smothering intercrops, non-chemical and biological methods of weed control, weed dynamics in crops and cropping systems, management of parasitic weeds, allelopathic studies, management of perennial weeds and other invasive weeds in non-crop areas and transfer of improved weed management technologies.

Issues and strategies for weed management

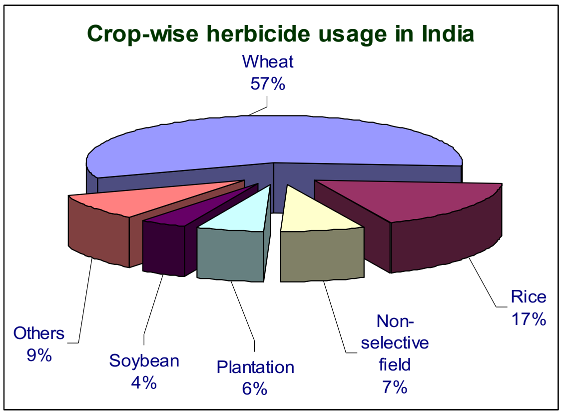
The main issues concerning weeds and weed management in India along with the strategies to tackle these through scientific research and technological redressal are highlighted below:

1. Invasive Alien Weeds: Invasive alien weeds (IAWs) are plants that are moved from their native habitat to a new location and in the absence of their co-evolved predators and parasites they eventually become established and spread rapidly causing tremendous harm, often irreversible to the environment, economy and in some cases to human health. As per Convention on Biological Diversity (CBD, 1992) alien invasive species are the biggest threat to biodiversity next only to human resettlement. A large number of alien invasive weeds have invaded our ecosystems and are threatening their survival and productivity.

a) **Management of IAWs that have already entered the country**: Majority of the important weeds in India have been introduced into the country in the past either accidentally or deliberately. Some of the major alien invasive weeds include *Lantana camara, Eichhornia crassipes*, *Savlinia molesta, Parthenium hysterophorus, Chomolaena odorata, Mikania micrantha, Mimosa spp.* etc. These weeds (except aquatic ones) have invaded vast areas of forest, grassland, wastelands, and in some areas orchards and plantation crops too. *Lantana* was introduced in the year 1908 and since then it has invaded almost all parts of the country. *Chromolaena odorata,* earlier restricted to NE region and Western Ghats is now fast spreading to other areas. Besides wastelands, grasslands and cleared forests, it is proving to be major weed in orchards and plantation crops. In non-crop areas of Western Ghats it has almost replaced *Lantana camara*. Similarly *Mikania micrantha,* which is popularly called *mile-a-minute* weed on account of its rapid growth is a big nuisance in forestry and plantation crops in NE and South India. Similarly, *Parthenium hysterophorus* is a serious weed which has spread throughout the country in a big way. These weeds are a serious threat to the biodiversity or native flora. Hence, management of such IAWs is a great challenge to the weed research scientists in the country as these are not only adversely affecting the human and cattle health but some have now also entered the crop fields, thus reducing crop yields.

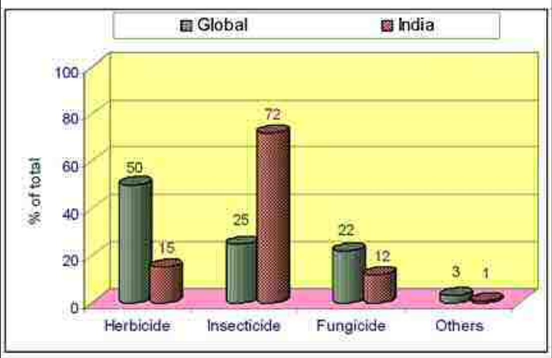
b) Management of future introductions of AIWs: Increasing trade and globalization coupled with liberalization policies will further increase the risk of invasion by such weeds leading to decrease in native biodiversity, reduced productivity of different ecosystems, reduced input-use efficiency and increased production cost.

It is observed that a record number of major weeds which exist in other countries, are at doorstep awaiting entry into the country. Therefore, we should be careful in preventing their introduction into the country. In order to prevent future introductions, more weeds, particularly the ones that are problematic in related countries, need to be subjected to rigorous Weed Risk Analysis (WRA). There is also an urgent need to design safeguards and strengthening of quarantine regulations to lower the risk of their entry. Australia, New Zealand, USA have developed detailed protocols for WRA and for identification of quarantine weeds. NRCWS would foster collaborations with the concerned organizations in these countries to develop protocols for WRA.



2. Enhanced use of herbicides: Herbicides are the most successful weed control technology ever developed as they are selective, cost effective, fairly easy to apply, have persistence that can be managed, and offer flexibility in application time. They are eco-friendly if applied at proper dose, method and time, besides being quite safer in comparison to other pesticides like insecticides. In India, around 96 per cent of the herbicides are slightly to moderately toxic while more than 70 per cent of the insecticides are highly to extremely toxic. In general, herbicides account for the largest proportion of crop protection chemicals sold on a world-wide scale. Globally, herbicides constitute 50 per cent of the total pesticides sale and in some countries like USA, Germany and Australia, the figure is as high as 60-70 per cent. In India, however, the position is different as herbicides form a meager 15 per cent of total pesticide consumption. But still, the consumption has increased rapidly from 4100 metric tonnes (MT) in 1988-89 to 11,000 MT in 2001-02 and it is likely to further increase in future. It is estimated that the herbicide market would grow at over 10 per cent per annum.

Fig. 1. Global and Indian Pesticide use scenario (% of total)



Herbicides have come as a big boon to farmers in areas where the labour supply is limited and wages are high. The major impact was first felt in Punjab where most of the agricultural operations are done by immigrant labour. Other states where the herbicide consumption is high are Haryana, Western U.P. and Uttaranchal. The advantages of herbicides over the other methods are appreciated mostly in wheat and rice crops in managing the grassy weeds. Due to the morphological similarities it is difficult to identify and remove grassy weeds manually whereas selective herbicides could kill them successfully without causing any damage to the crop. Further, the use of hoes and other intercultivation tools is difficult in these crops, as they are closely planted. In addition in many regions the crop is sown by broadcast thus making matters still worse. Currently wheat and rice crops account for 57 per cent and 17 per cent of the total herbicide consumption in the country.

The third field crop, where herbicides are popular is soybean in which the area under herbicides has increased from 4,25,000 ha in 2003 to 8,04,000 ha in 2004, accounting for 4 per cent of the total herbicide consumption. Tea is another crop where herbicides are extensively used. Being an organized sector manual weeding is cost-prohibitive in tea. Though, the herbicides are not very popular in other crops at present, their use however, is picking up in crops like fennel, onion, potato, groundnut, maize, sugarcane, vegetables etc. The data on herbicide consumption shows that they are being used in approximately 20 million hectares, which constitute about 10 per cent of the total cropped area.

There is also a lot of regional variation in herbicide consumption. For example, only 17 per cent of the total wheat acreage of 26 mha is being treated mostly in Punjab, Haryana and western Uttar Pradesh. Similarly only about 14 per cent area out of 42 mha under rice is treated with herbicides, almost entirely in transplanted rice. As herbicide use in other crops at present is very low, there exists a very good scope for their use in future. Some of the issues relating to the enhanced herbicide use are discussed below:

a) Herbicide resistance in weeds: Continuous long-term use of herbicides can result in the development of resistance in weeds. Recent instances of resistance to isoproturon in *Phalaris minor*, an important weed in wheat in parts of Punjab and Haryana is a case in point, which was evident in an estimated area of nearly one million hectares. The use of new herbicides clodinafop, fenoxaprop and sulfosulfuron though have successfully contained the problem at present, thus restoring the productivity of wheat in this region which is considered the wheat basket of the country. This technology alone is estimated to have saved wheat production to the extent of 1.5 million tonnes annually valued at Rs. 100 crores at current prices. The new herbicides are currently used in an area of about 1.8 million hectares. Similarly the resistance of *Echonochloa colona*, a major weed in rice to butachlor, one of the prominent rice herbicide in several parts of the country has posed a serious threat to the sustainability of rice-wheat system in the country. As the plant systems have their own in-built mechanisms for their defence, there is every likelihood that herbicide resistance in weeds will continue to be a problem in the forseeable future as well. We need to be watchful of similar problems emerging in other crops and cropping systems.

b) Herbicidal toxicity to succeeding crop and environment: Although herbicides are a boon to the agricultural community in substantially increasing crop yields, their use is not without potential problems. Some of the unintended negative impacts of herbicide use are persistence in soil, pollution of ground water, toxic residues in food (contamination), feed and fodder and adverse effect on non-target organisms. The potential of herbicides in contaminating the ground water have gained considerable attention in recent years. Some herbicides like triazine, diuron, alachlor and metolachlor have been detected in ground water in India. Herbicides that are highly water soluble and weakly adsorbed to soil particles such as sulfonyl urea and imidazolinone have potential for contaminating the ground water. There are indications that few herbicides not only damage the microbial population but crops too when applied in succession. Notwithstanding such apprehensions, herbicides would remain as one of the major tools in weed management as these offer huge benefits to the farmers and as herbicide use is likely to increase substantially in the future, their judicious use is of utmost importance.

c) Competitiveness in world market: In the new WTO regime our products have to be competitive both in price and quality. Weed management forms an important input in crop production. At present the production costs are very high as weeding operations are performed mainly by manual labour which is not only becoming scarce in supply but also expensive. The country is, therefore, losing on crop production heavily due to inappropriate weed management technologies being adopted. There is big scope for reducing the cost of production by adapting improved weed management technology which would also enhance the efficiency of other inputs like fertilizers and irrigation as weeds waste both these resources. In addition to herbicides, resource conservation technologies like zero- tillage can cut down the production cost substantially without penalizing productivity. The presence of pesticide residues is another major issue in world trade, which may be used as a non-tariff barrier affecting food exports. Although herbicide consumption in the country is very low at present, bulk of the herbicide use is in wheat, rice and soybean while commercial crops like groundnut and some spice crops (e.g. fennel) also consume some quantity of herbicides. However, as the country is exporting all these commodities we must ensure that these do not contain any herbicide residues.

d) Threat to native biodiversity: It is observed that a large number of indigenous flora possess medicinal and aromatic properties. The increased use of herbicides in the crop fields is likely to pose a serious threat to the existence of such useful native flora, which are existing since time immemorial.

3. Weed shift:

a) Rainfed farming: Since the availability of water to agriculture will be greatly reduced in future, the importance of rain-fed and dry-land agriculture will result in shift in weed flora, development of problem weeds difficult to control such as *Orobanche*, *Striga* etc., besides reduced efficacy of herbicides due to moisture stress.

b) Organic farming: The growing concern for human health and sustainability of agricultural production is giving way for organic farming in some parts of the world. In view of this, integrated weed management practices involving non-chemical methods such as mechanical and cultural (zero tillage, conservation tillage, plant residue management, growing intercrops, cover crops and green manure crops) would gain importance.

c) Resource conservation technologies: Increased adoption of resource conservation technologies like zero tillage, bed planting etc., will lead to reduced cost of cultivation, better management of problem weeds like *Phalaris minor* in rice-wheat system. In addition it may also result in weed flora shift favoring the perennial weeds besides increasing the herbicide use.

4. Global climate change: The CO_2 level in the atmosphere has been rising owing to various human activities such as burning of fossil fuels, deforestation, industrialization urbanization etc. If the present trend continues, the concentration of CO_2 in the atmosphere would be about 600 ppm accompanied by an increase of 1.5^0C - 4.5^0C in mean surface temperature by the middle of the 21st century. As weed populations show greater variations, it is possible that with a changed global climate weeds too will achieve a greater competitive fitness against the crop plants and development of new weed types.

5. Development of super weeds: Imparting resistance to normally herbicide susceptible crops to produce herbicide-resistant crops (HRCs) has been the most extensively exploited area of plant biotechnology. Resistance genes for several herbicides or herbicide modes of action have been incorporated into the genome of corn, cotton, canola and soybean which are now commercially available. Remarkably, the global biotech crop area increased more than fifty-fold in the first decade of commercialization from a meager 1.7 million hectares in 1996 to 90 million hectares in 2005. Herbicide tolerance has consistently been the dominant trait during all these years. In 2005 alone, herbicide tolerance, deployed in soybean, maize, canola and cotton occupied 71 per cent or 63.7 million hectares of the global biotech area (90.0 million hectares).

Introduction of Herbicide Resistant Crops (HRCs) besides helping in efficient management of problem weeds with minimum risk to the crop and increasing the yields may also lead to development of 'super weeds'. Their management will be essential in the days ahead.

6. Reduction in manual weeding: Weed control through manual/mechanical though very effective, has certain limitations such as unavailability of labour during peak period, high labour cost, involves drudgery, unfavourable environment particularly in rainy season etc. In addition, the manual labour traditionally being employed for weeding is gradually becoming scarce and expensive owing to rapid urbanization and industrialization. Liberalization policies and welfare activities initiated by the Government coupled with diversification of agriculture etc. will further limit the labour availability. At present, an estimated 8 to 10 billion man-days are engaged in weed control in a year which in other words means that every Indian is involved in weeding for at least 8 to 10 days in a year. According to some estimates, by the year 2020, nearly 50 per cent of the population would be living in urban areas, creating unprecedented shortage of labour force for use in agriculture. Therefore, in future, management of weeds through improved technologies involving herbicides and improved weeding tools will attain more significance which will result in labour saving, better and timely weed control and increased food production besides promoting gender equality and reducing human drudgery. The economic analyses of the data obtained from large number of trials and demonstrations carried out in farmers' fields through out the country have also reflected higher levels of productivity coupled with benefit:cost ratios of over 2:1. In addition, the labour saved (about 20-40 man days per hectare) through adoption of improved weed management practices, can be utilized in other related and more productive enterprises such as livestock rearing, poultry, fishery, mushroom cultivation, sericulture, bee keeping etc. which would yield greater income. This will also raise the esteem of women and provide them with more free time which can be devoted towards children, sanitation, health care etc.

7. Biological control of weeds: Technologies employing natural systems, biological organisms, bio-pesticides would gain importance to overcome or reduce the dependence on herbicides, wherever possible. There is sufficient scope for managing weeds at least in non-cropped areas through the use of exotic insect pests as has been successfully proved in the management of *Parthenium* by the Mexican beetle (*Zygrogramma bicolorata*), water hyacinth by *Neochetina* spp. and *Salvinia* by *Cyrtobagous salviniae*. Looking to the various advantages in this technology, the work on biological control of weeds will intensify in the future. However, any biocontrol agent has an associated risk to change its behaviour and host specificity which may have to be looked into with great depth and vision.

8. Management of parasitic weeds: Parasitic weeds are posing problem in the productivity of some of the major crops and cropping systems. *Cuscuta* spp. is a major problem in niger (Orissa, parts of Madhya Pradesh and Chhattisgarh), in lucerne (Gujarat), blackgram/greengram (in rice-fallows of Andhra Pradesh), berseem, lentil, linseed and chickpea (parts of Madhya Pradesh). Some species of *Cuscuta* also infest ornamental plants, hedges and trees. *Orobanche* spp. is a major parasite in tobacco in parts of Karnataka, Andhra Pradesh, Tamil Nadu, and Gujarat, mustard in parts of Gujarat, western Uttar Pradesh, Rajasthan, Haryana, etc., and more recently in tomato and potato in Karnataka. *Striga* spp. infest mostly sugarcane, maize, sorghum and pearl millet grown in dry areas in some parts of Karnataka, Madhya Pradesh and Chhattisgarh. *Loranthus* is noticed on economically useful tree crops in southern states. The most preferred host trees are mango, neem, teak, *Cassia* spp., rose wood, *Dalbergia* spp., *Albigizzia* spp., *Terminalia* spp., rain tree, *Pongamia* spp., Gulmohar, *Madhuca* sp., *Ficus* sp., etc. The problem of perennial weeds is increasing enormously. It is necessary to develop the management technology for such weeds.

9. Aquatic weed management: India has a total area of about 7 million hectares under different kinds of water bodies such as reservoirs, tanks, lakes, ponds, oxbow lakes, derelict water and brackish water. In addition about 1.7 lakh km is under rivers and canals. However, the area under these aquatic bodies is increasing with the building up of dams, canals and tanks for irrigation and fisheries production. The aquatic weeds have been found to increase the loss of water through transpiration, interfere in navigation, affect fisheries, mar recreational value of water, severely impede the flow of water in canals, thereby reducing availability of water to agriculture. The most prevalent method of managing the menace of aquatic weeds is their physical removal from the water bodies which is highly laborious and expensive, besides the disposal of the harvested material is also a big problem.

In view of the restricted use of herbicides in aquatic bodies due to the multifaceted use of water for purposes like fish culture, irrigation, domestic use etc., use of biological agents through insects like *Neochetina* *spp.* and hydrophilic mite *Orthogalumna terebrantis* against water hyacinth, *Cyrtobagous salviniae on Salvinia molesta* (water fern) and herbivore fishes such as a common grass carp (*Ctenopharyngdon idella)* against small floating and submerged weeds would be more prevalent. In depth and more comprehensive eco-friendly research work is required to be carried out on the management of such weeds.

10. Exploitation of weeds for beneficiary use: Weeds like water hyacinth, *Chromolaena, Lantana, Parthenium*, *Ipomoea*, etc., are rapidly spreading through out the country at the cost of other useful vegetation. Proper utilization of such biomass through appropriate technologies like vermicompost, mulch, phytoremediation etc., may help in supplementing chemical fertilizers besides adding organic matter to the soil. Utilization of weeds as a source of ayurvedic medicines, bio-pesticides and bio-fuel also has enough potential. Technology for using weeds for making paper, particle boards, furniture etc., has to be developed ahead. Such activities are expected to raise income and employment opportunities.

11. Awareness raising and technology transfer

The weed management technologies have not reached the farmers at the same pace as happened in case of varieties, fertilizers and insecticides. One of the main reasons could be that unlike other pests, the losses caused by weeds are invisible and many a time these are ignored by the farmers in spite of the fact that they cause maximum losses. Lack of awareness regarding losses caused by weeds and ways to control them are still the major reasons for poor adoption of weed management technologies. Therefore, there is a great need to popularize the cost-effective weed management technologies.

Proper weed management technologies can result in an additional income, which can increase the share of agriculture in India's GDP by 14 per cent. Thus, the increase in agricultural productivity will eventually result in significantly increasing the country's overall GDP and its growth rate. The socio-economic status of the farming community especially the rural poor will improve. Human drudgery involved in manual weeding will decrease and more gender equality will prevail, providing more time for rural women and youth to take up other subsidiary and more remunerative activities like sericulture, bee keeping etc. Our environment will be clean and native biodiversity will be preserved. At the end, proper weed management would strengthen the food security scenario and also alleviate the fears of food insecurity in the country by resulting in significantly increased food production.

Management of Dwindling Water Resources for Sustainable Agriculture

R.K. Nema

Professor
Department of Soil & Water Engineering
College of Agricultural Engineering
JN Krishi Vishwa Vidhyalaya, Jabalpur – 482004 (M.P.)

While land, water, air, forests and oceans have always been viewed as resources useful to human well-being, thinking about managing these, has been relatively recent. For a long time, these were considered so abundant and easily available – and therefore, commanding little economic value – that there was little need felt to plan their use, to invest in protecting and augmenting them and in general to husband them better. All these were relevant only for natural resources like minerals, coal, oil which nature had hidden so inconveniently that humankind has had to try harder in prospecting, locating and extracting these. With the rising pressure of human population and the demands made by modern economic progress, natural resources like land, forests and oceans have come under increasing pressure; in the industrializing societies, clear air and safe drinking water, too are becoming short in supply. With this pressure rowing inexorably, the scarcity value of natural resources has risen and the idea of managing these has become worthwhile.

Efficiency, Equity and Sustainability

Managing a resource, any resource for that matter, would normally mean its optimal husbanding for one or more objectives. Managing a manufacturing facility well would mean keeping the production costs low and product quality high; managing a portfolio of assets well would mean ensuring high overall return without increasing the risk too much. Equity would normally mean fairness in access, appropriation and use of a resource. Similarly, sustainability too, is often used to convey much more than what it should convey on its face value – which is inter-generational equity.1 It presupposes that the present generation is the custodian of mother earth for future generations; and that it must enjoy her bounties to the fullest but without in any way infringing on the future generations' rights over them.

Alternative Perspectives

Thinking on natural resources and environment management has then little in common with normal management; in particular, it has come to mean some amalgam of a variety of perspectives from which different actors/decision-makers look upon what is involved in NR & EM.

Production Perspective: Well-entrenched in technical bureaucracies, the production perspective essentially views natural resources as production systems (as distinct from ecological systems). It focuses on the economic and technical efficiency in the management of natural resource systems.

System/Infrastructure Management Perspective:

The system/ infrastructure perspective is in some ways similar to the production perspective but is concerned with the technical and economic efficiency of the infrastructure or technical system created to capture, harness, appropriate and use a natural resource in an input-output system. A typical example is irrigation – both canal as well as lift – in which engineers typically treat the value of water as zero but manage for high 'system efficiency'; a canal system is designed to command a certain area with a certain duty and with little or no attention paid whatever to how it will change the overall aquatic and/or biotic environment, or how it will affect the groundwater ecology. The objective function is the economic return on capital investment in developing and appropriating the water impound in a reservoir.

Conservationist Perspective:

At the other end of the continuum lie the conservationists – powerful, vocal and highly articulate individuals and groups participating in the NR & EM debate – who are often influenced by the conservation perspective. They believe that degradation has reached critical proportions, and that the only way to arrest it is to conserve natural resources and protect the environment at any cost.

Livelihoods Perspective:

Many development programmers and doctrines that originated from poverty and livelihoods perspectives viewed natural resources essentially as livelihoods for the poor improving poor people's access to natural resources like trees and water can be a more powerful poverty-alleviation strategy than those compared to the integrated Rural Development Programmed (IRDP) and such like.

Sustainable Resources Management Perspective:

The sustainable management perspective – best embodied in the watershed development method – takes into account all these other perspectives but focuses on ecological balance as the bottom line. In a dynamic sense, it advocates management in place of extraction, husbanding of a natural resource instead of just exploiting it. It argues for investment of effort and resources in enhancing yields of natural resource systems and containing the use-levels to rising sustainable yields. In groundwater systems, for example, the sustainable management approach advocates restricting groundwater withdrawals from an aquifer to a long-term rate of recharge which, it seeks to augment through investment in recharge structures. Unlike other perspectives which mimic single-objective programming, the sustainable management approach represents a multi-objective, multi-constraint programming approach. It focuses on all natural resources in a locale; it takes into account all needs and uses; it recognizes the inter linkages amongst various natural resource systems in that locale. Based on all these, it attempts to lift the interaction between people and their environment to a higher level of equilibrium that yields more in terms of income, environment and employment. The benefits of proactive sustainable NR & EM are best illustrated in the watershed development work in Ralegaon Siddi.

Under pressure of population growth and economic progress, a common property management regime has given way either to private property rights or to an open access management regime in which anyone can have any kind of access to the resource without let or hindrance. Open access is then a ‘spoils system’ and is the sure formula for degradation.

The central challenge to which most of the action in the field of NR & EM is directed then is not technological but institutional. It is aimed at communities and seeks to modify the way communities relate to their natural resources. And just as there are a variety of perspectives to understand the NR & EM challenge, so too, there are a variety of approaches to responding to the challenge

The key groups of actors involved are:

- Government and Public Agencies
- Non-governmental Organisations (NGOs) and Civil Society
- People’s Organisations and Social Movements
- Knowledge Institutions
- Donors

Each group has its own strengths, weaknesses, proclivities and strategies; and with in each group, we find many shades and variations. The government and public agencies have the scale and overarching authority to bring wide-scale change and make it stick. However, these are commonly afflicted by a lack of imagination and drive. NGOs display incredible variety: there are some small, agile ones with bees in their bonnets, as it were, who often have a profound impact. And yet at the other extreme, there are huge NGOs that often operate as development contractors with varying levels of effectiveness. Donors, likewise, include the likes of the World Bank with its. Mega-projects in multiples of 100 million dollars on the one hand, and small grant makers go back a diversity of local initiatives. People’s organizations and social movements are conspicuous by their scarcity knowledge institutions which undertake a variety of tasks including research, advocacy, experimentation, process documentation, education and training, networks and dissemination of ideas.

Government and Public Agencies

Government intervention in the society to achieve public policy goals essentially take three routes, undertaking public production such as in large irrigation projects, reserve forests, etc.: deploying an appropriate tax subsidy regime such as subsidies to encourage poor households to take to irrigated farming and putting in place a promotional and regulatory framework such as the Forest Conservation Act. The state can also use a promotional framework to encourage, catalyses and promote institutions and initiatives that can help it achieve larger public policy goals: the government forming village watershed committees for watershed development.

In the field of NR & EM, the government role has tended to be characterized by the over-use of the public production route, under-use of the promotion-regulation route. Many natural resources – most notably, tanks and tank systems in Tamilnadu – were apparently much better managed by local communities for centuries until the colonial state took these over and handed them to the Public Works Department some time during the second half of the 19th century.

While the state’s performance as natural resources manager has been dismal, its nonperformance is unforgivable in creating suitable regulatory and promotional frameworks. The absence of legal foundation is the prime barrier to our moving towards a more responsible NRM.

A classic case is groundwater whose appropriation and use is governed by the law of the jungle. Many states have been thinking for decades about some kind of law to regulate groundwater withdrawal. Gujarat in fact, passed a Groundwater Act in 1975; but the chief minister kept it from becoming a law apparently because he realised that there was no way that it could be enforced, and that its only impact would be that local bureaucrats would have one more reason to extract bribes from farmers.

Finally, in India – as in other developing countries – the state has been incredibly inept in using effective tax subsidy regimes to promote sustainable NRM. In contrast, populist policies such as subsidized canal and tube-well irrigation have not only discouraged investments in developing and conserving the resource but actively encouraged the profligacy and misuse of water.

In recent years, then, talk about centralized control by the state is passed and it is increasingly granted that decentralized management over natural resources is critical for their sustainability as well as for livelihoods generation. However, there are several views about how, and to what extent to decentralize management over natural resources.

A great deal of institutional experimentation has taken place in small-scale irrigation management as well as in forestry. In irrigation, the direction of institutional experimentation has shifted from public management to community management to pump irrigation markets.

Donors and the government involved in decentralized resources management projects have long been pushing the principle of participatory development. This is the notion that people themselves have to be a part of the identification of their development needs and problems, and have to be a part of the design of the solution. Such participatory projects because they are need based and provide benefits for the poor, are often considered to have great potential benefit for participatory development. However, this participatory model of decentralizing management can succeed on a large scale only if we have some breakthrough on two fronts: [a] create a holistic approach that integrates NRM with livelihoods promotion and [b] the design of a robust, self-propelling local community organisation that can underpin national programs at the ground level.

It is impossible to evolve an integrated local strategy for the development of soil, water, forests, grazing land, etc. Watershed management has emerged in the last five years as an approach that tries to integrate all activities but has so far had limited and sporadic success, such as in the Indo-German Watershed Development Project in Ahmednagar district. Whether watershed and other natural resources management program succeed on a large scale will depend critically on the ingenuity in catalysing local organisations of people. At present, there is an unbelievably wide variety of local organisations being promoted in a fragmented manner by the government as well as nongovernmental agencies; village forest committees (VFCs) for JFM, water users associations (WUAs) for joint irrigation management, village watershed associations for the watershed program and all manner of self-help groups besides, of course, co-operatives of various hues. Yet, the absence of a local resources management institution which has statutory rights, is locally accountable and has a mandate to plan independently of departments or projects is the key challenge to be overcome.

Non Governmental Approaches

In terms of their scale, depth and outreach, NGO initiatives in NR & EM are small by the standards of government programs and are miniscule when compared to the magnitude of the national challenge. In our reckoning, by far the majority – over 95 per cent – of NGOs is tiny in the domain over which their work is spread (three-five villages), employ less than five people and implement standardised government programs. This majority of NGOs get little opportunity for innovative work and it is uncertain whether many of these have the drive and lean for innovation and experimentation. With the government increasingly using NGOs to implement its development program, the quality of a whole new generation of NGOs – and their reasons for existence – have come into question. According to some observers, several thousand NGOs have got registered in the country only because of the integrated watershed development program. There are probably 100 – at the maximum, 150 – NGOs in India today which pursue

Innovative NRM work

It is these that have created the glory in which the entire movement has been basking. And these 100-150 derive their significance not so much from the scale and outreach of their work – although huge scale and outreach always tend to captivate NGO leaders – but from the windows of opportunity they create in learning about innovative approaches to sustainable NRM. NGO initiatives in NRM vary greatly in their size, objectives, approaches and orientation.

Perspective: Some – like the Aga Khan Rural Support Program in Gujarat, Sewa Mandir in

Udaipur, and PRADAN in Eastern India – work in NRM primarily from the livelihoods and entitlement perspectives. Others like VIKSAT in Gujarat, PRADAN in Madurai, Tarun Bharat Sangh (TBS) in Rajasthan work on participatory NRM but from a sustainable NRM perspective.

l **Focus of Work:** A majority of NRM NGOs began with grass-roots projects of their own. However, over time, a new layer of support NGOs has come up at the national and regional level which services the requirements of grassroots NGOs in a number of different ways. The Society for Promotion of Wastelands Development (SPWD) was an early such support NGO which retailed funds to grass-roots NGOs without registration under the Foreign

Contribution Regulation Act; more recently, Development Support Center in Ahmedabad has been playing such a more broad-based support role at the regional level in watershed development and participatory NRM. A number of regional support organisations catalysed by PRIA – such as UNNATI in Gujarat, CYSD in Bhubaneshwar, PARIVARTAN in Bhopal – play a powerful training support role for grass-roots NGOs.

Specialised Versus Broad-based: Few NGOs in India come up with a clearly articulated goal and strategy in a playing field like, for instance, the International Development Enterprises (IDE) which has steadfastly pursued for over a decade a single-product focus and achieved great scale.14 Most, even among the elite 150 NGOs, operate on multiple fronts; they may operate NRM program in some villages and also organise self-help groups of women in the same area, with or without any overlap between the two. In its extreme form, the broad based approach gets reduced to complete lack of focus and this has great implications for the performance and impact of the NGO.

Scale: Some NGOs tend to develop a strong institutional capacity base in certain programs and begin to focus energies on scaling-up such programs while operating**.**

Others at low-energy levels. Thus PRADAN's lift irrigation work in Bihar expanded much faster than some of its other programs because the idea made sense for the people as well as for PRADAN; and after a stage, PRADAN built a formidable capacity which got translated into 80-100 lift irrigation schemes every year. Similarly, Tarun Bharat Sangh which has done some outstanding work in reviving johads in Alwar district of Rajasthan, too, hit a respectable scale by specialising in a particular intervention and concentrating its energies on it. TBS has achieved what most NGOs want but fail to achieve – scale. They work in roughly 550 villages spread over five subdivisions of Alwar district. Their water harvesting work covers an area of approximately 6,500 square kilometer; and therefore, its impact is visible to outsiders as well as to people living in these villages

Implementation Approach: Common to all NGOs operating NRM programs is a local people's organisation which is used as the primary structure for implementing their programs. However, the form of this organisation, its design and other aspects vary a great deal. The NTGCF organises tree growers' co-operatives to manage and protect plantations. Trivandrum-based SIFFS organizes fishermen's co-operatives. The Sadguru Water and Development Foundation and the Aga Khan Rural Support Program form user co-operatives to own and manage lift irrigation co-operatives. Many other NGOs use informal

people's organisations – such as village forest committees or village watershed associations – which do not have a legal status. There are also differences in the approach taken to the formation of these local organisations. NGOs like Sewa Mandir consider village institutions as an end in themselves, and spend a great deal of time and effort in doing adequate process work; others like Tarun Bharat Sangh are cavalier about the exact shape and robustness of local organisations; TBS forms its organizations quickly and, once the johad is completed, does not worry unduly about whether these last or not. Many NGOs engaged in watershed development and other NRM got great lengths to create, nested or federated structures of their grass-roots organisations. Besides being limited in the scale of its impact, NGO work in NRM is also geographically uneven. The NGO movement has matured in some Western and South Indian states better than elsewhere. Moreover, the population of registered NGOs is huge in Orissa, Bihar and the North-East, and the need for sustainable NRM is greatest in Central India, however, the really innovative and influential NGOs operate only in Gujarat, Rajasthan, Maharashtra and Karnataka.

People's Organisations and Social Movements

Together, an NGO as well as a government program for watershed development, the JFM management and all manner of self-help

Groups should by now have created vast bedrock of people's institutions at the local level on which we could have built a sustainable NRM movement. However, the experience so far suggests that the local people's institutions – the VFCs and the watershed associations and water users organisations – created under these programs tend to be weak, faceless and short lived and wither away as soon as the program funds dry up. On the other hand, however, spontaneous people's movements which have somehow struck the right chord with the populace have generated a powerful and enduring response to natural resources degradation. One such formation has been witnessed in recent years in Gujarat and Maharashtra. Cultural traits, community traditions and religious beliefs and values have always been a powerful social force in India. But nowhere has it been channelised as constructively as by spiritual formations such as the Swadhyaya Parivar movement and the Swaminarayan Sampradaya in Saurashtra, North Gujarat and parts of Maharashtra. Swadhyaya Parivar is a relatively young formation; swadhyaya in Sanskrit is study of the self and introspection; while parivar is family. Thus Swadhyaya Parivar is the growing family of individuals devoted to the ideal of a reflective and virtuous life, who deeply respect the dignity of a human being, be it their own or others. A concept that has held wide-scale appeal amongst swadhyayees is of instrumental devotion as a social force. These apparently simple ideas caught on like wildfire amongst swadhyayee communities; and an important outcome was the creation of numerous 'common properties' through acts of instrumental devotion by swadhyayees. All these were and still are created spontaneously with voluntary labor, donated materials and funds; similarly, these assets are operated also through community effort and management with only occasional acts of encouragement and moral support from the movement itself. Some of the Swadhyaya experiments of creating such common properties have direct bearing with the current social science debate on common property management.

In coastal Saurashtra, for example, many swadhyayee fisher communities have created matsyagandhas or fishing boats, which are owned by the whole fishing village, managed by voluntary labor and their produce, devoted to God, is available for use by the poor, weak, disabled, widows and the old and infirm of the community. Similarly, swadhyayee communities create common property forests as vriksha mandirs (tree temples), common property nurseries and orchards as madhava vrund and common roperty farms as yogeshwar krishi. What drives and sustains these selfless acts by communities is the deeply held belief swadhyayees have in their practice of instrumental devotion. By far the most eloquent expression of instrumental devotion can be found in the well recharge movement which began in the late 1980s and has since caught on Following the fateful years of 1985-87 when Gujarat reeled under three successive droughts, many swadhyayee farmers began trying out alternative methods of capturing rainwater and using it for recharging wells. In the 1989 monsoon, there were isolated experiments throughout saurashtra; but in some swadhyayee villages, the entire community tried out such recharge experiments on all or a majority of the fields; and here, they found the results stupendously beneficial. And during 1990, the beneficial results of early well recharge experiments by swadhyayee communities began getting communicated and shared widely.20 Come 1991, the well recharge experiments began multiplying in scale and 1991 was a good monsoon, which helped these experiments to succeed. It was in the 1992 monsoon that these recharge experiments began taking the shape of a movement. Farmers of all hue – swadhyayees and others – began collecting as much rainfall as they could on their fields and in the village and channelised it to a recharge source.

Way back in 1978, speaking at the inauguration of a common property forest (vriksha mandir), Pandurang Athavale, the leadercatalyst of the Swadhyaya Parivar had lamented before his followers in Saurashtra, 'If you quench the thirst of Mother Earth, she will quench yours..'. Swadhyayees found this teaching prophetic, but 10 years later. The three successive drought years that Gujarat – in particular, Saurashtra and Kutch – faced during 1985-87 brought water issues to their cyclical peak in the public mind. Taking a clue from Israel, Pandurang Athavale began asking his followers why farmers in North Gujarat and Saurashtra could not adapt and improvise on the techniques used the world over for harvesting and conserving rainwater in situ and thus came Swadhyaya's doctrine on water harvesting: 'The rain on your roof, stays in your home; the rain on your field, stays in your field; the rain on your village, stays in your village'.

20 Swadhyaya Parivar is a close-knit community; the more devoted and committed among the swadhyayees spend a good deal of time and effort in 'communicating' new ideas across swadhyayee communities. Audio and video recordings of Athavale's talks are widely in demand and are played before voluntary gatherings of swadhyayees. These offer a powerful medium for spreading new ideas and messages. The most convenient forum is the time when Pandurang Athavale presides over a public meeting; three to four lakh swadhyayees throng such meetings from far and wide. Athavale does some of the planting of new ideas in the course of his talk; the rest is done by other swadhyayees in a person-to-person exchange or in small group meetings. Junagadh's swadhyayees organized a technical training workshop on well recharge methodologies for

some 525 volunteers who came forward to further extend the techniques. A loose organisation got formed around well recharge work; a group of 11 volunteers from each village, 15 at the taluka level and 25 at the district level got constituted to undertake the necessary coordination and mobilisation (Bhatt 1994). Numerous villages came to know about recharge techniques through the Bhakti feries (devotional goodwill marches). Bhakti feri is an other device Swadhyaya Parivar uses to achieve multiple ends and involve groups of swadhyayees finding few days or weeks every year to visit people in different parts of the country; during these visits, they make a fetish of being self-dependent to the extreme, cooking their food themselves and refusing all offerings. During these, groups of swadhyayees traveling together will meet anyone who will care to receive them and talk about Swadhyaya doctrines and values. Sometimes, they will play an audio tape of a talk by Athavale; at other times, they will also end up facing hostile groups smelling rat; commonly, however, the selfless and agenda-less outlook of the visiting swadhyayees first inspires curiosity and then a sense of goodwill and friendship. Bhakti feries serve many important purposes: they are a powerful educative and maturing experience, and encourage swadhyayees – many of whom are from the urban elite to mingle with common folk and develop a more realistic world-view; second, through Bhakti feries, many people and communities get attracted and won over by Swadhyaya Parivar and its ethic of life; third, Bhakti feries keep the Parivar's communication machine well oiled; it is often through these that technical knowledge – such as on well recharge methods – gets propagated.

Stories began doing the rounds within and outside the Swadhyaya Parivar about groups of swadhyayees building check dams or deepening tanks or building anicuts, or working together to recharge all private wells of the village. Soon many small and big NGOs joined the movement, each trying to help in its own way. Another major influence on the whole movement has been of the Swaminarayan Sampradaya, which too has a huge following but is fascinatingly different in its organising philosophy and management style from the swadhyaya Parivar.22 Saurashtra Lok Manch compiled information about technologies used by different groups of farmers for well recharge, and printed it along with illustrative pictures and made these leaflets available in every nook and corner of Saurashtra. The well recharge movement had caught on like wildfire; and now, it was not just swadhyayees, but farmers of all persuasions joined in.

There are no formal studies of the actual scale of the well recharge work; however, many different sources suggest that between 1992-96, about to 92,000 to 98,000 wells were recharged in Saurashtra; and some 300 nirmal neer (farm ponds for recharge) were constructed. Swadhyaya Parivar workers were so enthused that they set themselves a target of over 1,25,000 wells and over 1,000 farm ponds during 1997. It is widely believed that if five lakh wells in Saurashtra are recharged, the region can solve its irrigation as well as drinking water problem (Krishi Jeevan, 1996: 2); and at the rate at which the movement is growing, it would not be surprising if this target has been met. By 1993-94, the well recharge movement had begun spreading to other parts of Gujarat, notably Sabarkantha, Mehsana and Panchmahals districts.

In the meanwhile, a large volume of anecdotal evidence has begun doing the rounds normally and through the media to highlight the exceedingly beneficial economic impact of the well recharge programs. Then, there are assertions based on back-of-the-envelope calculations; for example, Vayak and Khanpara estimated that the 10,000 wells recharged in Kutch and Saurashtra during 1993-94 cost the farmers Rs 50 lakh but raised a net output by Rs 80 crore.

The impact and the potential of social formations such as these have been largely ignored by the mainstream discourse on NRM; and so have their lessons, which seem relevant to everyone working in the field. Why they have not received the importance they seem to deserve is not clear. Many dismiss it as a religious, sectarian affair; others see these successes as un-replicable and donors are lukewarm to it because these movements neither accepts external funding nor can they be catalysed by funding support; and scholars are timed by it because it does not fit into the normal linear logic pattern. All in all, then, the larger implications and lessons that the Swadhyaya movement offers in mobilising masses for regenerating natural resources are more or less lost on the Indian debate on NRM.

Knowledge Institutions

Another major group of actors in the field of NRM are knowledge institutions primarily engaged in their role in mediating ideas and action.

An extraordinary dimension of the NRM idea machine is that it is almost wholly driven by knowledge institutions outside India Indian knowledge institutions commonly hitch-hike on the reigning bandwagon rather than take up an original line. Worse, many knowledge institutions

– commonly those like the dozen Water and Land Management Institutes WALMIs), the forest training institutions and such others held captive by government departments – tend to be hopelessly uncritical in accepting and propagating ideas accompanied by grants and quickly turn them into orthodoxies.

There is a great variety among donors, too. The World Bank, for example, is a completely different from DANIDA or the Swiss Development Corporation (SDC) – although both operate in the same action space in the NRM field. And the foundations – like Ford and Rockefeller – are even smaller in terms of the amount of funds they dispense but command great 'leverage', especially in the field of NRM. The World Bank, the UN agencies, the EC and such multilateral donors command great power in shaping what is perceived as the 'mainstream' in NRM at any given point in time. When a new idea – such as people's participation or participatory rural appraisal (PRA) or civil society – gets accepted by these and integrated into their programming methods, it becomes a part of the mainstream.

Formulating an assessment of donor work in the Indian NRM sector is a major and difficult enterprise; but it would certainly be an admixture of successes and failures.

The point still remains that donors – their analyses, world-view, assumptions and policies remain the single most important determinant of the goings-on in the NRM sector. Both the donor as well as the recipient run the risk of moral hazard as well as adverse selection.

V. Linking Research with Monitoring and Evaluation

The best approach to becoming a high leverage grant maker seems to be to transform project monitoring and evaluation (M & E) into an applied research tool. M & E in most donor-supported projects are designed to serve the limited purpose of a project management tool. However, projects – especially of the innovative kind – seldom evolve and play out the way they were originally designed. In such situations, M & E can be designed to serve as management and a research tool.

Two examples from ongoing work under the IWMI-Tata Water Research Policy Program suggest the value of designing M & E systems as a research tool as well. During the 1960s, many state governments initiated a program of public tube-wells to provide irrigation to small holders; however, like many other governmental forays into economic activities, these too became a drag. During the 1990s, the Gujarat Water Resources Development Corporation (GWRDC) contracted out hundreds of public tube-wells to groups of farmers in the command area. GWRDC's monitoring systems regularly threw up information on the performance of tube wells under government management and farmer management. However, except for routine monitoring, this information was never used to study how this management intervention was faring. When we began working with GWRDC, we found that the M & E data showed unequivocally that transferred tube-wells were performing much better in terms of efficiency, equity and socio-economics sustainability. Indeed Gujarat's experiment can serve as a model to the rest of the state governments in salvaging their public tube-well program.

Similarly, the M & E system of the Sardar Sarovar Project which manages the Narmada project has all along showed that there is no way that the originally planned assumptions made in the project could be met. For instance, the original plan assumed that the government would build lined canals upto each village service area and that the local water users association would build the distribution system within the village. In reality, we found that in none of the 800 villages where the Narmada water was released for irrigation in winter 2002- 2003 was there either a functional WUA or a village-level distribution system. Instead, farmers in each village had invested in thousands of diesel pumps and tens of thousands of rubber pipes to lift water from the lined canals and transport it to their fields. The Narmada authorities were aghast and embarrassed that the project was not evolving according to design. Our view is: true, but the pump-and-pipe based distribution system that is now emerging may not be necessarily inferior to the canal and field-channel distribution system, especially when we take into account the fact that building the latter would cost the government over Rs 15,000 crore in the entire command and that the state government is too broke to generate such funds.

An urgent need in the NRM sector is for a new generation of local institutions of two distinct types: first, those that combine experimental implementation with innovation and learning; and second, those – like we find in who take a tested and proven change proposition and gun for a big scale.

Take the watershed development project: in a decade of its implementation, the only NGO which has given us something of a replicable model is the Indo-German Watershed development Project; and no NGO has been able to do watershed development on a scale that can be considered big by Indian standards.

Indian Scenario

Out of the annual precipitation of about 4000 km3 in India, the accessible water is 1869 km3. However, barely 690 km3 water is currently used, and the remaining 1179 km3 of water directly drains into the sea — much of it in 100 days that define the India's wet season (Aiyar, 2003). India's water problem basically stems from disparate precipitation, mismanagement, and the fact that while nearly 70% of precipitation occurs in 100 days, the water requirement is spread over 365 days. In a number of regions, water tables have been falling at an average rate of 2 to 3 m per year due to the growing number of irrigation wells (Postel, 1993). In addition, the growing pollution of freshwater from point and no point sources and seawater intrusion into freshwater aquifers in coastal areas of the country are posing a serious problem. Consequently, India's food security is under a serious threat and the lives and livelihoods of millions are at risk. Besides India, the countries where water scarcity is posing a serious threat include China, Pakistan, Iran, Egypt, Mexico, and dozens of smaller countries (Brown, 2000). The population of India is expected to stabilize around 1640 million by the year 2050 (UN, 1995). As a result, the gross per capita water availability will decline from about 1500 m3/year in 1995 to 810 m3/year in 2025 (Shiklomanov, 1997). Thus, water is a critical factor in determining the limits of socio-economic development of various regions in India as well as in sustaining the health of ecosystems.

Strategies for Sustainability

Integrated Water Resources Management

Water resources management has been undergoing changes worldwide due to the population growth, economic development, improved sanitation, technological revolution, and changing legislative and administrative conditions. These changes will continue in the future as well, with their intensity dependent on the demographic and economic processes in different parts of the globe. It is a well recognized fact that new sources of water are increasingly expensive to utilize, and hence there is a limit to new potential of water sources. Thus, the best option is efficient management of available water resources. The looming threat of climate change adds a new dimension to the ongoing dynamics of water supply and demand. The climate change will significantly impact the water cycle, with wide-ranging consequences for human society and ecosystems. In view of growing freshwater scarcity, food insecurity and environmental degradation, the need for prudent use of freshwater and improvement of present water management practices are of paramount importance in order to ensure sustainable development.

It is predicted that the impact of climate change will be severe on the water sector, which will have large implications for other sectors. Therefore, if the challenges of climate change for the world's water are not understood and addressed, it would be almost impossible to ensure sustainable future. As a result, "the way we use and manage our water today will decide to address the challenges of tomorrow". The adoption of modern and structured water management approach known as "Integrated Water Resources Management" (IWRM) in practice is an urgent need throughout the world to ensure sustainable management of vital water and land resources. "IWRM is a process which promotes the coordinated development and management of water, land and related resources in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems".

Increasing Water use Efficiency

In most of the canal command areas, the overall irrigation efficiency varies from 15 to 30%, exceptions are there. In a canal command, a farmer is charged water taxes according to the area cultivated and the crop and not on the basis of volume of water used. In most of the cases the farmers at the head reaches of the command uses more water and the tail-enders suffer from low supply during the period of scarcity and water logging during the period of flood. There are several causes which should be addressed for the over irrigation.

1. Most of the farmers do not know that they are using excess water.
2. They do not pay according to the volume of water used.
3. The farmers suffer from a fear psychosis about the uncertainty of supply.
4. They do not know the technique of applying proper quantity of water.
5. Extension Officers posted at block levels to train the farmers are also not aware of the fact that the farmers are applying excessive water.
6. Most of the Officers also do not know the technique of applying proper quantity of water.
7. The farmers do not know the harmful effects of excessive application.

According to the crop root zone depth and soil type, ideal depth of each irrigation should have been 5 to 7 cm. Actual depth applied to the crop from the canal supply varies in the range of 7 to 22 cm. Similar measurements taken on private owned shallow tube wells showed that the irrigation depth varied from 3 to 7 cm. This is due to the fact that the farmers had to spend heavy amounts on diesel for running the diesel engine pump sets to operate the tube wells. In a canal command, if a farmer in the head reach is told that the tail-enders would suffer for his action, he is not convinced and not ready to make efforts to apply optimum depth. But if he is told that his fertilizer is leaching below the root zone depth and is wasted then he is concerned to some extent.

It was seen that the fields were divided into neither borders nor check basins for efficient irrigation. Although they look like check basins, but there is no separate channel to connect them. Water from the field channel enters into the adjacent check basin, irrigates it and then the partitioning bund is cut to allow the water to cross over to the next basin and the process continues till the last basin of the series of 5 to 6 basins is irrigated. By the time the last basin receives about 5 cm of irrigation, the first basin may receive 20 to 30 cm depth. Therefore, it is essential to adopt the following measures:

1. Water Management Specialists should be posted in all command areas.
2. The officers should have thorough knowledge of water management techniques.
3. Periodic state level training of the officers should be organized.
4. Awareness should be created among the farmers regarding the benefits of proper water management.
5. They should be suitably trained to acquire the skill of efficient water management.
6. Suitable legislation should be enacted to enforce proper water management.
7. Legislation should also be enacted to enforce consolidation of land holding of a farmer.
8. Substitute crops with low water requirement should be introduced.

Ground water in M.P.

The depth of water level in phreatic aquifer generally varies between 5 and 10 m below ground level (bgl) with localized pockets of water levels exceeding 20 m bgl in alluvium. In general pre and post monsoon water level fluctuation is 4 m in phreatic aquifer. The central and eastern part shows 2 to 4m fluctuation. The availability and utilization of G.W. is varying in different districts. The ground water survey during the year 1998 shows that level of ground water utilization (which is the ratio of net yearly draft and utilizable ground water resources) is 18.81 percent for old M.P. The distribution of the level of ground water utilization is not uniform throughout the state It has been changing with respect to time and space. The level of development of ground water in the state has increased from 11.5 percent during the year 1984 to 18.8 percent in the year 1998. It was varying from 1 to 60% in various districts during 1984 which has gone up to 2.2 percent in Mandla to 72.17% in Indore during 1998.

Water Table categories in the Pre monsoon Season

Observations recorded in 595 out of 951 observation wells. During pre monsoon period (May) of the year 2003 and 2004 following is the water table position in M.P. The majority of the wells 51 percent are falling in general category i.e. 5-10 m bgl. A large number of wells, 36.4 % in state are showing water table from 10-20 m and makes these areas as susceptible for water shortage, high energy use, and deterioration of quality of ground water. It is a warning signal that there is sharp increase in wells showing deeper water table and is extending over larger and larger areas every year. This has to be taken care.

Effect of command and Non command area

It was also found that ground water draft was less in Command areas and hence the ground water development was low resulting safer category. On the contrary ground water level was found increasing in canal irrigated areas.

A study conducted in Rani-Awanti Bai Sagar Irrigation project concluded that water table is rising in canal irrigated area by 23cm/year in Jabalpur district. But in well irrigated area of Narsingpur depletion of 10 cm/year was marked. This indicates the necessacity of planning conjunctives use of canal and Ground water to maintain dynamic equilibrium. In shallow water table areas conjuctive use in 60:40 ratio has been found appropriate for maintaining dynamic equilibrium. Similar situation has been observed in other command areas like Tawa, Chambal, Mahi and Command of Minor and medium irrigation project.

Developed Irrigation capacity and utilization in Madhya Pradesh
(area in thousand ha)

Year	Major Project			Medium Project			Minor Project			Total		
	Capacity	Utilization	Percentage Utilization	Capacity	Utilization	Percentage Utilization	Capacity	Utilization	Percentage Utilization	Capacity	Utilization	Percentage Utilization
1	2	3	4	5	6	7	8	9	10	11	12	13
2001-02	977	497	50.87	390	242	62.05	713	201	28.19	2080	940	45.19
2002-03	1001	398	39.76	391	202	51.66	737	176	23.88	2140	776	36.45
2003-04	1069	528	49.39	391	232	59.34	740	247	33.38	2200	1007	45.77
2004-05	1116	575	51.52	391	232	59.34	751	227	30.23	2258	1034	45.79
2005-06 Estimated	1174	543	46.25	393	171	43.51	774	155	20.03	2341	869	37.12
2006-07 (Provisionl)	1243	574	46.18	403	174	43.18	802	189	23.57	2448	937	38.27

Conjunctive use of groundwater and surface water

For an optimum utilization of water resources of the State, an integrated approach for surface and groundwater development is the call of the day. Surface and groundwater can not be treated as independent units as they are a part of same hydrological cycle. Conjunctive use of groundwater and surface water in all the Major and Medium Irrigation Projects and all the CADA (Command Area Development Authority) areas will lead to an efficient utilization of the available water resources, extension of the areas of irrigation, increases the cropping intensity and mitigate the problems of water logging, salinity etc. Special emphasis should be given to the surface irrigation schemes in the alluvial valleys of Narmada and Chambal rivers. The conjunctive use schemes should be planned as per the requirement of specific area.

It is often observed that provision of augmentation wells is given in irrigation schemes in the name of conjunctive use of surface and groundwater without much relevance to the area. For example, in Rani Avanti Bai Sagar Project (Baragi Project) in Narmada upland valley, the Irrigation Department is contemplating construction of 1000 augmentation tube wells to counteract the likely water logging and salinity problems. In the Bargi left bank canal command, already rich potential of groundwater exists.

Therefore, conjunctive use of surface and groundwater in such area should imply irrigation through canal irrigations in areas adjacent to the left bank canal which is poor in groundwater potential and providing irrigation through large scale groundwater development in areas away from the L.B.C. adjacent to Narmada river which is very rich in groundwater resources. Canal net work has been extended to this highly groundwater potential area which may have a dampening effect on the present rate of groundwater development due to availability of surface water at cheaper rates.

Prevention is better than cure

The seepage from the canal net work and decrease in the groundwater draft may combine together to cause water logging in the command area. Construction of augmentation wells all along the canals, more so when the surface water in canals is sufficient, is not the correct approach for conjunctive use. Rational schemes of conjunctive use of surface and groundwater would go a long way in providing maximum benefit to the people and also would help in preventing likely water logging and salinity problems.

Ground water Conservation

Madhya Pradesh covered mainly with hard rocks, has special relevance for groundwater conservation and artificial recharge, Major rivers like Narmada, Tapi, Chambal, Mahanadi and Mahi along with their numerous tributaries originates from the hill ranges located in M.P. The hilly terrain often causes heavy run-off and equally fast depletion of groundwater storage in the form of base-flow to rivers and streams which drains in impervious rocky terrain. The situation demands conservation of groundwater flow at appropriate locations to replenish the phreatic aquifers to their available capacity. In areas like Mandsaur district, the relevance of groundwater conservation is more so because potable water occurs generally within 30 m depth and the deeper aquifers contain saline water.

Need of Increasing Ground Water Recharge

Due to fast development of groundwater the dug wells are getting dry thereby creating scarcity of even drinking water. Suitable artificial recharge structures like sub-surface dykes, percolation tanks etc. help greatly in restoring the depleting groundwater reservoirs. Locating appropriate artificial recharge structures based on the site specific hydro geological situations can be replicated in large parts of the Malwa Plateau. In Madhya Pradesh all programs of groundwater conservation should be taken up in the form of small watershed management with the objective of controlling the surplus surface run-off during the monsoon and augmenting the groundwater storage.

Pollution Level demarcation

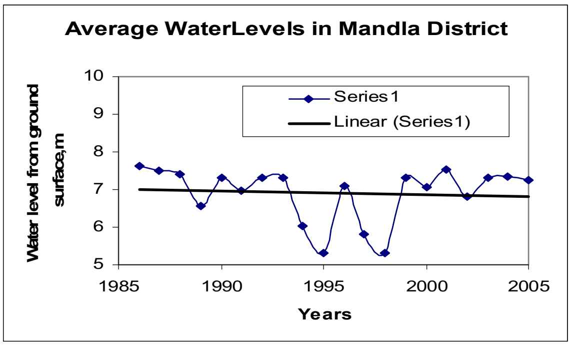
The geochemical studies have shown the presence of excessive fluoride content in groundwater of some localized pockets. There is a need to precisely demarcate the acutely affected areas in M.P. with excessive fluoride content and to arrange for an alternate source of safe drinking water. Large areas also show the common pollution of excessive Nitrates which is mainly as a result of improper sanitation. In addition to these, the groundwater pollution due to industrial effluents is drawing attention of planner and executing agencies. For safe drinking water and suitable water for irrigation and industrial purposes a proper monitoring of quality of groundwater is very much essential.

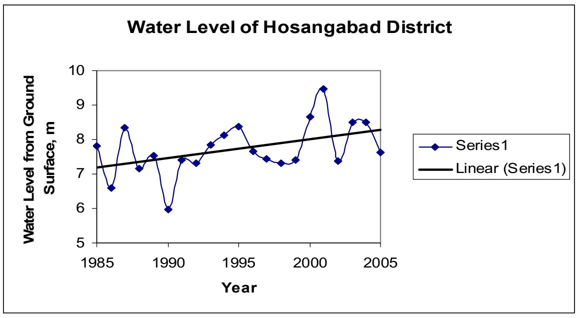
Further Strengthening of Monitoring Network

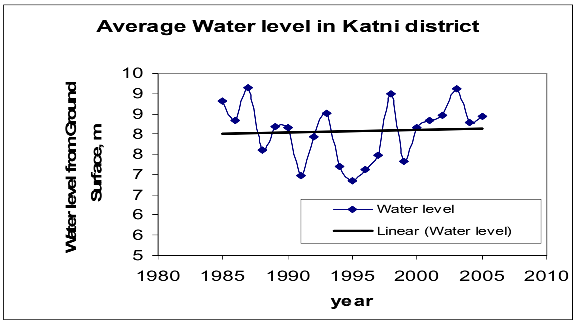
For monitoring network in the State on a more scientific line to avoid redundancies due to unnecessary overlap of work National Hydrology project is a good initiative for this. It shall provide a strong platform for G.W. development works in future in terms of the quality of data and the processing capabilities. There is a need for training of personals to take up the challenges of the modern inputs for its efficient utilization and providing scientific base for the development of groundwater resources of Madhya Pradesh.

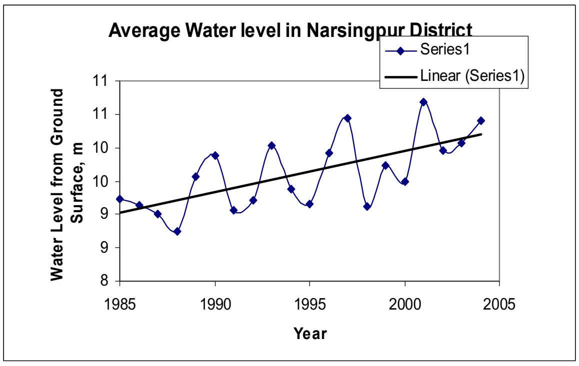
There is low ground water development in 42 blocks of 6 districts lying in Narmda basin. The average ground water development in Dindori and Mandla district is below one digit figure. This warrants necessity of ground water development at faster rate in these districts. This will not only keep ground water table at desired level but also help to boost local economy through increased irrigated area.

In Katni district which has ground water development in the range of 11% to 51% in different blocks with average ground water development of 27%, the water level show almost stable value. Districts namely Narsinghpur and Hoshangabad are lying in the fertile alluvial plan of basin. It has got very good ground water potential. Due to high ground water potential, the ground water development is also high in Narsinghpur which is more than 54%. There is a sharp declining trend in water level registers in Narsinghpur district. All blocks of districts mentioned so far belong to safe category and has got tremendous scope for ground water development.









On the other side the percentage irrigation intensity of districts Dindori, Mandla, Katni, Jabalpur, Narsinghpur and Hoshangabad district are 1%, 6%, 26%, 31%, 42% and 49% respectively for the year 2002-03. Looking to the state of ground water development there is a good scope of increasing irrigation intensity throughout the Mahakaushal region. Ground water utilization can increase irrigated area. The block wise ground water available for irrigation purpose has been worked out by the State Water Resources Department during 2004 using standard norms are presented in Fig. 2.

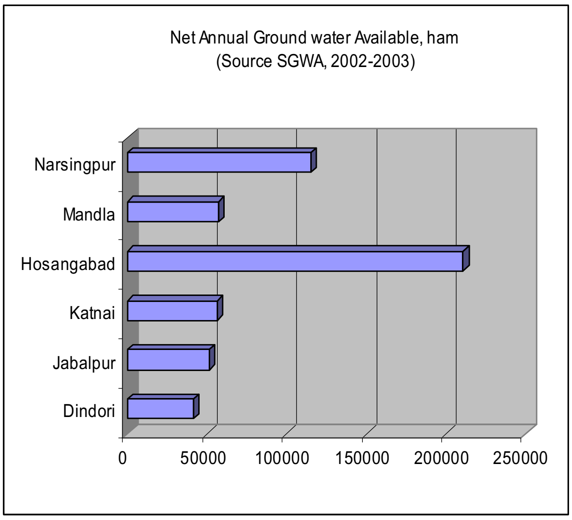


Fig. 2. Net available Ground Water in Upper Narmda Basin

In upper sub-basin of Narmda the ground water availability in Dindoni district is 41194 ha-m. Mandla is the other district of upper Narmda basin which has 57143 ha m ground water available. Ground water availability in Hoshangabad and Narsinghpur district is quite high. Hoshangabad being the highest gainer (2,10,889 ha-m) of ground water and Narsinghpur though has about half of the ground water availability than Hoshangabad but has almost double the ground water availability than other districts.

Vermi-Composting Boon for Farmers Farming and Ecology

S.B. Agrawal

Subject Matter Specialist
Krishi Vigyan Kendra
JN Krishi Vishwa Vidhyalaya, Jabalpur - 482004 (M.P.)

Vermicomposting is the process in which earthworms feeds on waste organic substances and convert them in compost by passing through their guts in the granular form called as vermicast. Thus vermicompost is a mixture of worm castings (Faccal excretions). Organic matter including humus, live earthworms, their cocoons and other organisms. It is an easy and effective way to recycle agricultural waste, city garbage and kitchen waste etc. The role of earthworms in improving soil fertility is welt known. Earthworms feed on any organic waste, consume 2-5 times their body weight and after use 5-10% of the feedback for their growth excrete the mucus coated undigested matter as worm cast. This worm cast consists of organic matter that has undergone physical and chemical breakdown through the activity of muscular gizzard, which grinds the material to a particle size of 1-2 micron. According to Tapiador (1981) 1000t moist organic matter can be converted into 300t of compost by earthworms. Concentration of exchangeable cations (Ca.Na.Mg.K) available N.P and Mo are higher in the worm cast (Shinde *et al.,* 1992). The nutrients present in worm cast are readily soluble in water for uptake of plants. Vermicasts are a rich source of macro and micronutrients, vitamins, enzymes, antibiotics, growth hormones and immobilized micro flora.

Composting

- Composting is an accelerated bio oxidation of organic matter passing through a thermophilic stage (450c to 650c) where micro organisms mainly bacteria fungi and actinomycetes liberate heat carbon dioxide and water.
- Heterogeneous organic material is transformed in to a homogeneous and stabilized humus like material or product.

Vemicomposting

Vermicomposting is also a oxidation and stabilization process of organic matter which involves the joint action of earth worms and micro organisms but it does not passes through the thermophilic stage. The earthworms play the role of turning, aeration & fragmentation

Points to be considered at planning level

I. Selection of site
II. Availability of decomposable organic waste, transportation and stocking etc.
III. Marketable outlet and requirement with future scope
IV. Collection and study of know how on earthworms to be cultured
V. Collection and procurement or suitable species
VI. Maintenance or seed culture:
VII. Availability of labour, water and packaging etc.

Selection of suitable earthworm species

Earthworm species which are being extensively used for vermin-composting arc *Eisenia foeiida, Eudrilus eugeniae and perionyx excavatus.*

However, *Eisenia foetida* is world widely most adopted species. These arthworms are red, brown or purple coloured, 6-8 inch long having 0.5-1.5 g body weight commercially known as pink worm, red worm, purple worm or tiger worm.

Methods

Vermicompost can be prepared by following methods. Any method can be adopted according to the suitability and convenience.

Pit/structure method

A pit or structure of 2m x 1m x 0.5 size with slopping floor may be constructed with bricks and cement at a high place so that rainwater is not collected in the pit but it should be near to a source of water. A 10-15 cm thick layer of good loamy soil above a thin layer (5 cm) of broken bricks and sand should be liad at the bottom. This layer is remains cool and inhabited by earthworms. First a 5 cm layer of decomposed cattle dung / FYM is laid at the bottom of the pit which will work as inoculum for earthworms. Then organic layering 5-10 cm is done at the vermibed with partly digested cattle dung. The compost pit is then layered to about 15 cm with dry leaves or hay. Water is sprinkled to maintain 40% moisture content in the pit without flooding. About one thousand earthworms are introduced into a compost pit. Wet organic layering (5cm thickness) is done with moist/green organic waste. This practice can be repeated every 3-4 days till pit is nearly full. Mixing of wastes periodically without disturbing the vermibed ensures proper vermi-composting. The pit is covered with moist gunny bag and water is sprinkled periodically to maintain moisture. At maturation the moisture content is brought down by stopping the addition of water for 3-4 days. This ensures drying or compost and migration of worms into the vermibed. The mature compost a fine loose granular mass is removed from the pit sieved dried and packed.

Heap Method

Vermicomposting can be done on ground also. For this ground is levelled and a manageable sized platform 12-15 cm above the ground is made, it could be 1m wide and 10-20m long. This platform is plastered with soil fee of stones. Glass or many form of chemical contaminants. Over the platform a 15 cm feed layer of partly digested material is made. After watering, live earthworms are spread. Finally more layers of pre-treated waste materials can also be heaped. The plant wastes are mixed with small quantities of mature cow dung manure i.e. FYM roughly 0.5kg FYM for 10.20 kg of plant material. This is only to given bacterial inoculums for enhancing decomposition process and ultimately faster vermin-composting. These heaps are sprinkled with little amount of water (5 litre per 20 kg waste) and covered with a hesian cloth or left on ground. Whole waste heap b kept moist for 3-7 days. And periodically turning is given for proper mixing. If platform are already under thatched roof shad. Heaps can also be covered with broad leaves locally available heaps.

Construction and Location of pit

- Generally pits or heaps should be located under the tree shadow or at the vicinity of the cattle shade where there is shadow with favourble ambient temperature.
- A source of Water should exist near the pit.
- All the pits or heaps should be under the shade and also above the ground to avoid the entry of rainfall and also to prevent from extreme temperature.

Vermi-composting in container

Any container made up of wood. Plastic, Aluminium, glass or steel may be used for vermin-composting purpose. A wooden box of 50 cm x 50 cm x 160 cm size is appropriate for this purpose. At the bottom a layer (6-8 cm) of slow decomposing material is laid ,firs. Second layer of decomposed cow dung/Vermicompost (5-8 cm thick) is spread uniformly. Now about 200 earthworms are introduced. The fourth layer 15-20 cm thick of kitchen waste /garden waste mixed -with qow dung is systematically laid. It is then covered with jute cloth. Appropriate moisture is maintained by sprinkling water at regular intervals. At maturation moisture content is brought down and the vermicompost is taken out and used.

Precautions during Worms Production

Some of the important point may take care during worm production the pit,

i. Maintenance of moisture at 50-60% level in the pit.
ii. Temperature between 25-28^{0}C
iii. Base material should be partially decomposed organic matter.
iv. Proper aeration should be provided without disturbing the worms

Collection of vermin-compost

When vermicompost is ready after 60-70 days. top layers appear somewhat dark brown, granular as used dry tea leaves. Watering should then be stopped for 2-3 days and gently-compost should be scrapped from top layers or to a depth, if appears vermin-composted. This should then be removed to side and left undisturbed for 6-24 hours. If there are adult worms present these would move down or away from the composted material.

Stocking

The vermicompost should be stocked separately in bags after sieving through 2 mm mesh galvanized sieve. Collected vermin-compost, if in bulk. can be stocked on ground under shade. For commercialisation. Vermin-compost should be \packed in plastic bugs or cloth bags of marketable quantity.

Nutrient content

There are appreciable differences in the nutrient content of vermicompost produced by different species of earthworm. On an average it contains

Nutritional composition of vermicompost and conventional compost

Nutrient element	Vermi compost	Conventional compost
Moisture (%)	46.5	41.5
Water-soluble carbon (%)	0.88	1.60
Total organic carbon (%)	27.2	28.0
Nitrogen (%)	1.9	0.64
C:N ratio	13.6	20.6
Phosphorus (P_2O_5) (%)	1.18	0.88
Potassium (K_2O) (%)	1.88	0.72
Zinc (ppm)	100	80
Copper (ppm)	18	14

Application rate

Mature vermicompost is recommended @ 5t/ha; broadcast sowing and 2.5t one month after sowing of crop.

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Potassium: the Important Component for Eco-Friendly and Sustainable Agriculture

S.D. Sawarkar

Seniro Scientist
Department of Soil Science & Agril. Chemistry
JN Krishi Vishwa Vidyalaya, Jabalpur – 482004 (M.P.)

Role and importance of potassium

Potassium is the third important nutrient element required largely by several crops and is gaining importance with intensification of agriculture in recent years. Higher yields of better quality depend greatly on the capacity and capability of the crop to resist or tolerate moisture and temperature abnormalities, diseases and other stresses during growth. It is involved in many physiological processes, such as photosynthesis, photosynthetic translocation, protein and starch synthesis, water and energy relations, translocation of assimilates and activation of number of enzymes. It also improves the water use efficiency by regulating stomatal movement and through its influence on maintenance of turgor potential.

K stimulates the degree and extent of root proliferation, root branching etc. The greater root proliferation usually gives plants better access to sub soil moisture. Adequate K decreases the rate of transpiration through stomatal conductance. Available literature reveals that K application decreases the incidence of fungal diseases by 70%, bacteria by 69%, insect and mites 63% and viruses 41%. Simultaneously, the yield of plants infected with fungal diseases by 42% with bacteria 57% with insect and mites by 36% and with viruses by 78%.

Based on its relatively ease in availability to plants, soil potassium can be classified into three main groups *viz.,* unavailable, readily available and slowly available K. The bulk of soil potassium (about 98% of total K) usually exists in unavailable form in primary (micas and feldspars) and secondary (illite group) clay minerals. The readily available K constitutes only 1-2% of total K and exists in soil in two forms, viz., solution and exchangeable K adsorbed on soil colloidal surface. These forms remain in a dynamic equilibrium with one another. The readily available or water soluble K has been reported to be a dominant fraction in the initial stage while exchangeable and non- exchangeable K contribute more in the later stages of growth. But due to continuous removal of potassium by crops and through leaching losses from soil, steady state equilibrium probably never occurs and there is a continuous but slow conversion of potassium from primary minerals to the exchangeable and slowly available forms

Generally, Indian soils are considered to be rich in potassium but under intensive cultivation of high yielding varieties of crops with application of high rates of N and P tends to deplete the K reserve of soil at a faster rate and decline in productivity has been seen at many places due inadequate supply of K sound fertilizers recommendation.

Under intensive cultivation, readily available exchangeable K is removed by crop. This is followed by further release of exchangeable K from non- exchangeable forms. The dynamic equilibrium are markedly affected when applied soil solutions K is either taken up by plants or leached into the lower soil horizons or converted into unavailable form. Under this situation non- exchangeable K plays an important role by releasing K to exchangeable and solution forms. The dynamics of potassium in soil depends on the rate of application and mining of K from the system

Distribution of various potassium fractions in soil

Many research workers found that the amount of water soluble, exchangeable, non-exchangeable, lattice and total-K in Vertisols profiles ranged from 3.0-31.8,54-278,83-787,1243-7387 mg kg^{-1} and 0.14 - 0.82%, respectively. In general, surface horizon showed higher content of water soluble, exchangeable and non-exchangeable K than lower horizons.

Other workers estimated different forms of K in soils and reported that the total K ranged from 10100 to 17500 mg kg^{-1} (1.01 to 1.75%). Different components of total K viz. water soluble, exchangeable, available, non-exchangeable and lattice K were 0.09 to 0.15, 1.04 to 1.63, and 1.1 to 1.76. 3.16 to 5.25 and 93.17 to 95.66 per cent, respectively.

Sources of potassium & their suitability for crops

Sources	K_2O content (%)	K content (%)
MOP	60	50
SOP	50	41.5
KNO_3	44	37

Other sources: Wood ash, manure, crop residues, distillery & coir industry wastes, cement kiln dust etc.

percentage in sugarcane and some other quality parameters in other crops.

Yield of crops

Balance and adequate application of potassium is necessary along with nitrogen and phosphorus to achieve higher yields besides other micronutrients. Reports indicate that application of integrated use of optimal fertilizer dose with manure is successful in maintaining high level of soybean and wheat productivity and in the maintenance and improvement of soil fertility.

Table 1 : Effect of different treatments on available K and its fractions in soil (mg kg^{-1})

Treatments	Available – K			Water soluble – K			Exchangeable – K		
	Soil depth (cm)								
	0–20	20–40	40–60	0–20	20–40	40–60	0–20	20–40	40–60
50%NPK	123.65	118.93	112.50	18.58	16.05	15.63	105.08	102.88	96.88
100%NPK	134.63	126.58	119.50	21.85	18.28	17.58	112.78	108.30	101.93
150%NPK	142.10	138.05	131.90	22.78	20.58	19.50	119.33	117.48	112.40
100%NPK+FYM	147.60	142.93	137.55	24.85	22.80	21.95	122.75	120.13	115.60
Control	101.30	96.08	90.30	15.55	12.13	10.58	85.75	83.95	79.73
CD (P=0.05)	12.55	7.77	7.87	4.36	2.10	2.91	9.58	8.15	7.13

Treatments	Non exchangeable – K			Lattice – K			Total – K		
	Soil depth (cm)								
	0–20	20–40	40–60	0–20	20–40	40–60	0–20	20–40	40–60
50%NPK	750	721	705	3933	3409	3132	4807	4249	3950
100%NPK	770	742	724	4035	3507	3421	4939	4375	4265
150%NPK	813	773	763	4353	3656	3447	5307	4567	4342
100%NPK+ FYM	885	818	786	4366	3756	3518	5398	4716	4441
Control	736	706	694	3856	3319	2848	4693	4121	3632
CD (P=0.05)	88	114	85	588	436	437	598	419	459

(Source: Annual Progress Report of AICRP on LTFE 2009 -10)

Crops sensitive to high amounts of KCl :-

- Tobacco, Grapes, Fruit trees, Cotton, Sugarcane, Potatoes, Tomatoes, Straw berries, Cucumber and Onion.
- KNO_3 also contains 13% N, is preferred fertilizer for spraying on fruit trees and horticultural crops.
- Schoenite (double salt of K & Mg) is a good source of K as MOP for groundnut, banana, rice, wheat and maize.

Potassium and crop quality :

Potassium has long been referred to as the quality nutrient. The quality effects are more closely linked to nutrient interactions such as N-K, than to absolute levels of K. Studies in India have shown that potassium increases the proportion of best quality grade tubers in potato, protein in cereals, oil content in oil seeds, total sugar, sucrose and vitamins etc. in fruits, sucrose content and extraction, sucrose

Researchers observed that the higher yield due to farmyard manure application may be due to additional nutrients supplied by it as well as improvement in physical and biological properties of soil. Similarly other workers showed that the application of recommended dose of NPK (100:50:40 for sorghum and 120:60:60 kg ha^{-1} for wheat) and 10 t FYM ha^{-1} recorded the highest grain and straw yield of sorghum and wheat and also improved available NPK and organic carbon content of soil.

The data of above table indicate that all forms of potassium decreased with depth due to the effect of different treatments. Maximum part was under lattice-k followed by non-exchangeable-k. The next in order was available-k and water soluble -k

Table 2 : Potassium uptake by different crops under field conditions

Crop	Botanical name	Yield (t ha^{-1})	Total uptake (kg Kha^{-1})
Wheat	*Triticum aestivum* L.	3.90	137
Rice	*Oryza sativa* L.	5.14	180
Chickpea	*Cicer arietium* L.	1.50	49
Pigeonpea	*Cajanus cajan*	1.20	16
Groundnut	*Arachis hypogaea*	2.54	95
Mustard	*Brassica juncea*	2.60	133
Soybean	*Glycine max* Merr.	2.50	101
Sunflower	*Helianthus annus* L.	2.38	141
Sugarcane	*Saccharum officinarum* L.	87.60	270
Tea	*Camellia spp.*	1.00	37
Tobacco	*Nicotiana tabacum* L.	2.85	65
Alfafa	*Medicago sativa* L.	91.90	669
Potato	*Solanum tuberosum* L.	29.50	119
Banana	*Musa paradisiacal* L.	38.00	1053
Pineapple	*Ananas sativa* Schuff	84.00	440
Papaya	*Carica papaya* L.	150.00	415

Source: Tandon (1991)

Factors affecting availability of potassium:

1. **Soil Texture:** The effect of texture on K status is more conspicuous in alluvial (Illite dominant) soils than in black (Smectite dominant) or red (Kaolinite dominant) soils because of the presence of K bearing minerals in the finer fraction of soil.

2. **Depth:** Calcareous alluvial soils show a decrease in both the available and non-exchangeable form with depth. In swell shrink (Vertisols / deep black) soils both available and reserved K decreased with depth. Indo-Gangetic plains show more available K in the surface soils while non-exchangeable K is more in the sub surface soil.

3. **Soil pH:** Soil pH has a significant role in the availability of potassium in soil. In acid soils, H^+ and hydroxy-aluminium ions compete with K ions for the exchange or adsorption sites and are able to keep more K^+ ions in the solution phase and reduce their susceptibility to fixation. As the pH increases the H^+ and hydroxy-aluminium ions are neutralized or removed, making it easier form of K^+ ions to move closer to soil colloidal surfaces where they become susceptible to fixation.

4. **Liming:** Liming of acid soils (with pH dependent negative charge) increases the cation exchange capacity (CEC) of soil which results in increased K adsorption by the soil colloids and a decrease in the K level in the soil solution.

Losses of potassium:

The losses of potassium may be due to luxury consumption, leaching and soil erosion.

1. **Luxury Consumption:** Some crops tend to absorb and accumulate potassium far in excess of their needs if it is present in sufficiently large quantities in the soil. This tendency is termed “luxury consumption”, because the excess K absorbed does not increase crop yields to any appreciable extent. Wasteful luxury consumption occurs especially with forage crops.

2. **Leaching losses of K:** Significant losses of applied K due to leaching occur mainly on sandy soils, organic soils and soils with kaolinite as the dominant clay minerals. On fine textured soils, the vertical movement of K in the profile is restricted. Since considerable amount of K adsorbed by soil colloids, leaching losses of this element normally do not result in yield loss except on very sandy soils. For some crops, split application of K is recommended under high leaching conditions.

3. **Soil erosion:** Soil erosion also leads to considerable loss of total potassium from the soil. The erosion losses of K are serious and generally exceed those of any other major nutrient elements.

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Biotechnology for Management of Biotic and Abiotic Stress for Sustainable Agriculture

Sharad Tiwari[1] and Sunil Kumar[2]

[1]Professor & Head
[2]Scientist
Biotechnology Centre
JN Krishi Vishwa Vidhyalaya, Jabalpur - 482004 (M.P.)

Introduction

Biotechnology is a set of tools that utilize living organisms or parts of organisms to make or modify products, to improve plants or animals for agriculture, or to engineer microorganisms for specific purposes. People have been doing this for centuries. Breeding livestock is one example. Another is using bacteria, yeast, and other living organisms to make such familiar foods as bread, cheese, beer, wine, sausage, pickles, and yogurt. Our understanding of biology and how to use it has grown tremendously over the last 200 years, and especially in the last 30 years. Scientists' greater understanding of life and its processes has enabled them to develop newer, more specialized techniques. These modern techniques using molecular biology have been labeled "biotechnology." Biotechnology promises to reduce world hunger and disease by improving local productivity by adapting crops to local climates and soils; increasing yield by making plants stronger and more pest-resistant; making plants more nutritious by creating plants with higher vitamin and protein content; and making produce more affordable on the world market.

Think of biotechnology as a scientific toolbox filled with many tools. Some of the tools developed in recent years include cell and tissue culture, embryo transplantation, microbial fermentation, and genetic engineering. Scientists use these tools to do many things. They make new food products. They breed improved plants and animals. They do research on how living systems interact, such as plants with insects and soil organisms.

Plants biotechnology research is now focused to make crop production more efficient. Scientists are working to develop crop varieties that can withstand environmental stresses such as drought, flood, frost, or extreme temperatures. A related area of research is adapting crops to regions where they are not normally grown because of climate, altitude, or rainfall.

Crop adaptability and productivity are limited by major abiotic stresses including drought, heat, frost, chilling, water logging, salinity and mineral toxicities. Although the type and the severity depend on the specific crop location, abiotic stresses can result in crop damages as high as those caused by biotic stresses. Furthermore, crops under abiotic stress are usually more susceptible to weeds, insects and diseases, which increase considerably the losses. Application of biotechnology approaches can contribute efficiently to solve or reduce these problems. Successful application of biotechnology to biotic/abiotic constraints will require both a good biological knowledge of the target species and the mechanisms underlying resistance/tolerance to these stresses. In this lecture, relevant advances in marker-assisted breeding, tissue culture, genetic transformation, and gene expression, including large-scale approaches and functional analyses will be presented and discussed as a way to overcome biotic and abiotic stresses in crops.

Crop production is greatly constrained by numerous biotic and abiotic stresses. Many of the diseases, pest and abiotic stresses are common to all crops; however, their incidence and importance vary according to the crop, management practices and regions. The major biotic stresses are fungal diseases, insects, nematodes, viruses, bacteria and parasitic weeds which drastically decrease crop production. Weeds are also a problem for all the crops but will not be covered here.

Abiotic stress is a broad term, which includes multiple stresses such as heat, chilling, excessive light, drought, water logging, wounding, ozone exposure, UV–B irradiation, osmotic shock and salinity. It has been estimated that only 10% of arable land can be classified under the non-stress category, which implies that crops grown on the other 90% of arable lands experience one or more environmental stresses. Some of these stresses like drought, extreme temperature, and high salinity dramatically limit crop productivity. The prediction is that water deficits will continue to be the major abiotic factor likely to affect crop yields globally.

To face the threat represented by these stresses several genetic improvement strategies are available, from classical breeding to a more direct physiological genetic approach. However, only with an understanding of the mechanisms underlying a specific stress, will the later strategy be feasible. In general for the stresses mentioned above, low yields in developing countries are primarily due to a lack of effective disease management practices, particularly the availability of disease-resistant cultivars. Moreover excessive and often inappropriate fungicide usage in many situations can contribute to higher input costs, human health problems and contamination of water supplies and the environment. In this context, biotechnology is a powerful tool that has potential to contribute to sustainable agriculture. Biotechnology approaches such as marker assisted breeding, tissues cultures, in vitro mutagenesis, and genetic transformation can contribute to speed up classical breeding and overcome major problems such as lack of natural sources of resistance/tolerance.

Molecular marker-assisted breeding

The use of genetic and genomic analysis to help identify DNA regions tightly linked to agronomic traits in crops, the so-called molecular markers, can facilitate breeding strategies for crop improvement. The use of molecular markers for the indirect selection of improved crops speeds up the selection process by alleviating time-consuming approaches of direct screening under greenhouse and field conditions. Molecular markers are particularly useful when targeting characters controlled by several genes. The potential to map different Quantitative Trait Loci (QTL) contributing to an agronomical trait and to identify linked molecular markers opens up the possibility to transfer simultaneously several QTLs and to pyramid QTLs for several agronomical traits in one improved cultivar.

Numerous molecular marker-related techniques have been used in relation to biotic and abiotic stresses. Random Amplified Polymorphism (RAPD), Restriction Fragment Length Polymorphism (RFLP), Amplified Fragment Length Polymorphism (AFLP), Simple Sequence Repeat (SSR) and derivatives have been reported both for biotic and abiotic stresses. As a result, genetic maps for many species were established in which potential resistance and/or tolerance loci or QTLs have been located. This improved the knowledge of the genetic control of specific resistance and/or tolerance in many crops by providing information on the number, chromosomal location and individual or interactive effects of the QTLs involved. More importantly, these technologies have identified specific molecular markers that may be used in breeding programs through Marker-Assisted Selection (MAS) to enhance stress tolerance.

However, the application of molecular markers in breeding programs requires preliminary studies to identify and validate potential markers. In this process, the following factors have to be considered: (a) level of polymorphism existing between parental lines, (b) unclear expression of some markers inherent to the marker class used, (c) false-positive markers, (d) discrepancy between the presence of the marker and target gene, which requires testing the gene with conventional screening and (e) presence of multiple genes scattered over several linkage groups (Yu et al., 2004).

Although the use of MAS may be helpful for crop improvement, its practical application for the genetic improvement of resistance/tolerance to stress has been limited, being mainly hampered by lack of investment and the genetic complexity of most stress-related traits. There are some exceptions where MAS has already facilitated breeding efforts for several crops against important biotic stress.

Gene pyramiding assisted by MAS

Breeding durable resistance to biotic and/or abiotic stresses is a major task for plant breeders and pyramiding different resistance or tolerance genes into a genotype is one way of achieving this. There are numerous examples of introgression and pyramiding of favourable alleles and QTLs. However, only in a few cases has MAS been used to assist in gene pyramiding to overcome stresses. The general knowledge of abiotic stress QTLs in most of the crops is still at an early stage so that gene pyramiding has not been applied yet. Nevertheless, cultivars having appropriate combinations of resistance and/or tolerance to biotic and abiotic stresses, achieved through gene pyramiding, could provide durable resistance, and MAS can be a valuable tool to guide and identify the pyramiding of these genes. It is also important to validate the results with resistance or tolerance tests, due to the possibility of gene mutations, background effects, recombinants and adverse interactions among resistance genes that can occur during breeding programs and influence the expected phenotype. In addition, combining molecular markers with other technologies may improve the efficiency of MAS. Moreover, the use of the information generated by gene expression experiments may help to improve MAS. Gene expression analysis helps to increase the understanding of the molecular basis of stress resistance in plants. Generation of markers based on genes with altered expression patterns in response to stresses, could result in more effective and targeted MAS. Some of these genes are described in the gene expression section and may be good candidates for future MAS studies.

Tissue culture

In vitro regeneration is a major constraint in transgenic plant production for many crops, since advances in molecular genetics, e.g. gene over-expression, gene suppression, promoter analysis and T-DNA tagging, require efficient transformation systems. Efficient tissue culture is therefore a vital step, required for both the validation and exploitation of data generated by these powerful molecular tools. Implementation of robust protocols for regeneration is therefore a necessary condition for both genetic transformation and other tissue-culture derived techniques to generate genetic diversity such as somaclonal variation, in vitro mutagenesis, doubled haploids culture, and wide hybridization.

Somaclonal variation and in vitro mutagenesis: Tissue culture generates a wide range of genetic variation in plants, which can be incorporated in plant breeding programmes. It is well known that somaclonal variation involving callus cultivation and somatic embryogenesis has the capacity to generate genetic variation. The possibility of producing agronomically useful somaclones via organogenesis and somatic embryogenesis has already been reported in many crops. These variations are not desirable for some applications such as genetic transformation or massive micropropagation, but can be useful for breeding. These techniques, separately or combined with chemical or physical mutagenesis, generate diversity, which is a major breeding goal.

In vitro mutagenesis strategies such as treatment with ethyl-methane-sulphonate (EMS), fast neutron radiation and insertional mutagenesis have been applied in plant breeding. These methods induce point mutations, deletions, or insertions, respectively and have been useful in breeding for biotic and abiotic stress. Indeed, combining mutagenesis techniques with MAS through TILLING as described later will make mutagenesis more attractive and applicable for crop improvement. The major difficulty with these techniques is the high quantity of individuals required to find the desired trait. Nevertheless, by using *in vitro* selection systems this disadvantage can be minimized.

In vitro selection: In vitro selection has been used for both biotic and abiotic stress. The best-studied biotic stresses have been fungal diseases, using toxins or filtrate culture as selective agents. In vitro selection resulted in the isolation of resistant lines in many crops for various diseases. Salinity is the main abiotic stress that has been addressed by in vitro selection, although applications to other stresses, such as zinc tolerance, have also been reported. Currently, these techniques are considered to be an important complement to classical breeding methods. This system can also be coupled to other approaches in addition to somaclonal variation. Putative stress-resistant lines derived from both conventional breeding and transgenic approaches could be screened using in vitro selection. This is particularly attractive for some abiotic stresses, where appropriate screening methods are unavailable or have low efficiency. Although the advantages of the recent high-throughput technologies, coupled with genetic transformation, are emerging as attractive approaches, somaclonal variation and in vitro mutagenesis following by in vitro selection offers an alternative way for breeding.

Double haploids and wide hybridization: Doubled haploid (DH) technology refers to the use of the microspore or anther cultures to obtain haploid embryos. This technology offers breeders a tool for the rapid production of homozygous lines. These homozygous lines can be multiplied and released as cultivars, or used as recombinant inbred lines for molecular mapping and/or in breeding programs. An efficient DH production technology can greatly reduce the time and costs of cultivar development and many crop varieties have been produced with this technology.

Successful application of DH technology in the near future would be a major achievement. However as not all homozygous lines are of interest, the coupling of DH and MAS technology will be more efficient to select individuals carrying desirable traits.

Wide hybridization depends on various factors, and can be as wide as one can make them. Stress-related characters available in wild germplasm could be introgressed into economic target species through improved wide hybridization techniques such as embryo rescue and protoplast fusion. Efficient embryo rescue has allowed the production of interspecific hybrids in many crop species. Protoplast fusion also has potential applications for crop improvement by overcoming sexual incompatibility or reproductive barriers, and by generating novel combinations of nuclear and/or cytoplasmic genomes. Intergeneric somatic hybrid plants between sexually incompatible species have also been reported in many crop species. Despite the potential of this technique, limited efforts have been applied to overcome stresses. Nevertheless, the successful transference of resistance or tolerance achieved in many crops to biotic and abiotic stresses together with advances in tissue culture should encourage breeders to exploit somatic hybrids. For an excellent overview of advances on intergeneric somatic hybridization and its application to crop genetic improvement see Liu et al. (2005).

Genetic transformation

Crop improvement through genetic engineering has become a reality. It is now possible to transform many crop plants although in some cases the rate of recovery of transgenic lines is still low. The use of *Agrobacterium tumefaciens* as a vector for transformation was an important breakthrough. Both micro-particle bombardment and A. tumefaciens have been used for DNA delivery into either embryogenic or organogenic cultures. Transformation has been generally based on infection by A. tumefaciens, although A. rhizogenes is also used for transformation of some species to produce composite plants with hairy roots or hairy root cultures. The inserted DNA can be either a specific gene with a specific biochemical function, a regulatory gene that controls a network of other genes, or multiple genes to generate long-term durable resistance. A number of cultivars have been transformed in order to enhance the resistance to biotic stresses. Abiotic stresses generally involve perturbation of various cellular functions and activation of complex metabolic pathways, and are conferred by polygenic traits. This complexity together with the lack of good sources of natural tolerance makes this an area that is not readily amenable for conventional breeding strategies. In plants there is a poor understanding of most abiotic stress responses. Thus, the successful use of genetic transformation requires a better physiological and molecular understanding of these stresses. Recent progress achieved in plants supports the potential use of transgenic approaches to produce tolerant lines.

Genetic transformation is an attractive approach to overcome stresses. As we know many transgenics are now are commercially used for biotic stress carrying the insect resistance *cry* gene from *B. thuringiensis*. However, a low number of GE crops developed so far has been influenced by technical (regeneration recalcitrance of most crops), social (public concern issues) and political reasons. However, the advances in transformation protocols should see an increase in the production of genetically modified crops.

Gene expression

As already mentioned, the efficiency of both MAS and transgenic approaches can be improved by using the information from gene expression studies. Understanding the mechanisms employed by plants to defend themselves against stresses and a more complete knowledge about the genes involved, will allow a more precise use of MAS and transgenics. Sequence information, while valuable and a necessary starting point, is insufficient to answer questions concerning gene function, regulatory networks and the biochemical pathways activated in response to stresses. To address these questions, more comprehensive approaches, including quantitative and qualitative analyses of gene expression products, are necessary at the transcriptomic, proteomic, and metabolomic levels.

Transcriptomics: An important step in the control of stress responses in plants is the transcriptional activation or repression of genes. Thus, identification of differentially expressed genes is particularly important to understand stresses response in plants. To achieve this objective, tools such as microarrays. Suppression subtractive hybridization library, serial analysis of gene expression and quantitative measurement of transcription factor expression patterns have been developed in addition to older techniques such as Northern blotting. Gene expression patterns following biotic stresses have been more extensively studied than those following abiotic stresses. Large-scale analyses of gene expression patterns in response to pathogens have revealed the differential expression of large numbers of genes. Known defense gene families are usually expressed differentially in these studies independent of the specific host-pathogen interaction being investigated. The coupling of these powerful large-scale gene expression profiling methods with recombinant inbred lines or near isogenic lines that differ in susceptibility/resistance to key pathogen and pests will greatly facilitate a more comprehensive understanding of genes involved in the defense response to specific biotic stresses.

With respect to abiotic stress, gene expression analyses have been mainly based on studies with cloned genes. Other work has shown that transcriptomic tools are also a good option for breeding to environmental stresses. Extensive expression studies have been performed in some crops like Arabidopsis, and the resulting knowledge can also be used in other crops through comparative genomics.

Transcription factors: Transcription factors are proteins that play an important role in controlling the expression of genes in most biochemical pathways including the response to stress. Genomics studies over the last few years have identified numerous TFs (mainly in Arabidopsis) and revealed a high degree of complexity and overlap in the transcriptional regulation of gene expression in response to many stresses. The understanding of the role of TF may open new avenues for improving resistance or tolerance to stresses. A given TF can mediate the response to various stresses. This characteristic makes the TFs especially attractive for genetic transformation, because a single TF gene can result in resistance or tolerance to various stresses. On the other hand, attempts to knockout specific TFs have often not resulted in any obvious phenotypes, perhaps due to overlapping function. Thus, use of TFs for genetic improvement requires a comprehensive knowledge of their biological functions.

Proteomics: In parallel to the accumulation of a wealth of genomic and transcriptomic data, recent technological developments have allowed the establishment of valuable methods for quantitative and qualitative protein profiling. This approach is very important in evaluating stress-responses because mRNA levels do not always correlate with protein accumulation. Indeed, large differences in protein turnover and post-translational modifications may lead to large variations between transcriptomics and proteomic data. Thus, protein studies are needed to provide information on their levels and activities. To this purpose, proteomic based techniques that allow large-scale protein profiling are powerful tools for the identification of proteins involved in stress-responses in plants. Extensive studies have evaluated changes in protein levels in plant tissues in response to stresses. Although further studies are needed to determine exact function of genes in stress-response, these genes could be promising candidates for genetic transformation and/or MAS approaches.

Metabolomics: Transcriptomic and proteomic data are important steps in deciphering a complex biological process, but they are still insufficient to understand them fully since most biological processes are ultimately mediated by cell metabolites. Alternative mRNA splicing, protein turnover rates and post-translational modifications that modulate protein activity imply that changes in the transcriptome or proteome do not always correspond to alterations in the cell metabolome. Therefore, the only way to the complete understanding of both gene function and molecular events controlling complex plant processes is to analyze in parallel the transcriptome, the proteome and the metabolome in an integrative manner. Although large-scale, comprehensive metabolomic studies are difficult, a number of targeted analyses have been performed to assess the involvement of subsets of metabolites in various stresses. Most studies on plant stress responses focused on flavonoid and isoflavonoid phytoalexins.

Large-scale analysis by using different “omics” technologies are providing extensive data sets that will help identify potential candidate genes for an increase in intrinsic resistance and/or tolerance levels in important crops. Identification of these candidate genes, may allow their direct application in crop improvement through MAS, or genetic engineering. However, in most cases, the roles of these candidate genes remain unknown and it will be important to carry out functional studies as a preliminary step towards their use in genetic improvement.

Functional analysis

To date the completion of the Arabidopsis and rice genomes have been achieved and the genome of other plant sequencing projects is underway. The traditional pursuit of a gene starting with a phenotype (forward genetics), has given way to the opposite situation where the gene sequences are known but not their functions. The challenge is now to decipher the function of the thousands of genes identified by genome projects, and reverse genetics methodologies are key tools in this endeavour.

The ability to knockout genes or suppress their expression are powerful tools to determine the function of a gene. This can be done by anti-sense RNA suppression, targeted gene replacement, insertional mutagenesis, gene silencing and targeted-induced local lesion in genome (TILLING) approaches. Anti-sense RNA suppression requires considerable effort for any given target gene before even knowing whether it will be successful and targeted gene replacement i.e. via homologous recombination has not yet been reproducibly achieved for higher plants. Collections of random T-DNA or transposable element insertion mutants are currently available. Researchers have developed different RNA silencing strategies as tools for selective knockout of targeted genes. Despite the successes of this technique in several species, RNA silencing has several drawbacks, i.e. phenotypic instability in later generations and the requirement for a reliable plant transformation system. RNA silencing is believed to be a natural plant defense against viruses. Following this principle, another technique, Virus-induced gene silencing (VIGS), has been developed to suppress plant gene expression through infection with virus vectors that harbour a target region of the host gene.

The limitations of RNA silencing or insertational mutagenesis, previously stated, can be overcome by TILLING. This technique combines chemical mutagenesis with a powerful screening method for potential mutations. The generation of phenotypic variants without introducing foreign DNA in the plant makes TILLING very suitable not only for functional analysis, but also for agricultural applications.

The TILLING facility for collection of mutants is available at various advanced centers. The diversity of species for which this technique will be available, opens up new possibilities for researchers both for the functional analysis of genes previously identified by the “omic” technologies, as well as the generations of new varieties.

Conclusions

Over the years biotechnology has emerged as a promising tool to overcome stresses in plants, but to date, progress has been limited leave some important crops. The current advances in tissue-derived techniques, genetic transformation and MAS, together with the advances in powerful new ‘omic’ technologies offer great potential to improve this situation. Indeed, it is now possible to target almost all crops with a variety of biotechnological approaches for genetic improvement. As such, the more efficient regeneration protocols recently established should encourage researchers to resume the use of techniques such as DH, wide hybridization and mutagenesis in breeding programmes frequently. On the other hand, crops without appropriate regeneration protocols may also be improved by mutagenesis through TILLING. It is important to provide breeders with the broadest variety of biotechnology tools as possible since each stress-crop case has its own particularities and so would need one or a combination of specific biotechnological approach(es) to tackle them efficiently. Strategies such as resistance gene pyramiding assisted by MAS could be useful to overcome resistance breakdown. Although the advances in biotechnology greatly facilitate crop improvement, a more comprehensive knowledge of resistance or tolerance mechanisms is required to direct breeding. Indeed, only a better understanding of the underlying mechanisms activated in response to stresses will allow an efficient application of biotechnology in sustainable agriculture. The advent of the ‘omic’ technologies together with the functional genomic tools is a promising approach to achieve this.

The integration of knowledge generated by the different approaches described here, should lead to more accurate and efficient breeding of key crops. In the case of genetic engineering, this would not only allow the targeting of transgene expression to particular conditions (e.g using stress-responsive or tissue-specific promoters), but also monitoring the effect of the transgene (e.g. by proteomic and metabolomic approaches). Additionally, researchers dealing with others strategies such as MAS or even classical breeding will be able to take advantage of the results being gathered from “omic” technologies. However, the delivery of “omic” information should be done in a friendlier mode for plant breeders in order to facilitate its efficient application in genetic improvement. Overall, for biotechnology to fulfill its potential for plant breeding there needs to be good and regular communication between classical breeders and biotechnologists to firstly, make sure that the tools of biotechnology are applied to the most pressing and appropriate problems and secondly, to ensure that pathways for delivery/uptake into breeding programs are in place.

Persistence of Herbicides Residues in Soil, Water and Food Chain

Shobha Sondhia

Senior Scientist
Directorate of Weed Science Research
Jabalpur-482004 (M.P.)

Introduction

The present day agriculture can be considered sustainable if it ensures that today's developments are not at the cost of tomorrow's prospects. Weeds cause enormous yield losses if present in cropped condition. Apart from yield loss; weeds causing great disturbance of the local biodiversity and creating potential threat to ecology due to their competitiveness, production of large number of seeds, seed dormancy and production of allelochemicals. Over the years herbicides have emerged as an important tool in the management of weeds. Rate of use of herbicides in India is increasing due to several reasons such as increasing labour cost and to control weeds in crop and non-crop area; thus herbicides become effective and efficient tools to deal with these critical issues. Herbicides represent a large chemistry with many chemical classes to control variety of weeds. Due to intensive research in herbicide discovery and mode of action of herbicides, many new molecules are available to cater the farmers need. Isoproturon, sulfosulfuron and metsulfuron are giving promising results in wheat crop. Similarly butachlor, anilofos, pretilachlor and new breed of chemical such as fenoxaprop are controlling weeds of rice field. Pendimethalin, fluchloralin and alachlor which are taking care of weeds of leguminous crops are some of the classical examples.

At present nearly 400 herbicides are available worldwide for weed control. With the discovery and development of 2, 4-D as a herbicide following IInd World War, there has been a phenomenal growth in development of new molecules as herbicides. Triazines (1956), carbamates (1954-58), ureas (1960), toludine (1965), amides (1966), diphenyl ethers (1970) and diazines (1974) were introduced. Trifluralin and fluchloralin were particularly useful in a wide variety of crops. Dual action herbicides like pendimethalin were introduced during 1980's. Now sulfonylurea group herbicides are more selective and effective at very low application rates of few grams per hectare. At present the world consumption of herbicides is 36 % followed by the insecticides (25 %), fungicides (10 %) and others (29 %). Herbicide use has increased to 30 % during the last 10 years in managing weeds in the country. Excessive and repeated use of herbicides may pose problems such as phytotoxicity to crop plants, residual effect on susceptible inter-crops or succeeding crops or non-targets organisms and ultimately health hazards due to accumulation of residues in the soil, crop produce and ground water. Many herbicides are found as bound residues which make them not only unavailable to the targets but also polluting the soil ecosystem in a number of ways. As herbicides are necessary for weed management and to achieve maximum yield, thus role of herbicides becomes significant in soil, water and food chain.

Fate and Persistence of Herbicides an the Soil

As soon as a herbicide is applied a number of processes immediately begin to remove the compound from the original site of application. For the herbicide which is intercepted by plants, the chemicals may be taken up by the plant itself may be washed off by precipitation onto the soil, may undergo photodegradation on plant surface or may volatile back into the air. Herbicides persistence in the soil is expressed as half life or time required to degradates fifty percent of the original molecule (Table 1). However the half life is not absolute because it depends on the soil type, temperature, and concentration of the herbicide applied. The persistence varies with the nature of a chemical, soil properties and climatic conditions. The herbicide should persist long enough to check weeds until the end of critical period of weed competition but should not persist beyond the crop harvest, as it would be injurious to the sensitive crops grown in rotation. Very rapid loss of herbicides from soil will cause insufficient weed control, which is considered as unsatisfactory as their unduly long persistence within soil. Beside herbicides structure, soil conditions prevailing during and after the application of a herbicide as well as herbicide application methods influence the fate of the herbicides in the soil. Heavy rainfall in monsoon will cause greater leaching and runoff. Sandy soil would have a higher leaching potential than a clay soil due to larger pore spaces and lower CEC (Sondhia and Yaduraju 2005) .Higher humidity enhances the soil microflora proliferation. Similarly the persistence of herbicides in dry soil is greater as compared in wet soil.

Table 1: Half-lives of some herbicides in soil

Herbicides name	Half lives (Days)	Herbicides name	Half lives (Days)
Atrazine	13-58	Metribuzin	23-49
Butachlor	5-24	Metolachlor	8-27
Fluazifop-p-ethyl	8-24	Oxyfluorfen	19-29
Fluchloralin	12-13	Pendimethalin	15-77
Imazethapyr	57-71	Sulfosulfuron	3-8
Isoproturon	13-21	2, 4 D	7-22

**Source: (Sondhia 2007)*

A herbicide is said to be persistent when it may be found to exist in soil in its original or a closely related but phytotoxic form longer than one crop season after its original application (Sondhia 2005). Herbicide residues in crop produce above the safe level can cause health hazards to man and animal (Table 2). Ultimate fate of herbicide in soil depends on number of processes such as volatilization, leaching, runoff and degradation by microbes, chemical processes and photodecomposition

Table 2. Residues of some important herbicides in the soil, food grain and straw

Herbicides	Crop	Dose (g/ha)	Residues*		
			Soil	Grains	Straw
Butachlor	Rice	1000	0.005	0.012	0.029
Sulfosulfuron	wheat	25	BDL**	0.010	0.004
Fenoxaprop-p	Wheat	100	0.089	0.0024	0.0013
Metsulfuron-methyl	Rice	4	BDL	BDL	BDL
	Wheat	4-8	BDL	BDL	BDL
Isoproturon	Wheat	1000	0.032	0.035	0.065
Oxyfluorfen	Rice	150-250	BDL	BDL	BDL
Imazethapyr	Soybean	100	0.016	0.210	BDL
Imazosulfuron	Rice	30-40	BDL	BDL	BDL
		50-60	BDL	0.006-0.009	0.009-0.039

**Source: (Sondhia 2007),*

**BDL-Below detection limit

Effect of Herbicides on Microflora and Fauna

Nowadays soil health and microbial diversity have become vital issues for the sustainable agriculture. Loss of microbial biodiversity can affect the functional stability of the soil microbial community and soil health. Generally, negative effects of herbicides on the population level or composition of species are decreased for a while but subsequently improves. Beneficial organism known to be affected negatively by specific herbicides includes nitrogen fixing bacteria (Rhizobium) and some mycorhizal fungi. Actinomycetes are relatively resistant to herbicides and affected at high concentration only. Fungi are probably the more sensitive to the majority of herbicides than are bacteria.

Apart from soil microflora, herbicide may have adverse or stimulatory effects on some beneficial soil fauna. Earthworms are perhaps the most important soil organisms in terms of their influence on organic matter breakdown, soil structural development, and nutrient cycling, especially in productive ecosystems. Isoproturon did not cause lethal effects at 1.4 g/kg soil on mature earthworm (*Lumbricus terrestris* L.) after 60 days.

Effect of herbicides on succeeding crop

Herbicide persistence in soil may injure succeeding crop. From example, injury to pea from sulfosulfuron is noted in field treated with sulfosulfuron in the previous year (Sondhia and Singhai 2006). Several substituted ureas, sulphonylureas, dichlobencil and 2, 3, 6-TBA often pose phytotoxic residues problems on crop land. Even a short residue herbicide like glyphosate has been reported to damage tomato transplants (Cornish, 1992). Sometimes non-phytotoxic residues of previously applied herbicides may damage the rotation crop by interacting with the herbicide applied to the present crop.

Most of the herbicides are absorbed through plant roots and underground absorptive sites besides they undergo number of degradation processes. At the recommended dose of herbicide application the problem may not arise and they selectively kill the weeds. But when the dose is more than the recommend rates that happens due to indiscriminative use and improper calibration and method of application, there is possibility of residual hazards in soil particularly in persistent herbicides such as triazines and uracils. Repeated application of the same herbicides in a mono crop sequence may cause accumulation of residues in soil, which in turn will affect the sensitive crops. Leaching of herbicides can cause crop injury due to transport of herbicide into the absorption zone of susceptible crop plants and accumulation of herbicides in toxic level in tolerant crop plants.

In some experiments it was found that pre-emergence herbicides such as thiobencarb, butachlor, pretilachlor and anilofos applied at recommended doses continuously for four seasons in rice crop did not influence the germination and yield of urdbean raised subsequently (Balasubramanian *et al.*, 1999). Pretilachlor at 0.50 to 1.00 kg /ha, 2, 4-D at 1.50 to 2.50 kg/ha, anilofos 0.40, to 0.60 kg/ha and pendimethalin 1.50 to 2.00 kg/ha applied as pre-emergence to transplanted rice did not affect succeeding wheat and peas crops but cucumber germination was reduced by 28 % in 2.5 kg/ha dose but 2, 4-D showed a greater level of persistence in soil (Gupta *et al*., 2000). Sulfosulfuron applied at 25, 50 and 100 g/ha in wheat crop did not show any adverse effect on succeeding maize and sorghum crop however significantly affected the growth of lentil and pea (Sondhia and Singhai 2008). Toxic and nontoxic effects of some important herbicides are given in Table 3.

0.069 and 0.028 ppm residues in pond and canal water, respectively. 2,4-D increased pH, EC, carbonates and free CO_2 increased after treatment at 1.0 and 2.0 ppm dose but the dissolved oxygen decreased and the 2, 4 -D residues become non-detectable after 42 days.

Monitoring of butachlor residues at 0.75 kg/ha application rate in underground water and drainage water system revealed that butachlor could not result in residues at harvest in the underground water sample in rice-rice system.

Table 3. Effect of some important herbicides on succeeding crop

Crop	Herbicides	Dose (Kg/ha)	Toxic	Nontoxic	Reference
Wheat	Sulfosulfuron	0.25-100	Pea, lentil	Sorghum, maize	Sondhia and Singhai (2008)
Wheat	Pendimethalin	1-1.5	-	Sorghum	Kulshrestha and Yaduraju, (1987)
Sorghum	Atrazine	0.25-1.0	-	Fingermillet Cotton	Jayakumar (1987)
Cotton	Fluchloralin Oxadiazon Oxyfluorfen Pendimethalin	1.0 0.5-1.5 0.1-0.2 1.25	Cucumber	Fingermillet Foxtail millet Mungbean	Jayakumar *et al.* (1988)
Sunflower	Fluchloralin Butachlor Alachlor Pendimethalin	1.0 1.0 1.0 1.0	Mungbean	Groundnut Cowpea Cucumber	Basavarajappa and Nanjappa (1994)

Herbicide Residues in water system

With the increasing use of herbicides for weed control, the applied herbicide may find it way into streams and underground water sources by run off and leaching mechanism. Many herbicides are routinely detected from the surface and ground water sources in developed countries like, USA, New Zealand, Australia, Canada, Japan and European countries. The most often detected herbicides above the prescribed maximum residues limits are 2, 4-D, atrazine, cyanazine, carbaryl, simazine, bromacil, diuron, Diazinon, prometon, metolachlor, dinoseb, picloram, metribuzin, metsulfuron, glyphosate, metolachlor, propanil, butachlor, pendimethalin, oxyfluorfen etc. Many herbicides are strictly banned or restricted such as butachlor, atrazine, pendimethalin, and paraquat in USA, and European countries due to their high concentration in the ground and surface water and potential heath hazards to aquatic, animal and human lives.

The studies conducted at AICRP weed control in water system revealed that butachlor residues were ranged between 0.001 to 0.093 ppm in the water of rice field at Banglore. Residues of paraquat were not detected after 20 days at 0.80 kg/ha application rate to control Eichornia but application of 1.8 kg/ha showed

2, 4-D residues at lower level than the acceptable daily intake (0.01 mg per kg body weight) were detected in fish samples in KAU, Thrissur at recommended rate of application of 2, 4-D (1.0 kg/ha) at all the sampling interval and therefore 2, 4-D at1.0 kg/ha application rate considered as safe for consumption and if 2, 4-D is applied as higher dose viz 2.0 or 4.0 kg/ha waiting period of more than 4 month is suggested. Paraquat residues in the fish samples were also detected below the acceptable daily intake of 0.002 mg per kg body weight. It is reported that only 0.80 to 1.11 % of the applied paraquat remained in the sediment fraction however paraquat at 0.8, 1.6 and 3.2 kg/ha application rates increased the pH and electrical conductivity of water. Ground water collected from tube wells of Hisar district where isoproturon in rice-wheat cropping system was being applied at recommended dose of 0.94 kg/ha for many years. It is reported that isoproturon residues were not present in the ground water in all the water samples collected from different districts.

Conclusion

In India use of herbicides is increasing at a faster rate as compared to other pesticides. Newer molecules are added each year. Due to environmental and health concern, the regulatory requirements have been made longer. Herbicides have lower residue concern than other pesticides in view of their lower mammalian toxicity. Further contrary to other pesticides, herbicides are applied at planting or during early stages of crop growth, thus giving more time for degradation of the chemical in the plant and environment. Further the soil and climate conditions prevalent in the country enable faster degradation of the chemical. The fate of herbicides in the soil is a concern of many segments of society. The soil acts as an important buffer governing the persistence and fate of most herbicides in the environment. As long as soil system remains healthy, possible adverse effect from herbicides in the environment probably can be minimized. Herbicides in most instances when applied at recommended doses have not been detected in food chain or in soil at level that should cause concern.

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Sustainable Agriculture: Economic Inferences

Sunil Nahatkar

Principal Scientist
Directorate of Research Services
J. N. Krishi Vishwa Vidhyalaya, Jabalpur – 482004 (M.P.)
sbnahatkar@hotmail.com

A land based production system that is natural resources driven e.g. land, biological resources, atmosphere and water and human resources is referred as agriculture system. Sustainability and agricultural based economic growth is the two sides of the same coin because without sustainability, steady economic growth can not be achieved. The theories of role of agricultural in economic growth that stress: the passive role of agriculture as supplier of resources (Lewis & Rains, 1950-60), especially raw materials and labour and the active role of agriculture as a sector that is able to promote economic growth (Mellor- 1970-90) for Income generation, poverty reduction and food security are dominant up to 90th. The active role of agriculture as a sector that is able to promote sustainable economic growth (FAO, 2000) as product contributor, market contributor, factor contributor and trade promoter was emphasis on technology and growth, represents a productionist vision of sustainability, with economics the key focal point. Technology driven economic growth through sustained innovation and trade is the envisaged pathway, providing transitions out of agriculture or a shift of subsistence oriented old agriculture to a modern, commercial, new form of agriculture, with wider poverty reduction aims achieved through trickle down and employment benefits from improved agriculture led growth. This reflects towards clear goal of economic development policy as to raise living standards, providing steadily more goods and services to expanding population. The original emphasis in different growth theories was on promoting more productive agriculture. These apprehensions raise important questions about whether the forms of agriculture developed over the past century, and celebrated as technically advanced and modern, are able to respond to the complex and diverse array of challenges they will encounter in the 21st century?

Environmental pollution, a direct consequence of "economic development", is degrading the long run productivity of land, water, and air resources. Human population pressures are destroying other biological species, upon which the survival of humanity may be ultimately dependent. The current rate of species extinction is unprecedented -- except possibly during geologic events now characterized as global disasters. The human species is now capable of destroying almost everything that makes up the biosphere we call Earth, including humanity itself.

India has also witnessed a paradigm shift in food security, moving from a food deficit to a food surplus nation through big take off in agricultural production. Food grain production in India increased from 51 million tons (1950-51) to 196.81 million tons in 2000-01 and further spectacular growth in production of food grain was witnessed with the production of 235.88 million tons (2010-11); highest ever in the history of Indian economy. In the last 60 years, food grain production increased by 185 million tons (3 million t / year). A growth of 355 per cent in production with only 24 per cent increase in area was achieved through intensification of agriculture. But in next 40 years (2050-51) the food grain requirement in the country was projected at 450 million tons. Therefore, in next 40 years, food grain production required to be increased by 220 million tons, about 4.5 million tons per annum. But there are many constrains to further growth in agricultural production these are as follows:

Constraints:

Land - Limited & retorting

Water - Scarce and depleting

Forest - depleting

While:

Population - increasing,

Demand for food - rising and

Aspiration – enlarging

Supports:

Farm families - 120 million

Intensification of agriculture in developed as well as in developing countries resulted in:

- Loss of productivity due to soil erosion and degradation of land;
- Non-judicious use of agro-chemicals particularly pesticides and fertilizers;
- Pollution of surface and ground water due to bad agricultural practices and inputs;

- Diminishing supply of non-renewable energy sources;
- Decreased farm income owing to low commodity prices and increased production costs and lastly .
- Loss of ethics and values

It is expected that if the current practice of exploitative management of natural resources and low productivity of agriculture continue, a child born today has less chance of getting adequate food to eat, enough space to live, less clean water to drink and less of pure air to breathe in the years ahead. The growing awareness of these challenges to traditional development thinking has led to the increasingly wide acceptance of a new concept- that of sustainable development. Besides this, due to diversion of agricultural land to infrastructure development and urbanization; area for food grains production decrease and this may adversely affect the sustainability of life on the earth which is already being threatened due to environmental degradation. In addition, haphazard planning, lack of political will, lack of international support to develop clean technologies and many others further added to unsustainable production. Scarcity is the villain; it causes tension and unrest. Thomas Malthus expresses his concern about the human capacity to achieve a balance between population growth and the rate of growth in food production long back (1798) in his *Essay on Population.* Those who are concerned about sustainability "believe" we must find better ways of utilizing our natural and social resource bases in order to sustain human progress on earth. They believe these resources are finite, and thus, ultimately will limit growth in human consumption. They reject the belief that science and technology will yield substitutes for depleted resources, including extinct biotic life forms. They reject the belief that fundamental laws of nature ultimately can be repealed through human ingenuity.

Sustainable development: "Sustainable development is development which meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987 in Our Common Future). Sustainable development means development which protects the environment and leads to development which advanced social justice. The notion of sustainable development lies in the progress towards economic, social and environmental objectives.

Economic: An economically sustainable system must be able to produce goods and services on a continuing basis, to maintain manageable level of government and external debt, and to avoid extreme sectoral imbalances which damage agricultural or industrial production. Besides this, promotion of economic growth and encouragement of an open, competitive economy is a major economic objective of sustainable development.

Environmental: Must maintain a stable resource base, avoiding over exploitation of renewable resource systems and judicious use of non-renewable resources. This includes maintenance of biodiversity, atmospheric stability, and other ecosystem functions not in general classed as economic resources.

Social: A socially sustainable system must achieve distributional equity, adequate provision of social services including health and education, gender equity, and political accountability and participants. The principal of sustainable development are described as social progress that recognizes the needs of everyone; effective protection of the environment; prudent use of natural resources; and maintenance of high and stable levels of economic growth and employment.

Therefore, sustainability can be viewed as:

- Concept that must remedy social inequalities and environmental damage, while maintaining a sound economic base.
- The conservation of natural resources is essential for sustainable economic production and intergeneration equity.
- From an ecological perspective, both population and total resource demand must be limited in scale, and the integrity of ecosystem and diversity of species must be maintained.

Thus, goal of sustainability is to ensure opportunity for a desirable "quality of life" for those of the current generation and of all generations to follow. Quality of life has inseparable ecological, social, and economic dimension. Over the long run, systems cannot be ecologically sound unless they are also economically viable and socially responsible, they cannot be economically viable unless they are also ecologically sound and socially responsible and they cannot be socially responsible unless they are also economically viable and ecologically sound. All are necessary and none, alone or in pairs, is sufficient to ensure sustainability. All three are essential dimensions of the goal of sustainability.

Looking to the dimensions the objectives of the sustainable development include:

- Reviving growth
- Changing the quality of growth

- Meeting essential needs for jobs, food, energy, water. Sanitation
- Conserving and enhancing the resource base.
- Reorienting technology and managing risks
- Merging the environment and economics in decision making

Although following pertinent questions arises in the mind when we think about sustainability:

What is to be sustained? -- Development of resources: natural, human, and economic.

What is the purpose of development? -- Positive change or human progress, not necessarily growth in numbers or size.

Who is to benefit from such development? -- People of the current generation and of generations to follow.

For how many generations is development to be sustained? -- For all future generations, forever. Thus, sustainability is about sustaining a desirable quality of life for people, forever.

Sustainable Agriculture: Sustainable production system means a biological system that does not undergo degradation over a reasonably long period of time. In 1992 during Earth Summit at Rio de Janerio, the FAO define Sustainable Agriculture as the management and conservation of natural resource base and the orientation of technological and institutional change in such a manner as to ensure the attainment and continuous satisfaction of human needs for present and future generations.

Legal Definition of Sustainable Agriculture

The term "sustainable agriculture" (U.S. Code Title 7, Section 3103) means an integrated system of plant and animal production practices having a site-specific application that will over the long-term (NIFA, 2009).:

- Satisfy human food and fiber needs.
- Enhance environmental quality and the natural resource base upon which the agriculture economy depends.
- Make the most efficient use of nonrenewable resources and on-farm resources and integrate, where appropriate, natural biological cycles and controls.
- Sustain the economic viability of farm operations.
- Enhance the quality of life for farmers and society as a whole.

The concepts of sustainability in relation to food production have been generally focused on

1. **Ecological Food Production** (Begon, 1990) which aims to reduce environmental contaminations, conserves resources, and provides an acceptable and dependable income for the producers and affordable food for the consumers.

2. **Alternative Agriculture** (Wolf and Allen, 1995) it is a food production system which integrates local and macro level objectives and macro level concerns, and meaningfully deals with entities negatively impacted by resource allocation choices as viable alternative to the prevailing system.

3. **Localized food system** (Bellows and Hamm, 2001) includes the strategy of import substitution, increasing local food production for local consumption and a local food supply chain favours sourcing from local producers and processors, rather than from national and international sources of food.

4. **Organic agriculture** (Bell and Morse, 1999) is defined a produce that can be certified as organic depending upon the absence of defined substances (mostly pesticides and chemical fertilizers) during production.

5. **Low Input Sustainable Agriculture** (Bell and Morse, 1999) is low input, organic farming approach with a strong emphasis on small crops/fruit/vegetable farms.

The above definitions clearly indicate that it is a war of words organic agriculture ≡ conservation agriculture ≡ Good Agricultural Practices ≡ Low External Input Supply Agriculture-LEISA ≡ Biodynamic Agriculture. In brief it is system of “Living with harmony with nature”. Sustainability of agricultural production systems and agro-environment has emerged as a serious concern. The sustainability of environment and other natural resources like water is also being questioned. Hence, sustaining the past achievements without deterioration in environment and resources will continue to be the greatest challenge before agriculture. Thus the concept of sustainability of agriculture sector has several dimensions: socio-economic, cultural and environmental. The goal of sustainable agriculture is to maintain production at levels necessary to meet the increasing demand of an expanding world population without degrading the environments. Besides this it should:

- Reduces inputs.
- Uses ecological pest and weed management strategies.

- Cycles nutrients back into the soil for fertility and health.
- Strengthens rural and urban communities.
- Produces viable farm income.
- Promotes healthy family and social values.
- Brings the consumer back into agriculture.

Aims of Sustainable Agricultural

- Meet the changing food, feed, fiber and fuel requirement of the nation,
- Assure adequate profit to the farmers,
- Conserve and, if possible, improve the natural resource base,
- Prevent the degradation of the environment,
- Discourage regional imbalances, and
- Encourage gender equity

Economic Inferences

Economic viability is a necessary condition for sustainable agricultural and food systems. Profitability is a good place to begin. Evaluating the likely profitability of potentially more sustainable practices can start with budgeting. But economic viability is about more than profitability. Economics is the study of how people attempt to meet unlimited wants with limited means. Among the things that people care about are many that cannot be bought and sold in markets. Not least of these are health and environmental quality that we value for ourselves and our communities. Within limiting assumptions, economics offers ways to measure these more hard-to-quantify values.

From the point of view of neoclassical economic theory, sustainability can be defined in terms of the maximization of welfare over time. Most economists simplify further by identifying the maximization of welfare with the maximization of utility derived from consumption. According to standard economic theory, efficient resource allocation should have the effect of maximization utility from consumption. The concept of measurement of sustainability differs for different situations, places and time and therefore it may be location and time specific as well as the measures differ at micro and macro levels and therefore sustainability indicators can be varies for different situations as shown in the following table:

System	Based on
Dynamic	Time specific
Spatial	Space specific
Output	System specific
Resource	Input specific
Personal	Requirement specific
Community	CPRs

Fundamental Analysis: Sustainable development can be operationalized in terms of the conservation of natural resources (Daly 1994). For renewable, the rule is to limit resource consumption to sustainable yield levels. The demand and supply of natural resources may in the form of:

D > S	Un-sustainable
D < S	Sustainable
D = S	Sustainable (short run)

And therefore long term sustainability depends upon judicious use of available resources. Conventional economic theory is rooted in the "belief" that there are no limits to growth. The sustainability issue is rooted in the "belief" that there are limits to growth. Neither "belief" can be proven to be true or false.

Sustainability Indicators (SI): It may be easier to identify un-sustainability than sustainability- and the identification of un-sustainability can motivate us to take necessary policy action. All the measures of sustainability are subjective rather than quantifiable. For the study on sustainable agriculture, the question arises as to how agricultural sustainability can be measured. Some argue that the concept of sustainability is a social construct (David 1989; Webster 1999) and is yet to be made operational (Webster 1997). The precise measure of sustainability is impossible as it is site specific and a dynamic concept (Ikerd 1993). Some of the broad measures of sustainability are as follows:

- Nutrient deficiencies in crop plants
- Disease and pest hazards
- Soil sustainability indicators
- The quality and health of soils
- Soil ecology
- Soil salinity and alkalinity
- Environmental quality
- Resource base on which agriculture depends,
- Economic viability, and
- Quality of life for farmers and society as a whole.

Organization for Economic Cooperation and Development (OECD, 1997) has developed a common framework called “driving force state response (DSR) to help in developing sustainability indicators.

Driving force indicators refer to the factors that cause changes in farm management practices and input use.

State indicators show the effect of agriculture on the environment such as soil, water, air, biodiversity, habitat and landscape.

Response indicators refer to the actions that are taken in response to the changing state of environment.

These indicators are suitable to evaluate agricultural sustainability at aggregate level. They cannot, however, be used to assess sustainability at the farm level.

Two indicators are however commonly used to identify the practices, which give maximum sustainable yield or maximum sustainable income. These are 'Sustainable Yield Index (SYI)' and 'Sustainable value Index (SVI)'

Sustainable Yield Index

SYI is defined as :

$$SYI = \frac{\bar{Y} - \sigma}{Y\ max} \times 100$$

Years	Yield of wheat (kg/ha)
2004-05	1811.0
2005-06	1710.0
2006-07	1916.0
2007-08	1714.0
2008-09	1885.0
Mean	1807.0 σ 94.9

Other measures of sustainability

- Partial factor productivity and total factor productivity;
- Agronomic or incremental efficiency of external inputs;
- Physiological or internal efficiency of external inputs;
- Soil quality index;
- Soil organic matter levels; and
- Apparent nutrient balance sheets.

According to Lynam and Herdt (1989), sustainability can be measured by examination of changes in yields and total factor productivity

Factor Productivity: Defined in terms of the efficiency with which the factor inputs are converted to output within the production process. There are two measures of factor productivity:

Partial Factor Productivity: It is the ratio of output to a single input.

Total Factor Productivity: Total Factor Productivity (TFP) is a ratio of an index of aggregate output to aggregate input.

Condition I: (Unsustainable)

- If output goes up by 10% and input goes up by 6%, total factor productivity goes up by 4%.

Condition II : (Sustainable)

- If output stays the same and inputs go down by 5%, total factor productivity goes up by 5%.

Condition III : (More Sustainable)

- If output goes up by 10% and inputs stay the same, total factor productivity goes up by 10%.

Condition IV: (Highly sustainable)

- If output goes up by 10% and input goes down by 5%, total factor productivity goes up by 15%.

Most of the Empirical Studies show that in developing countries (IJAE)

- 40-45% of output growth comes from increased input use.
- 55-60 % comes from a combination of increased efficiency and new technology.

While in developed world (AJAE)

- 55-60 % of output growth comes from increased input use.
- 40-45% comes from a combination of increased efficiency and new technology.

Bridging yield gap at sustainable level: This approach of productivity Improvement on sustainable manner through bridging the yield gap I and II was exist in developing countries and this need to be achieved through improvement in productivity using local resources and knowledge because:

- It is an Economic necessity for higher marketable surplus & multiple sources of income.
- It is an Ecological necessity with limited land resources, otherwise we have to use pasture and forest land.
- More thorough incorporation of natural processes and reduction in the use of off-farm inputs
- Greater productive use of the biological and genetic potential
- Matching cropping patterns and their production potential

- Profitable and efficient production with emphasis on improved farm management and participatory NRM

Strategies to achieve this: This can be achieved through: focusing potential areas, formulation of differentiated strategies for different regions, crop diversification, scientific management of natural resources through conservation agriculture, sustainable water management, integrated nutrient management (INM), extension of technologies and managing Information input along with strong decision support system (DSS)

Required change in mind set for sustainability:

Operational changes such as shift in cropping pattern, adoption of intercropping, mixed cropping, mixed farming, varietal & seed replacement, method of sowing, organic farming, rainwater conservation, insitu moisture conservation, and contract farming etc

Structural changes such as production system diversification, integrated farming systems, and strengthening of required infrastructure

Managerial changes such as timely operations, timely application of inputs, supply of quality inputs, selection of suitable varieties, and strong decision support

Conclusions:

Thus we can say that for sustainable agriculture we have to **sustain gains** through productivity enhancement at sustainable level because we do not want to sustain our system at low productivity level. Wider diversity in crops and practices are required to mitigate the risk in farming and equitable distribution of gain of sustainable agriculture for higher social and economic security is required. At the same time we have to **suspend** commercial exploitation of resources so that future generations can also enjoy the benefits of natural resources.. .

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Biological Control of Problematic Weeds using Insects

Sushilkumar

Senior Scientist
Directorate of Weed Science Research
Jabalpur -482004 (M.P.)

Introduction

Biological control of weeds, using insects and pathogens, is a well established technique. However, the procedures for implementing biological control are relatively complex. Successful programmes require the coordinated effort for many years by experienced scientists. The increasing awareness of the dangers of pesticides has greatly stimulated the need for alternative control measures.

Discussions of biological control of weeds invariably elicit the following questions: How can we be sure that an introduced agent will not become a pest? What is the likelihood of an agent shifting to other plants? Why is it unnecessary to repeat host specificity tests for a known successful agent before it is released in another country? These questions reflect a natural fear of deliberately introducing new organisms. Unfortunately many people consider all insects as pests and all pathogens as diseases. Nowadays, more and more attention is being paid to the beneficial role of insects and pathogens, in natural and agricultural systems and their utilization in Integrated Pest Management (IPM) and biological control.

What is biological control of weed?

Weeds are said to be undesirable plants grown out of place, harmful to cultivate crops, forest and other environmental vegetation which also create health hazards to human beings and animals.

Generally chemical herbicides have been found to be cost effective but on account of world wide awareness about the hazardous effect of chemicals, weed control calls for alternate strategies and biological control is one of them.

The suppression of weeds by means of another living organism which are encouraged and disseminated by man is called biological weed control. Many authors have defined the biological pest suppression (biologcial control) in many ways.

Some of these are following :

a. The study and utilization of parasites, predators and pathogens for the regulation of host population densities (De Bach, 1964).
b. The use of encouragement by man, of living organisms or their products for the Population reduction of pest (Coppel and Martins, 1977).
c. This is the deliberate introduction of natural enemies (insect, nematode, pathogen, snalil, fish *etc*) in to area desired to be managed to bring down weed population to level at which damage is not serious.

Group of biological agents

Any living organism able to suppress or kill weeds may be considered biocontrol agent but insects, mites, nematodes, plant pathogens, animals, fish, birds and their toxic products are major weed control biotic agents and among these insects are one of the important groups.

Insects are of many kinds viz., Sap sucking, boring the roots and stems, destroying and feeding the leaves, making galls etc. Like wise fungus may also be of many type and may differ in their action.

Parts of weed which can be attacked by bio-agent

Following parts may be attacked by bioagents for effective killing of weeds :

- Root zone may be destroyed
- Leaves may be destroyed
- Main stem may be deformed or destroyed which may affect flow of nutrients
- Flowers and seeds may be destroyed

Methods of biological weed control

The methods used in biological weed control are:

(a) the classical approach targeting at the control of naturalised weeds by the introduction of exotic natural enemies from the weed's native place. This approach is frequently employed;

(b) the "augmentation" approach using periodic releases or redistribution of exotic or native natural enemies

(c) the "conservation" approach employing of environmental manipulation to enhance the effect of existing native or exotic organisms. This type of approach has so far received very little attention.

Biological control of weeds in India

Biological control using insect is one of the old tactics. In the world many attempts have been made to manage weeds with the help of insects and fishes. We may categorised biological control in three situations

A. Biological Control in Terrestrial situation

B. Biological control in Aquatic situations

A. Biological control of terrestrial weeds

Important bioagents imported in India to control weeds have been given in Table-1.

(a) *Lantana camera* : (Family Verbenaceae). The lantana is an obnoxious weed which has severely infested waste land, forest land and orchard and railway side tracks. (Sushilkumar, 1993). So far 9 insect species have been introduced in to India but none of the species caused extensive damage to lantana except lantana bug. *Teleonemia scrupulosa*.

(b) *Parthenium hysterophorus*

***By exotic insects*:**

Based on well documented success by insects from the native home of Parthenium, efforts were initiated in India in 1983 at Indian Institute of Horticultural Research at Bangalore and three insects namely defoliating beetle *Zygogramma bicolorata* Pallister (Coleoptera: Chrysomelidae), the flower feeding weevil *Smicronyx lutulentus* Dietz (Coleoptera: Curculionidiae) and the stem boring moth *Epiblema strenuana* (Walker) (Lepidoptera: Tortricidae) were imported in India (Singh 1993). *S. lutulentus* could not be multiplied in the laboratory while *E. strenuana* was found to complete its life cycle on a oil seed crop niger (*Guizotia abyssinica* L.(Asteraceae) hence its culture was destroyed (Jayanth 1987) in spite of the fact that this insect was considered to be a potential biocontrol agent in Australia (Mcfadyen 1985). Study of host specificity and damage potential revealed *Zygogramma bicolorata,* a safe bioagent Thereafter, field releases were carried out at Sultanpalya area in Bangalore.

Both the grubs and adults of *Z. bicolorata* feed on Parthenium leaves. Beetles are off white in colour with dark brown longitudinal markings on the elytra, measuring about 6 mm in length. Eggs are laid on ventral side of the leaves and hatch in 4-7 days. The grubs feed for 10-15 days on the leaves and on maturity drop down in soil and pupated below up to 15 cm and beetles emerge after 8-12 days. It takes 22-32 days to complete the development. In Bangalore, insect remains active from May to October, rainy season being the period of highest activity (Jayanth 1987). Insect completes 5-6 generations under field conditions in Bangalore. The temperature range between 20-30°C was most suitable for the development while maximum tolerance was recorded up to 45°C (Jayanth and Bali 1993[a]). Adults undergo in diapause between July and December while termination of diapause takes place on continuous exposure at 30°C for 22 days, 35°C for nine days and 10 hrs at 40°C. (Jayanth 1993). Some commonly used herbicides like alachlor, butachlor and fluchloridone and sodium salt of 2-4-D, glyphosate and killer 700 were recommended safe as pre and post emergent treatments against the beetle (Jayanth and Bali 1993[b]). The insect which was present in about 10 ha area in August 1988 in Bangalore has spread over 50 000 sq km area by October 1992 in Bangalore and by 1994, it had spread over 200 000 sq km area in and around Bangalore) from the epicentre ((Jayanth and Visalakshy 1994 , Jayanth and Visalakshy 1994). Bhumannavar and Balasubramanian (1998) studied the quantitative food utilization in different larval instars and physiological ages of adult *Z. bicolorata*. Among the larval and adult stages of the beetle, third instar larvae and egg laying females ingested maximum food. Various growth parameters like relative consumption rate (RCR), relative growth rate (RGR) and approximate digestibility (AD) were relatively higher in the first, third and fourth instar and egg laying females. Efficiency of conversion of ingested food (ECI) and efficiency of conversion of digested food (ECD) were maximum in first, third and fourth instar larvae and decreasing trend was observed in second instar larvae.

In 1991, a few hundred adults of *Z. bicolorata* from Bangalore were introduced in the Campus of Vindhyanagar National Thermal Power Corporation (VNTPC) in the district Sidhi of Madhya Pradesh. Initially, the introduction was considered failure as the beetle up to three years of its release noticed no appreciable damage. But in the fourth year, appreciable damage by the beetles was observed in the campus and by the 1998 the beetle spread up to 40 km periphery from the release point and appreciable damage was noticed up to the periphery of 25 km. Due to the action of beetle, Parthenium population was decreased drastically (Fig.5 and Fig. 6) which allowed to dominate other local vegetation (Sushilkumar 1998). This region represents extreme fluctuations in temperature and humidity as in winter temperature become low more than 8°C and in summer it scaled up to 45 °C (Sushilkumar and Bhan 1998). The success of *Zygogramma* under these extremes of temperature clearly indicates its potential in varied climatic conditions of India.

Table 1. Exotic bioagents used in the India against some important terrestrial weeds

Lantana *Lantana camara* L. . (Verbenacae); Tropical America.	1.Plume moth *Lantanophaga* (Platyptilia) *pusillidactyla* Lepidoptera: Pterophoridea); native of Central and tropical South America.	Introduction into india naturally by air current	Established but efficiency is not of high merit.
	2.The scale insect *Orthezia insignis* Dougles (Homoptera:orthizidae); origin obscure.	Probably got entry from Sri Lanka	Established but feed on many other useful plants, not able to control weed.
	3.Seed fly *Ophiomyia lantanae*(Frog.) Diptera;Agromyzidae); native of Mexico	In 1921 from Hawaii (Subramanium in1924 opined its presence before Rao (1920) survey	Established but not effective.
	4.*Teleonemia scrupulosa* St.,(Hemiptera:Tingidae); native of Mexico	In 1941 Australia	Accodently escaped from laboratory and established naturally, partially effective.
	5.Leaf minor *Octotoma scabripennis* (Coleptera :Chrysomelidae);native of Mexico.	In 1972 from Australia	Though declared safe and several releases were made not established
	6.Beetle *Uroplata girardi* Pic.(Col.:Chrysomelidai): native of Mexico	. --do-- --	do--
	7.Stem and root borer *Plagiohamus spinipennis* (Thoms)(Col.: Cerembycidae); (Australia) beetle. native of Mexico.	In 1972 from Sydney	Imported pupae failed to yield
	8.Tingid bug *Lepttobyrsa decora* Drake (Hemiptera: Tingidae); native of South	In 1976 from Australia	Declared unsafe hence whole culture was destroyed.
	9.Fruit borer, *Epinotia lantanae* (Busk) (Lepidoptera:Tortricidae); native of Mexico.	First recor ded in 1986 (Muniappan & Viraktamath): introduction obscure.	Not effective.
Carrot weed *Parthenium hysterophorus* L;native of Mexico Argentia and Trinidad.	1.Weevil *Smicronyx lutulentus* Dietz (Col.; Curculionidae); native of Mexico.	In 1983 from Mexico	Could not breed in laboratory
	2.Beetle *Zygogramma bicolorata* Pallister Col.; Chrysomelidae); native of Mexico	In 1983, from Mexico	Declared safe released at Bangalore, reported on sunflower and involved in controversy but controversy solved, very effective, established in several states
	3.Moth *Epiblema strenuana* (Walker); native of Mexico.	In 1985 from Australia	Completed lifecycle on niger hence culture destroyed.
Siam weed *Chromolaena odorata* Robinson, (=*Eupatorium odoratum* Compositae); native of Central tropical America.	1.*Apion brunneionigrum* B.B. (Col.; apionidae); (L.) R.M. King & native of West Indies.	In 1975 from Trinidad.	Not established
	2.Moth *Pareuchatus pseudoinsulata* Rego Barros (=*Amaloinsulata* Walker) (Lepidoptera: Arctiidae)	In 1981 from Trinidad	failed but Sri Lankan strain established.
	3.Moth Mescinia parvula Z. (Lep.; Pyralidae); native of West Indies.	In 1986 from Trinided	Failed to breed in laboratory
Crofton weed Eupatorium adenophorumSprengel (Compositae); native of Mexico(Centr-al America -	Fly *Proceicidochares utilis* Stone (Diptera; Tephritidae); native of New Zealand.	In 1986 from New Zealand	Established and spreading natura lly, got entry into Nepal partially effective.

(iii) Controversy over Parthenium feeding beetle Zygogramma bicolorata and its current status:

Seven years after first release of this beetle, it was found feeding on an important oil crop sunflower *Helianthus annuus* (Sridhar, 1991) followed by other reports (Narendra, 1993, Kumar 1992). This started a tug of war between proponents and opponents of the beetle as a bioagent. In view of this controversy, two independent Fact Finding Committee (FFC) were set up by the Government of Karnataka in February 1992 and Indian Council of Agricultural Research (ICAR) in November 1992, respectively. In its first meeting held by ICAR, FFC decided to suspend further intentional releases of the beetle till controversy is resolved. Field studies done by FFC have clearly revealed that *Z. bicolorata* fed only on the border rows of sunflower in certain fields adjacent to severely defoliated Parthenium area. It was found that dusting of Parthenium pollen stimulate adults to feed on treated sunflower. FFC members monitored the field situation of *Z. bicolorata* at four localities in Bangalore and Kolar district during October 1993 but could not observe any feeding by beetle on sunflower while beetle were abundantly present on Parthenium around. During July-September 1994, FFC noticed feeding by the beetle on sunflower at Kadur and Ajjampur (District Chikmagalore) area. At Ajjampur, the beetles affected 30 per cent of 30 days old sunflower plants. Grubs of beetle collected during July 1994 survey could complete life-cycle on sunflower under laboratory conditions at Bangalore. The matter was considered serious as till this finding, the grubs were not known to complete the stage on sunflower while beetle had spread over 20 million sq km area (Sushilkumar and Bhan 1994, Sushilkumar and Bhan 1995). On FFC recommendations, ICAR funded a project of about Rs 5. 2 million at five places of India namely, Project Directorate of Biological Control, Bangalore, Indian Institute of Horticultural Research, Bangalore, Agricultural University, Bangalore, Tamil Nadu Agricultural University, Coimbatore and National Research Centre for Weed Science, Jabalpur. After initiation of work in these five centres, fund was also provided to Agricultural University, Dharwad (Karnataka) to pursue research on the beetle. . FFC of ICAR has met seven times so far (November 1992 to May 1998).

Based on developmental, biological and biochemical studies conducted at various centres co-ordinated by FFC, it was unequivocally proved that *Z. bicolorata* is a safe bioagent against Parthenium. Little feeding by the 'O' day beetle and freshly hatched grubs on sunflower near the border rows of heavily infested Parthenium was attributed due to falling of Parthenium pollen on sunflower which attracted beetle to feed. Studies conducted at NRCWS, Jabalpur revealed that in spite of development of *Z. bicolorata* on sunflower for several generations in the laboratories, chances of beetle to become a potential pest was remote as the survival rate of larvae and beetles developed on sunflower was very less. The females survived in first generations were not able to produce sufficient eggs in next generations. If fed on sunflower delayed and less egg laying was a common feature. Continuous feeding on sunflower caused degeneration of the ovary. A compound 'parthenin' was found responsible to enhance the feeding of adult beetles many folds. When pure parthenin, isolated form the Parthenium leaves was sprayed in different PPM concentration, it was found to increased the feeding on sunflower by the beetles significantly Experiments conducted at Vindhyanagar in Madhya Pradesh clearly demonstrated that beetles did not feed on sunflower grown amidst heavily infested Parthenium by the beetle. However, it was established that *Xanthium strumarium*, an another weed act as alternate host for *Z. bicolorata (*Sushilkumar and Bhan 1997*).* Leaf area study and food preference studies also clearly showed beetle preferred Parthenium.

FFC in its seventh and last meeting held at Bangalore in May 1998, unequivocally, gave its recommendations to Government of India that *Z. bicolorata* feeds only on the border rows of sunflower under specific situations and is unlikely to cause economic damage. The benefits derived due to the suppression of Parthenium by the beetle outweigh the insignificant damage on sunflower. Therefore, the embargo imposed on its multiplication and release may be lifted. At present it is being used extensively and causing appreciable damage to Parthenium.

(c) Siam weed, *Cromolaena odorata* (Composita) :

This weed is a perennial weed which has assumed a serious status in plantation crops, forest areas, waste land and pasture land. It is a menace in north-east region (Sushil Kumar, 1993). Two insects have been introduced in India Among these, Pareuchaetes *pseudoinsulata* Raggo Barros has shown some optimistic results in the forest area to kill siam weed. Seven insects and three mite species from Tamil Nadu and Karnataka attacking this weed have been reported.

In past some attempts have been made to review the biological control of forest weeds of India (Sankaran, 1974; Sen-sarma and Mishra, 1986; Ahmad, 1989, Singh, 1989; Sushilkumar, 1993). Here, a fresh attempt has been made to evaluate the work done in India on biological control by insects on *Chromolaena odorata*. Spread and damage of *C. odorata* in forests

Its menace in Assam has been reported by Biswas (1934) and Sen-Gupta (1949). During 1933-34, the weed was reported in plantations in Buxa and Jalpaiguri Divisions where it caused damage to regeneration areas of *Acacia nilotica* (babool) and *Dalbergia sissoo* (shisham). It has invaded some parts of Maharastra, Himachal Pradesh and Punjab. It grows rapidly and achieves a height of 2-8 meters. Because of its shrubby and scrambling habit, it impedes access. After flowering, it dries hence cause fire risk particularly in summer season in dense forest area. It is also a weed of amenity and recreational areas as its thick stands were found to cover areas of Anamalai wild life sanctuary, Top hills (Tamil Nadu) in India (Ahmad, 1989).

Sen-Sarma and Mishra (1986) and Ahmad (1989) have explored the possibilities of its biological control by insects in India in their reviews.

Attempts to control of *C. odorata* by exotic insects

During an extensive survey in Trinidad (Cruttwell, 1968), several insects and mites were recorded and studied in detail. Of these, two enemies, an arctiid defoliator, *Pareuchaetes pseudoinsulata* Rago Barros (incorrectly named as *Ammalo arravaca* (Jordan) and *A. insulata* (Walker) (Lepidoptera; Arctiidae) and a flower and seed feeding weevil *Apion brunneonigrum* (Coleoptera: Apionidae) were considered potential and were introduced in India.

In 1970, the Trinidad strain of *P. pseudoinsulata* was imported by the erstwhile Commonwealth Institute of Biological control (CIBC) (now Project Directorate of Biological Control, Bangalore) and the culture was successfully raised. In host specificity test, out of 13 plants tested, nibbling on *Encalyptus odorata* HK and *Seramum indicum* were observed (Giriraj and Bhat, 1970). Extensive field releases were made at several sites (CIBC, 1974) in the Coorg district of Karnataka. But repeated attempt failed to establish *C. Odorata* probably due to predatory ants (Sankaran and Sugathan, 1974) and granulosis virus (Singh, 1980). Additional introduction of insect was made from Venezuela and Trinidad but of no avail (Annual Rep., 1983). Later on in 1984 Sri Lankan strain of *P. pseudoinsulata* was introduced in India and released in Trichur (Kerala) and Bangalore but trials proved partially effective as recovery of caterpillars were recorded up to one month. Again in 1985, about 40,000 larvae and 400 moths of this Sri Lankan Strain were released in a rubber plantation at Trichur which established partially Further releases in the same plantation resulted *C. odorata* defoliation in about two hectors (Annual Rep., 1986). This strain was failed to establish in Chikmagalur and Kodagu districts of Karnataka (Jayanth, 1987). But the same strain showed its establishment at Mallesara near Teerthahalli in Shimoga district, Karnataka (Annual Rep., 1987).

Ahmad and Thakur (1991) tested 42 forest tree species against P. pseudoinsulata and found that larvae did not feed even on the leaves of an allied species Eupatorium triplinerne. Ahmad (1991) again tried to establish this insect in the forests of Tamil Nadu and Kerala but he could found only faint recovery of larvae at some places but he was optimistic that inundative release of various stages of the insect in dense bushes of *C. odorata* in high rainfall areas and places around water reservoirs may lead to its firm establishment.

Recently, a gall forming insect species *Cecidochares connexa* has been imported and released by National Bureau of Agriculturally Important Insects (NBAII) . located at Bangaluru after host specificity test. It is being released in Karnataka, Kerela and Assam. In Karnataka and Kerala , it has been established. The impact evaluation studies revealed that this insect reduce the number of branches and flowers in the affected plants of *Chromolaena odorata.*

Weed suppression in crop situation

a. ***Nut sedge (Cyperus rotundus L.)*** **Cyperaceae**. It is a cosmopolitan weed with large number of insect enemies but most of these are polyphagous. A rhizome and stem boring weevil *Athesapaeuta cyperi* (Mshl.) and two tortricid stem borers *Bactra minima minima* and *B.venosana* have shown some promise which are host specific.

b**. Goat weed *Ageratum* spp.** Two species viz., *Ageratum conyzoidos* and *A. housterianum* are common in agricultural field of India. The weed is attacked by two cerembycid borers *Nupserha madurensis barvayensis* and *N. malabarensis* making tunnel in green stems. A noctnid larva *Perigea albomaculata* also feed on foliage.

3. Biological control of aquatic weeds

Aquatic weeds can be defined as those unwanted and undesirable vegetation which reproduce and grow in or on water bodies and if left unchecked may choke the water bodies. Increased pollution of surface waters by agricultural and urban affluent loaded with abundant rich nutrients have created ideal conditions for over abundance of aquatic plants.

Based on their habit and habitats, aquatic weeds can be classified into 5 groups.

1. Floating Weeds : *Eichhornia, Nelumbo, Spriodella, Lemna*
2. Emergent Weed : *Nymphea, Nelumbo, Numphoides*
3. Submerged weed : *Hydrilla, Najas, Vallisneria, Potamogeton*
4. Marginal weeds : *Typha, Phragmites, Cyperus, Colocasia, Panicum*
5. Algal Blooms : *Microcystis, Oscillatoria, Anabaena*

Subramanyam (1961) has described as many as 120 aquatic angiosperms in India in his monographic work . A large number of them are aquatic weeds. Tadulingam and Venkatanarayana (1955) have listed 29 species of pond species from South India but most of these weeds occur also in other parts of India.

Biological control agents

Use of aquatic mammals and rodents : Introduction of the Manatee (*Trichechus* *inunguis*) and the rodent, Coypu (*Myocastou coypus*), both known to feed on aquatic vegetation had earlier been suggested as possible biological control agents against aquatic weeds, but the slow reproductive rate of the former and the omnivorous feeding habits of the latter have dissuaded their trials.

Use of fish : Hickling (1965) has dealt with in detail the use of fish in biological control of aquatic vegetation. Amongst the several species of herbivorous fishes which feed on aquatic weeds, the more important are Tilapia *melanopleura, T. zillii, T. nilotica* and *Puntiux gonianatus*. Verigin (1963) tried *T. zillii* in the cooling ponds of a power station in Moscow and found it to be a great consumer of the weed *Vallisneria*, but this fish cannot survive below 55^{o}F. The Ruscians who consider fish as more valuable and more permanent agents for weed control than mechanical or chemical, are using the grass carp, *Ctenopharyngodon idella* and *Hypophhal michthys molitrix*. The former is said to be the more effective species. It feeds on a wide range of aquatic weeds and its other food plants include *Potamogeton, Lemna, Ceratophyllum*, *Elodea, Hydrocharis, Typha, Phragmitis, Enhydrias, Vallisneria and Myriophyllm*. The *C. idella* fish has been employed for weed control in Chinaa, Hungary, and Japan and is felt to have promise in other regions. It feeds on a range of submersed, emerged, and floating, plants, but prefers plants having soft tissue. Its rate of growth and development vary with the food source. Jhingran (1968) reported grass carp to feed voraciously on *Hydrilla, Azolla, Nechamandra*, and *Lemna* spp. in India. Ponds choked with *Hydrilla* have been cleared within a month by stocking 300 to 375 grass carps (weighing 78 to 173 Kgs.) per hector

Insects against water hyacinth

Waterhyacinth, *E. crassipes*, is of Brazilian origin. It propagates by vegetative and sexual methods. The seeds of waterhyacinth sink to the bottom mud where they can remain viable for as long as 20 years (Gopal and Sharma, 1981). Under ideal conditions waterhyacinth plants can double their number in 10 days. Waterhyacinth appeared in India early in the century and by now it has been recorded from all types of water bodies throughout the country, including major river systems-Brahmaputra, Cauvery, Ganges *etc*. Due to construction of dams on major river systems water hyacinth is no longer flushed out to the sea. It is also becoming a serious menace in flooded rice fields, considerably reducing the yield. The weed covers over 2000,000 ha of water surface.

In view of the seriousness of the problem and ineffectiveness of other control methods, in 1982, three exotic natural enemies *Neochetina bruchi* Hustache, *N. eichhorniae* Warner and *Orthogalumna terebrantis* Walk. (a mite) were introduced in India. Host specificity of the weevils was tested and they were found safe for evaluation and field testing (Nagarkatti and Jayanth, 1984; Jayanth and Nagarkatti 1987). Similarly *O. terebrantis* was found safe (Jayanth and Nagarkatti, 1987).

Both adults and grubs of *N. eichhorniae* and *N. bruchi* feed on leaves and petioles and destroy the weeds subsequently. The typical adult damage on the leaf in the form of symmetrical scrapings/scars could be easily distinguished. Up to 95% control in a 20 ha tank in Bangalore within 32 months of release by *N. eichhorniae* and 90% control in another 20 ha tank by *N. bruchi* been reported (Jayanth 1987). The weevils were in fact established in 4-6 months of release in all the tanks. The weevils travel with the plants from one place to another through water channels and thus are capable for self spread. In Jabalpur, the weevil has controlled waterhyacinth in almost all the ponds successfully and no reoccurrence of the weed has been reported in many ponds. It is one of the successful example of biological control by *Neochetina* spp.

O. terebrantis (mite) lays its eggs in the lower surface of the young central leaves of water hyacinth. The release of this mite will be complementary to the weevils and hasten the process of collapse. The mite has already been released and has established in many aquatic ponds in India.

Water fern *Salvinia molesta* D.S. Mitchel (Salviniaceae)

Water fern or *Salvinia molesta* is a free floating water weed of Brazilian origin. It reached India perhaps through introduction into botanical gardens. It was first observed in 1950"s in Veli lake, Trivendrum, Kerala and assumed pest status since 1964 (Joy, 1978). It choked rivers, canals, lagoons and covered Kakki and Idukki reservoirs; navigation, irrigation, fishing, shell collection and other operations were hindered. Approximately over 7000 km2 area in Kerala was affected by Salvinia.

Earlier efforts to control this weed with the introduced grass hopper *Paulinia acuminata* De Geer failed (Joy *et.al*., 1981). In 1982, the curculionid weevil *Cyrtobagous salviniae* Clader and Sands of Brazilian origin was introduced from Australia. In host-specificity tests involving 75 plants belonging to 41 families, the weevil did not breed on any other plant except *Salvinia* and was declared safe for field release (Jayanth and Nagarkatti, 1987d).

Adults of *C. salviniae* are small insects measuring 1.88 to 3.1 mm in length and 1.2 to 1.6 mm in width, females be 7 & 9 as table is self explanatory. In 1983-84 field experiments were conducted at Lal bagh, Bangalore where the *C. salviniae* adults were released in *Salvinia* infested water lily pond. The insects established within 2.5 months, in 3-6 months intense browning was observed and the widespread decay of the weed was noticed within 6-9 months and finally within 11 months almost entire *Salvinia* plants were dead and the lily growth which was suppressed by competition from *Salvinia* had resurrected (Jayanth, 1987d).

The cultures of *C. salviniae* supplied to Kerala met with similar success. In Kerala in the air temperature rang between 21 and 35^{o}C *C. salviniae* has established in all release sites and in some areas 99% suppression of the weed was achieved in 12-16 months (Joy *et. al*., 1985). The weevil has already cleared over 1000 sq. km of water surface in Kuttanad area (Joy, 1986). For paddy cultivation Rs. 250 to 750 were spent per hectare to remove the weed manually. The establishment of the weevil has resulted in saving this amount (Anon., 1987). The total saving comes to approximately Rs. 6.8 million every year only on account of labour.

Alligator weed, *Alternanthera philoxeroides* (Martius) Grisebach (Amaranthaceae)

Alligator weed is a perennial, aquatic herb native to river courses and coastal regions of South America. It has been accidentally introduced into India and has spread in north eastern and South India (Maheshwari, 1965; Sankaran and Naryanan, 1971). In many cases it can become a major pest in waterways and in paddy fields.

It creeps up to the banks and its shoots branch, rebranch, and intertwine to form dense, floating mats that may extend 12 to 15 m into the water, clogging irrigation and drainage canals, crowding out useful water forage plants, impeding water traffic, creating breeding sites for mosquitoes, and ruining waterways for fishing and recreational Large number of natural enemies have been recorded, Cassida sp. nr. enervis Boh. and C. syrtica Boh. from South India have some potential (Sankaran and Krishnaswamy, 1974).

A flea beetle, *Agasicles hygrophila* Selman and Vogt. has been successfully introduced into USA from Argentina and has spread rapidly through out the water sheds (Zeiger, 1967). Introduction of this beetle into India merits consideration.

Willow primrose, *Ludwigia adscendens* (L.) Hara (Onagraceae)

It is common annual in rice fields and other wet areas, as well as in irrigation channels and drains. The propagation through seeds which are scattered when the fruit capsules dehisce, and which may be further dispersed by water.

A Halticid beetle *Haltica caerulea* Oliv. and a weevil, *Nanophye*s sp. *nr. nigritulus* Boh. have been found attacking the common willow primrose in rice fields and shallow slow moving irrigation canals etc. *H. caerulea* severely defoliates the weed, but the *Nanophyes* sp. breeds in the developing fruits and arrests seed formation (Annon., 1974). Weevil N. sp. nr. nigritulus from Bangalore and Gauhati has been found potential (Sankaran and Krishna, 1967) and can be tried in other areas of the world against this serious weed. *Morpha ludwigiae* Brad. has been described a promising additional natural enemy of this weed (Bradley et al., 1973).

Water-lettuce *Pistia stratiotes* L. (Araceae)

The harmful effect of water lettuce are similar to water fern. A noctuid caterpillar *Namangana pectinicoris* Hmps. causes extensive damage to *P. stratiotes* in Kerala and other states (Sankaran, 1973) and appears to be a potential biocontrol agent.

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Herbicide as a Tool for Weed Management in Field Crops

Anil Dixit

Principal Scientist
Directorate of Weed Science Research
Jabalpur – 482004 (M.P.)

Weeds are as old as agriculture and have always been known as a problem in crop cultivation. The magnitude of the problem has increased many folds with the developments taking place in agriculture. Earlier the magnitude of the problem was such that simple hand pulling or hand hoeing often would take care of the weeds. Now, the magnitude of the weed problem too has become very large with the vast acreage of cultivated crops grown under the use of the most modern technology. In a stand of a crop, the requirement of each individual plant is the same as the next one and this intraspecific competition is intense. Weeds competiting with the crop for water, nutrients, light and space aggravate this competition and can bring the crop yield rattling down. In a natural plant community, any disturbance in the ecosystem tends to bring in a change in the competition or structure of the plant community. Those plants, which are susceptible to a particular kind of disturbance, decrease in number or even disappear.

Herbicide Use

Herbicides are chemicals that kill plants. The use of chemicals that selectively kill weeds in crops is an integral part of modern weed management. Weed control through manual/mechanical though very effective, has certain limitations such as unavailability of labour during peak period, high labour cost, and unfavourable environment particularly in rainy season etc. Under such conditions, use of herbicides is advantageous and economical. Broadly there are three categories of herbicides which could be used for effective weed control in crops.

Pre-plant soil incorporation: The herbicides which have greater toxicity on the emerging crop seedlings and decomposed due to solar radiation are applied before the crop is planted. They are incorporated in the soil up to the depth of 5 cm after the final land preparation. *e.g.*, fluchloralin and trifluralin.

Pre-emergence application: Herbicides are applied after sowing but before the emergence of both, the crops and the weeds preferably within 48 hours after sowing., *e.g.* pendimethalin, alachlor, butachlor, metolachlor, oxadiazon ,linuron, etc.

Post-emergence application: Herbicides are applied after the emergence of crops or weeds, around 15-25 days after sowing, e.g. 2,4-D, isoproturon, bentazone, chlorimuron-ethyl, sulfosulfuron, clodinafop, fluazifop-p-butyl etc.The key success with post emergence herbicides is timeliness. Many post emergence herbicides will control weeds only when they are small. Delayed application can also result in yield loss due to early season competition from the weeds. In contrast, applications made too early may miss weeds that have not yet emerged. The optimum application timing varies by herbicide and weed and is affected by several other factors. The introduction of herbicide resistant crops has also greatly increased use of the post emergence application method, especially in soybean.

Herbicides being selective, dependable and effective against target weeds gained popularity in the recent years especially under intensive agriculture. In India use of herbicides for weed management is meager as compared to developed nations. This is mainly due to low purchasing and risk bearing capacity as well as perception of dry land farmers about weeding.

The Present Scenario

High production agriculture characterized by growing dwarf or semi dwarf cultivars, responsive to increased applications of irrigation and fertilizer has simultaneously increased the problem of weeds. The dominance of little seed canary grass (*Phalaris minor*) in wheat and barnyard grass (*Echinchloa spp.*) in rice are a case in point. The control of these weeds through conventional means is difficult. Herbicides such as isoproturon in wheat and butachlor and anilofos in rice have been increasingly used to manage the problem. The use of chemicals to control weeds is increasing in almost all crops. Wheat, rice and tea are the major crops where maximum amount of herbicides are used in the country. The use in crops like onion, groundnut, soybean, cumin is showing a steady increase. The consumption of herbicides is likely to increase in the future due to the unavailability of labour in rural areas during peak crop season. The labour costs are also increasing in most areas, thus making manual weeding not only inefficient but uneconomical as well.

It was estimated that losses would rise to nearly 20 billion US dollar annually, if herbicides were no longer available. The estimated net societal loss from banning of only 2, 4-D in the U.S. would be 1.638 billion dollar, whereas, banning all phenoxy herbicides would result in a loss of 2.559 billion dollar annually (Burnside *et al*., 1996). In general, herbicides account for the largest proportion of crop protection chemicals sold on a world-wide scale. Globally, the herbicides constitute 52% of the total pesticides sale and in some countries like the USA, Germany and Australia; the figure is as high as 60-70 %. In India, however, the position is different as herbicides form a meager 20 % of total pesticide consumption (Table1). Sharp increase in wages and unavailability of labour as a result of industrialization and urbanization are bound to make herbicides more acceptable to farmers. Currently about 95 % of the herbicides is consumed in wheat (42%), rice (30%) and tea plantation (23%). The use pattern might change soon with the introduction and indigenization of more chemicals.

Table 1. Pesticide use in India, and world (Pesticide Industry Data 2008)

Pesticide	% Total pesticide			
	India		World	
	1997	2008	1998	2008
Herbicide	16	20	47	52
Insecticide	52	61	29	7
Fungicide	30	17	19	32
Others	2	2	5	4

In India, the chemical weed control is mostly prevalent in states of Punjab, Haryana, Western UP, Tamilnadu and Andhra Pradesh. In Punjab and Haryana, the major use of herbicides is in rice and wheat crop, Tamilnadu and Andhra Pradesh (in rice), Madhya Pradesh (in soybean and wheat) and Gujarat (in groundnut and spices). Nearly 75% of rice and 50% of wheat in Punjab and 60% of rice and 40% of wheat in Haryana is using new technology based on herbicide use for weed management. The other area where weed management technology is mostly herbicide based is plantation crops, more specially tea, where mechanical disturbance of the land is discouraged.

Agricultural activity is a devastating kind of disturbance to a natural plant community. In agricultural lands newly brought under cultivation most plants from the natural community disappear in the very first year while others may take a few years before they are eliminated. The undesirable plants- the weeds, usually introductions from other agricultural areas that survive from year to year either through seeds or through some other preempting organs, obviously are a special category of plants possessing characteristics that give them the ability to survive and compete with an advantage over most agricultural crops.

Weed management cost is a major input cost in crop production. Herbicides are economical to use in crop production with a larger profit margin. The benefit: cost ratio of controlling weeds in transplanted rice ranged from 16:1 to 26:1 for herbicides against 3.3:1 to 6.3:1 for hand weeding (Ampong-Nyarko and De Dutta, 1991). The input cost of herbicide is in general comes to be nearly Rs. 1000- 1200/ha. This varies from state to state and also on the capacity of the farmers to use herbicides under prevailing weed infestation. The labour cost for doing the mechanical and manual operations do come to around Rs. 2000-3000/ha for one weeding. Where inter row cultivation is done using bullock or tractor power, the cost is around Rs. 600-700/ha. But mechanical weeding is possible only in wider row spaced crops and provides partial weed control between crop rows and weeds in intra-rows remain uncontrolled. It has been observed that the cost of weed management either based on mechanical methods or through herbicides provide minimum of 20 % increase in crop yield. In rice, wheat and soybean, the cost of 150-200 kg of produce meets the requirement, while the increase is to the tune of 500-800 kg/ha. This indicates an overall increase of production of respective crops without increasing the cost of operation.

Advantages of herbicides

- Herbicides can kill many weeds that survive by mimicry, e.g. *Phalaris minor* and *Avena spp*. in wheat and *Echinochloa spp*. in rice.
- Herbicides can be safely used where manual weeding damages the crop, e.g. onion, garlic, groundnut, etc.
- Herbicides are more effective on perennial and parasitic weeds.
- Herbicides can effectively be used in closely planted crops where manual and mechanical weeding is not possible.
- Herbicides are safe on erodable and sloppy lands where tillage may accelerate soil and water erosion.
- Herbicides enable early and timely planting of crops.
- Herbicides can be used where physical condition of soil is not conducive to manual weeding, e.g., during rainy spells.
- While one time application of a herbicide is often enough, the manual/mechanical method is repetitive.

Table 2. Herbicide recommendations for field crops

Crops	Herbicides	Dose/ Rate (kg ai/ha)	Application time	Remarks
Rice				
a. Nursery				
	Butachlor or Thiobencarb	1.0-1.5	6-7 DAS*	If moisture is less, follow immediately by irrigation.
	Pendimethalin	1.0-1.5	6-7 DAS	If moisture is less, follow immediately by irrigation.
	Pretilachlor	0.75-1.0	3-5 DAS	Sufficient moisture must be there.
b. Direct seeded upland rice	Butachlor or Thiobencarb Pendimethalin Pretilachlor	1.0-1.5 1.0-1.5 0.50-0.75	Pre-emergence Pre-emergence Pre-emergence	Apply after the sowing but before emergence of crop. In addition to these herbicides 1 hand weeding may be given at 30-35 DAS.
c. Direct seeded puddle and transplanted rice	Butachlor or Thiobencarb Pendimethalin	1.0-1.5 1.0-1.5	3-5 DAT* 3-5 DAT	Apply at 3-5 days after transplanting on saturated soil but not flooded for 3 days after application.
	Anilophos	0.40-0.60	3-5 DAT	Apply at 3-5 days after transplanting.
	Fluchloralin Followed by Butachlor,	1.0-1.5 1.0-1.5	Pre- trans-Planting 3-5 DAT	Apply before transplanting on puddled soil.
	Pendimethalin or 2,4-D	1.0-1.5 0.5	3-5 DAT 20-25 DAT	Apply 20-25 days after transplanting where sedges and broad weeds are dominant.
	Fenoxaprop-p-ethyl	0.06-0.07	25-30DAS/ DAT	Controls grassy weeds only
	Cyhalofop-butyl	0.09-0.120	25 DAS/ DAT	Controls grassy weeds only
	2,4-D	0.75-1.0	35-40 DAT/DAS	Controls annual broad leaved weeds and some annual grasses and sedges. Drain before application and reflood where relevant within a few days.
	Oxadiazon	0.5-0.75	Pre-em. or early Post-emergence	Do not disturb soil surface after application.
	Bensulfuron+ pretilachlor (Londax powder)	10 kg/ha (Commercial product)	0-3 DAS/DAT	Controls grassy, broad leaved and sedges
Wheat				
	Isoproturon	0.75-1.0	30-35 DAS	Apply after first irrigation but in areas in Punjab, Haryana and Western U.P. where isoproturon is not controlling Phalaris minor, pendimethalin or sulfosulfuron or clodinafop or diclofopmethyl could be used at the given rates.
	Pendimethalin	1.0	Pre-emergence	Apply on finely prepared seed bed and ensure adequate soil moisture in the surface soil.
	Pinoxaden	0.05	30-35 DAS	After the first irrigation for controlling Wild oats and *P. minor*.
	Clodinafop-propargyl	0.06	30-35 DAS	For controlling Wild oats and P. minor.
	Sulfosulfuron	0.025	30-35 DAS	For controlling Wild oats and P. minor.
	Fenoxaprop	0.10		For controlling Wild oats and P. minor.
	2,4-D	0.4-0.6	30-35 DAS	Apply after first irrigation for controlling broad leaved weeds only. Should not be used in sensitive cultivars such as HD 2009.
	Carfentrazone	0.04	30-35 DAS	For controlling broad leaved weeds

Maize				
	Atrazine	0.75-1.0	Pre-em. or early Post-emergence	Apply either prior to emergence of crop or within 2 weeks after emergence. Also mixtures of atrazines (0.5 kg/ha) and alachlor(1.0 kg/ha) or pendimethalin (0.5 kg/ha) gives broad spectrum weed control
	Alachlor	2.0-2.5	Pre-emergence	
	Pendimethalin	1.0-1.5	Pre-emergence	.
	2,4-D	0.75	Post-emergence	For the control of broadleaf weeds only.
	Atrazin+ Pendimethalin	0.75+0.75	Pre-emergence	Excellent control of all weeds. For sole maize only.
Sorghum				
	Atrazine	0.5-0.75	Pre-emergence	Avoid use of atrazine in Maize, Sorghum and Pearlmillet when legumes are grown as intercrops.
	2,4-D	0.75	5-6 WAS	For control of Striga and broadleaf weeds only.
	Pendimethalin	0.75-1.0	Pre-emergence	
Pearlmillet				
	Atrazine	0.5	Pre-emergence	Controls most annual weeds.
	Pendimethalin	0.75-1.0	Pre-emergence	Ensure adequate surface moisture for optimal activity.
Green gram/ Black gram/ Pigeon pea	Fluchloralin	0.75-1.0	Pre-planting	Incorporate into the surface soil before sowing of the crop.
	Alachlor	1.0	Pre-emergence	Should be applied after sowing but before emergence of the crop.
	Pendimethalin	0.75-1.0	Pre-emergence	Some soil moisture in surface soil will enhance herbicide activity.
	Quizalofop ethyl	0.05	Post-emergence	Excellent for grassy weed control
	Imazethapyr	0.100	Post-emergence	Good control of grasses and broad leaved weeds
Chickpea/ Lentil/Peas	Fluchloralin	1.0	Pre-planting	Incorporate into the surface soil before sowing of the crop.
	Pendimethalin	0.75-1.0	Pre-emergence	Apply after sowing but before emergence of the crop.
	Metribuzin	0.5	Post	For contolling grasses and broad leaved weeds in peas only
Groundnut				
	Fluchloralin	1.0	Pre-planting	Incorporate into the surface soil before sowing of the crop.
	Alachlor	1.5-2.0	Pre-emergence	Apply after sowing but before emergence of the crop.
	Pendimethalin	0.75-1.0	Pre-emergence	
Soybean				
	Alachlor	1.0-2.0	Pre-emergence	Controls annual grasses and broad leaved weeds.
	Fenoxaprop-p-ethyl	0.1	Post-emergence	Controls annual grasses
	Fluchloralin	1.0	Pre-planting	Incorporate into surface soil immediately after application.
	Metribuzin	0.25-0.50	Pre-emergence	Many annual grasses and broad leaved weeds are controlled.
	Pendimethalin	0.75-1.0	Pre-emergence	Incorporate it in dry conditions as pre-plant treatment.
	Imazethapyr	0.10	Post-emergence	Controls grassy and broadleaf weeds
	Quizalofop ethyl	0.050	Post-emergence	Controls grassy weeds
	Chlorimuron ethyl	0.012-0.015	Post-emergence	Controls broadleaf weeds
Sunflower				
	Alachlor	1.0-2.0	Pre-emergence	Apply to weed-free soil of fine tilth.
	Fluchloralin	1.0	Pre-planting	Incorporate into surface soil before sowing of the crop.
	Pendimethalin	1.0	Pre-emergence	Apply after sowing but before emergence of the crop.
	Oxadiazon	0.5-1.0	Pre-emergence	Moist soil is essential for activity.
Rapeseed- Mustard				
	Fluchloralin	1.0	Pre-planting	Incorporate into surface soil before sowing of the crop.
	Pendimethalin	1.0	Pre-emergence	Apply before the crop emergence.
	Isoproturon	0.75-1.0	Pre-emergence	Good soil tilth and Some soil moisture
	Oxadiazon	0.5	Pre-emergence	Enhances activities.

Jute				
	Fluchloralin	1.0	Pre-planting	Incorporate into surface soil before sowing of the crop.
	Fenoxaprop	0.07-0.09	Post-emergence	Excellent for grassy weed control
	Quizalofop	0.05-0.06	Post-emergence	Excellent for grassy weed control
Cotton				
	Fluchloralin	1.0	Pre-planting	Apply after sowing but before emergence of the crop.
	Pendimethalin	1.0	Pre-emergence	
	Oxadiazon	0.5-0.75	Pre-emergence	Moist soil is essential for activity.
	Trifluralin	0.5-1.0	Pre-planting	Incorporate into surface soil immediately after application.
	Diuron	0.5-0.75	Pre-emergence	Do not apply to coarse sandy soil. Crop may be damaged if seed has been treated with systemic insecticide.
	Glyphosate	1.5-2.0	Post emergence	As directed spray when cotton is over 15 cm high.
Sugarcane				
	Atrazine Atrazine +	2.0 1.0	Pre-emergence Pre-emergence	Good soil tilth and soil moisture enhances the herbicide activity of pre-em. Herbicides. Tank mix atrazine with alachlor 2.0 kg/ha for broad spectrum weed control.
	2,4-D	1.0	Post-emergence	Apply 5 weeks after planting
	Metribuzin	1.0-1.5	Pre-emergence	It can be applied as pre-emergence or early post emergence. Can be mixed with 2,4-D in early post emergence application for broad spectrum weed control.
Potato				
	Pendimethalin	1.0	Pre-emergence	Apply before emergence to crop and weeds.
	Paraquat	0.5	At 5% sprouting	Apply at 5% sprouting. Delay causes phytotoxicity. Does not control weeds which emerge after application.
	Isoproturon	0.75-1.0	Pre-emergence	Apply pre emergence or early post-emergence.
	Metribuzin	0.5	Pre-emergence	Apply pre emergence or early post-emergence.
Tomato / Brinjal				
	Pendimethalin	1.0	Pre-emergence	Apply before transplanting followed by irrigation.
	Alachlor	2.0	Pre-emergence	This should be followed by 1 hand weeding.
	Fluchloralin	0.75	Pre-emergence	5-6 weeks after planting / sowing.
	Fluchloralin Metribuzin (in Tomato)	1.0 0.5	Pre-emergence or early post-emergence	Should be applied pre-emergence or early post-emergence. Avoid contact with tomato plants.
Onion / Garlic				
	Fluchloralin	1.0	Pre-emergence	Pre-emergence to weeds at the time of transplanting followed by irrigation.
	Pendimethalin	1.0	Pre-emergence	Apply before or after transplanting and pre- emergence to weeds.
	Oxyfluorfen	0.25		Apply before or after transplanting and pre- emergence to weeds.
	Quizalofop	0.05	Post-emergence	Excellent control of grasses
Cabbage/ Cauliflower/ Kolkhoz	Fluchloralin	1.0	Pre-emergence	Should be applied at the time of planting and followed by irrigation.
Beetroot/ Radish/ Carrot	Pendimethalin	1.0	Pre-emergence	Should be applied after transplanting but before the emergence of weeds.

DAS – Days after sowing, WAS – Weeks after sowing; DAT - Days after transplanting

- Herbicides kill weeds insitu without permitting their dissemination.
- Herbicides can safely be used to control weeds growing in obstructed situations such as right-of-way, under fruit trees and on undulating lands.
- Herbicides provide timely weed control by controlling weeds at the critical period of their competition.

- In dry land agriculture, effective herbicidal control ensures higher water use by the crops and less crop failure due to drought.
- Planning and management of labour for various agricultural operations in big farms are facilitated by use of herbicides.
- Use of herbicides offers gender equality as manual weeding is largely done by female laborers.
- In many parts of the country the cost of weed control through herbicides is lower than that of manual weeding.

Concerns

Despite the above advantages, several concerns have also been made with the indiscriminate use of pesticides. These are as under,

Weed shift

Correct identification of weed problems is extremely important for their effective and economical management. Changes in weed flora occur with time cropping system and management practices adopted. Therefore, monitoring of such changes /shifts in weed flora is important to avoid build up of highly undesirable weed population.

Continuous use of the same herbicide year after year in the same crop in the same area leads to shift in weed flora. For example, due to continuous use of grass killers in rice, particularly in Punjab and Haryana, the weed flora is shifting to sedges like *Cyperus* sp., *Scirpus* sp., *Fimbristylis* sp., sp., etc. In this chapter attempts have been made to review the past and present weed scenario in major crops and cropping systems and the recommendations.

Toxicity and residue problem

The indiscriminate use of pesticides leaves behind residues in food and produce. Widespread and increasing use of herbicides is causing concern about potential ecological effects. But still the herbicides are quite safer than the insecticides. In India, around 96% of the herbicides belong to slightly toxic to moderately toxic. Compared to this, more than 70% of the insecticides are highly toxic to extremely toxic. Further, herbicides are never applied directly on grains/fruits which are directly consumed by human beings. A Harvard scientist calculated the risks associated with spraying 2, 4, and 5-T- a relatively toxic herbicide (LD50 value 300). If a person worked applying 2,4,5-T with a backpack sprayer 5 days a week, 4 months a year, for 30 years, the chances of developing a tumor would be 0.4 per million. In comparison, other risks of developing a tumor are large (Zimdhal, 1993).

With the normal use rate, the quantity of herbicide applied to soil at one time is too small in relation to total soil volume to have any detectable influence on a soil's physical or chemical state. Moreover, the herbicides are applied either before sowing or with in one month after sowing of the crop. Results of the experiments conducted under All India Coordinated Research Project on Pesticide Residue and All India Coordinated Research Project on Weed Control indicated that herbicides when applied at recommended doses did not leave any toxic residues either in soil water or in food chain. They provide a long waiting period. The high temperature and rain fall conditions in India would result in quick degradation of the chemicals. Most herbicides have half-lives of less than 30-40 days in the soil.

Groundwater Contamination

The basic role of groundwater as a primary and irreplaceable resource of good-quality water for human consumption raises public concern regarding its possible contamination by the use of herbicides. However, such a concern in developed countries is justified, where the herbicides accounting for almost 60 percent of the pesticides used, are reported to be typical contaminants of ground water. Generally, herbicides have relatively high water solubility, and a low soil sorption coefficient, in comparison with insecticides, and to a lesser extent, fungicides, and thus have higher leaching capability (Funari *et al.,* 1995). The problem of groundwater pollution is more with herbicides which are relatively more mobile in soil as well as in light soils in comparison to heavy soils. Worldwide, atrazine followed by alachlor is reported to be a frequent contaminant in ground water and therefore its use was restricted or banned in some European countries like Italy, as early as in 1990. However, in USA, the largest consumer of atrazine (about 22,000 MT/annum), it is still being used in corn, for the reason, that its ban could result in substantial loss in producer income and societal net benefit (EPA, 1993).

The current level of herbicide use in India is too low to result in groundwater contamination. Recent studies initiated under AICRP-Weed Control have indicated no traces of isoproturon in water samples drawn from tube wells in Punjab, the state with the largest consumption of herbicide isoproturon.

Soil microorganisms

Because of large populations, short reproductive cycles and great adaptability to environmental change, microorganism populations are very resilient. Nearly all investigations show a positive or negative effect. Reactions such as nitrification are suppressed, but at field use rates, the suppression is not permanent. By and large, herbicides applied at their recommended doses have only temporary effect on nodulation by legume crops. The effect on other soil micro-flora is transient and in the final analysis the crop yield is generally not influenced. There are very few reports of permanent injury to soil micro-flora, soil micro-fauna or invertebrates from herbicides used at normal field use rates.

Herbicide resistance

If the same herbicide, herbicides from the same chemical family, or those with the same mechanism of action is used on the same land for several successive years, development of resistance is more likely. The dependence on isoproturon led to development of resistance in *P.minor* against this herbicide in the north-western plains and as a result, it has emerged as a major weed limiting wheat productivity (Malik & Singh, 1995; Malik *et al*., 1995; Chhokar& Malik, 2002).Herbicide resistance is of course a global problem. However, crop and herbicide rotation and herbicide mixtures are important techniques to combat this problem. Integration of many methods of weed management rather than reliance on only herbicides to solve weed problems is an important consideration in the overall management of weeds resistant to herbicides.

Herbicides that are normally available in the Indian market are only listed here. To increase the spectrum of weed control tank mixing of two or more herbicides may be done but only after expert advice as it may sometimes lead to undesirable side effects.

Some points to note

- Hand weeding may be given wherever necessary in addition to herbicide treatment.
- Use lower rates in light soils and higher rates in higher soils.
- These recommendations are based on the sole cropping. For herbicide use in inter-cropping system, consult experts.
- Apply herbicide using a sprayer with 500-600 lit/ha water.
- Also spray solutions immediately after preparation. If delay is inevitable, stir the solution or shake the sprayer thoroughly before application to prevent settling down of herbicide in the bottom.
- Flood jet or flat pan nozzle should be used for spraying the herbicide.
- Match the swath correctly. Overlapping of spray may lead to crop phyto-toxicity and gaps may lead to poor control of weeds.
- Separate sprayer need to be used for herbicide and for insecticide spray. If not, then sprayer has to be thoroughly washed with soap water after the herbicide spray before it is used for insecticide spray.
- Avoid spraying on windy days as drifting may damage the neighboring susceptible crops.
- Do not spray against the wind.
- Avoid smoking or eating during spray application.
- Wash sprayer thoroughly after each spray.
- Handle chemicals carefully. Always keep them away from children and food articles.
- Dispose the empty container by burying in the soil or by burning.
- Use protective clothing (gum boots, gloves, etc.) goggles and mask wherever possible.

Research Methodology

R.B.Singh

Professor
Department of Mathematics & Statistics
JN Krishi Vishwa Vidhyalaya, Jabalpur- 482004 (M.P.)

Test of significance- it as set of procedure on the basis of each we reject the null hypothesis & make the decision about population parameter the set of procedure

(1) We make null hypothesis vs. alternative hypothesis

(2) Fixed the level of significance

(3) Choose the appropriate test statistics

(4) Compare the test statistics table value & make the decision

(5) Now we will discuss one by one in brief

Null hypothesis- the technique of randomization used for the selection of the large sample units makes the test of significance valid for us. For applying the test of significance we first set up a hypothesis a defined statement about the parameters. Such a hypothesis, which is usually denoted by *H*o. According to prof. *R.A. Fisher* null hypothesis is the hypothesis, which is tested for possible rejection under assumption that it is true.

Alternative hypothesis- Any hypothesis, which is complementary to the null hypothesis, is called an alternative hypothesis usually denoted by *H*1. For example

If we want to test the null hypothesis that the population has a specified mean μ_0 (say), *i.e.,* $\mathrm{H}_0 : \mu = \mu_0$, than the alternative hypothesis could be

$$\mathrm{H}_1 : \mu \neq \mu_0 (i.e., \mu > \mu_0 or \mu < \mu_0)$$

$$\mathrm{H}_1 : \mu > \mu_0$$

$$\mathrm{H}_1 : \mu < \mu_0$$

Error in sampling- The main objective in sampling theory is to draw valid inference about the population parameters on the basis of the sample result. In practice we decide to accept or reject the lot after examining a sample from it. As such we are liable to commit the following two types of errors:

Type I error: *reject H*o *when it is true.*

Type II error: *accept H*o *when it is wrong. i.e., accept H*o *when H*1 *is true.*

Critical region and level of significance- A region (corresponding to a statistic *t*) in the sample space *S* that amounts to rejection of *Ho* is termed as critical region or region of rejection. If ω is the critical region and if $t = t(x_1, x_2, \ldots x_n)$ is the value of a statistic based on a random sample of size *n*, then

$$p(t \in \omega / H_0) = \alpha, p(t \in \varpi / H_1) = \beta$$

where ϖ the complementary set of ω is called the acceptance region.

We have $\omega \cup \varpi = S$ and $\omega \cap \varpi = \phi$

The probability α that a random value of the statistic *t* belongs to the critical region is known as the level of significance.

One tailed and two-tailed tests- In any test the critical region is represented by a portion of the area under the probability curve of the sampling distribution of the test statistic.

A test of any statistical hypothesis where the alternative hypothesis is one tailed (right tailed or left tailed) is called a one tailed test. For example a test for testing the mean of a population

$$H_0 : \mu = \mu_0$$

against the alternative hypothesis:

$H_1 : \mu > \mu_0$ (right tailed) or

$H_1 : \mu < \mu_0$ (left tailed)

a test of statistical hypothesis where the alternative hypothesis is two tailed such as : $H_0 : \mu = \mu_0$ against alternative hypothesis $H_1 : \mu \neq \mu_0$ is known as two tailed test.

Test for single proportion- If *X* is the number of successes in *n* independent trials with constant probability P of success for each trial

$$E(X) = nP \text{ and } V(X) = nPQ$$

Where *Q*=1-*P*, is the probability of failure.

It has been proved that for large *n*, the binomial distribution tends to normal distribution. Hence for large *n*, *X~N (nP, nPQ) i.e.,*

$$z = \frac{X - E(X)}{\sqrt{V(X)}} = \frac{X - nP}{\sqrt{nPQ}} \sim N(0,1)$$

and we can apply the normal test.

Test of significance for difference of proportions- Suppose we want to compare to distinct populations with respect to the prevalence of a certain attribute, say A, among their members. Let X_1, X_2 be the number of persons possessing the given attribute A in random samples of sizes $n_1 and n_2$ from the two populations respectively. Then sample proportion are given by

$p_1 = X_1 / n_1$ and $p_2 = X_2 / n_2$

If P1 and P2 are the population proportions, then

$$E(p_1) = P_1, E(p_2) = P_2$$
$$and$$
$$V(p_1) = \frac{P_1Q_1}{n_1} and V(p_2) = \frac{P_2Q_2}{n_2}$$

Since for large samples, P1 and P2 are asymptotically normally distributed (P1- P2) is also normally distributed. Then the standard variable corresponding to the difference (P1- P2) is given by

$$Z = \frac{(p_1 - p_2) - E(p_1 - p_2)}{\sqrt{V(p_1 - p_2)}} \sim N(0,1)$$

Under the null hypothesis $H_0 : P_1 = P_2$, *i.e.,* there is no significant difference between the sample proportions, we have

$$E(p_1 - p_2) = E(p_1) - E(p_2) = P_1 - P_2 = 0$$
$$also$$
$$V(p_1 - p_2) = V(p_1) + V(p_2),$$

The covariance term Cov (P1- P2) vanishes, since sample proportion are independent

$$\therefore V(p_1 - p_2) = \frac{P_1Q_1}{n_1} + \frac{P_2Q_2}{n_2} = PQ\left(\frac{1}{n_1} + \frac{1}{n_2}\right)$$

Since under $H_0 : P_1 = P_2$=*P*, (say), and *Q1*=*Q2*=*Q*.

Hence under $H_0 : P_1 = P_2$ the test statistic for the difference of proportions becomes

$$Z = \frac{p_1 - p_2}{\sqrt{PQ\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}} \sim N(0,1)$$

In general we do not have any information as to the proportion of A's in the populations from which the samples have been taken. Under $H_0 : P_1 = P_2$=*P*, (say), an unbiased estimate of the population proportion *P*, based on both the samples is given by

$$\hat{P} = \frac{n_1 p_1 + n_2 p_2}{n_1 + n_2} = \frac{X_1 + X_2}{n_1 + n_2}$$

test of significance for single mean- We have proved that if $x_i (i = 1,2,...n)$ is a random sample of size *n* from a normal population with mean μ and variance $\sigma^2 / n, i.e., \bar{x} \sim N(\mu, \sigma^2 / n)$.

However this result holds, *i.e.,*

$\bar{x} \sim N(\mu, \sigma^2 / n)$, even in random sampling from non normal population provided the sample size *n* is large

Thus for large samples, the standard normal variate corresponding to $\bar{x}$ is :

$$Z = \frac{\bar{x} - \mu}{\sigma / \sqrt{n}}$$

under the null hypothesis, *Ho* that the sample has been drawn from a population with mean μ and variance σ^2, *i.e.,* there is no significant difference between the sample mean ($\bar{x}$) and population mean (μ) the test statistic (for large samples), is :

$$Z = \frac{\bar{x} - \mu}{\sigma / \sqrt{n}}$$

Test of significance for difference of means- let $\bar{x}_1$ be the mean of a random sample of size *n1* from a population with mean μ 1 and variance σ^2 1 and let $\bar{x}_2$ be the mean of an independent random sample of size n_2 from another population with mean μ 2 and variance σ^2 2.

Then since sample sizes are large,

$$\bar{x}_1 \sim N(\mu_1, \sigma_1^2/n_1) \; and \; \bar{x}_2 \sim N(\mu_2, \sigma_2^2/n_2)$$

Also $\bar{x}_1 - \bar{x}_2$ being the difference of two independent normal variates is also a normal variate. The Z(S.N.V.) corresponding to $\bar{x}_1 - \bar{x}_2$ is given by

$$Z = \frac{(\bar{x}_1 - \bar{x}_2) - E(\bar{x}_1 - \bar{x}_2)}{S.E.(\bar{x}_1 - \bar{x}_2)} \sim N(0,1)$$

under the null hypothesis $H_o : \mu_1 = \mu_2$, *i.e.,* there is no significant difference between the sample means, we get

$$E(\bar{x}_1 - \bar{x}_2) = E(\bar{x}_1) - E(\bar{x}_2) = \mu_1 - \mu_2 = 0$$

$$V(\bar{x}_1 - \bar{x}_2) = V(\bar{x}_1) + V(\bar{x}_2) = \frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}$$

The covariance term vanishes, since the sample mean $\bar{x}_1$ and $\bar{x}_2$ are independent.

Thus under $H_o : \mu_1 = \mu_2$, the test statistic becomes (for large samples),

$$Z = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{(\sigma_1^2/n_1) + (\sigma_2^2/n_2)}} \sim N(0,1)$$

Test of significance; For various population parameters taking small samples

Student's 't'- Let $x_i (i = 1,2,...n)$ be a random sample of size *n* from a normal population with mean μ and variance σ^2. Then Student's 't' is defined by the statistic

$$t = \frac{\bar{x} - \mu}{S/\sqrt{n}}$$

where $\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$ is the sample mean and

$S^2 = \frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2$ is an unbiased estimate of the population variance σ^2, and it fallows Student's 't'-distribution with v=(n-1) *d.f.* with probability density function.

<u>Applications of t-distribution</u>**-** The t-distribution has a wide number of applications an statistics, some of which are enumerated below.

1. To test if the sample mean $(\bar{x})$ differs significantly from the hypothetical value μ of the population mean.
2. To test the significance of the difference between two sample means.
3. To test the significance of an observed sample correlation co-efficient and sample regression coefficient.
4. To test the significance of observed partial and multiple correlation coefficients.

***t*-Test for single mean-** suppose we want to test :

1. if a random sample $x_i (i = 1,2,...n)$ of size *n* has been drawn from a normal population with a specified mean, say μ_0, or
2. If the sample mean differs significantly from the hypothetical value μ_0 of the population mean.

Under the null hypothesis *H*o:

a. the sample has been drawn from the population with mean μ or

b. There is no significant difference between the sample mean $(\bar{x})$ and the population mean μ.

The statistic $t = \frac{\bar{x} - \mu_0}{S/\sqrt{n}}$

Where $\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$ and

$$S^2 = \frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2$$

Fallows student's t-distribution with (n-1) *d.f.*

We now compare the calculate value of *t* with the tabulated value at certain level of significance. If calculated! *t* ! >Tab. *t*, null hypothesis is rejected and if calculated! *t* ! > tab.*t* *H*o may be accepted at the level of significance adopted.

<u>Assumptions for student's *t*- test</u>- the following assumptions are made in the student's *t*- test:

1. The parent population from which the sample is drawn is normal.

2. The sample observations are independent *i.e.,* the sample is random.

3. The population standard deviation σ is unknown.

***t*-test for difference of means-** Suppose we want to test if two independent samples $x_i (i = 1.2....n_1)$ and $y_j (j = 1,2,.....n_2)$ of sizes $n_1 and n_2$ have been drawn from two normal populations with means $\mu_x and \mu_y$ respectively.

Under the null hypothesis (*H*o) that the samples have been drawn from the normal populations with means $\mu_x and \mu_y$ and under the assumption that the population variance are equal *i.e.,* $\sigma_{x^2} = \sigma_{y^2} = \sigma^2$ (say) the statistic

$$t = \frac{(\bar{x} - \bar{y}) - (\mu_x - \mu_y)}{S\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}$$

where

$$\bar{x} = \frac{1}{n_1}\sum_{i=1}^{n_1} x_i$$

$$\bar{y} = \frac{1}{n_2}\sum_{j=1}^{n_2} y_j$$ and

$$S^2 = \frac{1}{n_1 + n_2 - 2}\left[\sum_i (x_i - \bar{x})^2 + \sum_j (y_j - \bar{y})^2\right]$$

is an unbiased estimate of he common population variance σ^2, follows student's *t*-distribution with $(n_1 + n_2 - 2)$ *d.f.*

Biomass Energy Option for Sustainable Development

B.M. Khandelwal

Professor
College of Agricultural Engineering,
JN Krishi Vishwa Vidhyalaya, Jabalpur – 482004 (M.P.)

Introduction

Bio energy is seen as one of the key options to mitigate greenhouse gas emissions and to substitute fossil fuels (Hall *et al*., 1993; Goldenberg, 2000). Large-scale introduction of biomass energy could contribute to sustainable development environmentally, socially, and economically (Ravindranath and Hall, 1995; Turkenburg, 2000; Van den Broek, 2000). Abundant biomass resources are available in most parts of the world Rogner (2000). The present Bioenergy use covers 9–14% of the global demand (of about 400 EJ in 1998), most of which as traditional, low-tech and inefficient cooking and heating in developing countries (Hall *et al*., 1993; Turkenburg, 2000). Modern production of energy carriers from biomass (heat, electricity and fuels for transportation or 'bio--fuels') contributes a lower, but significant 7 EJ (Turkenburg, 2000).

Fuel biomass comes from both primary and secondary sources. Primary sources are energy crops that have the sole purpose of energy production. Willows, miscanthus, sorghum, rapeseed, Jatropha curcas are examples of this category. Secondary sources are mainly from agricultural activities and wastes, including straw, forest residues sugarcane fiber, rice husks, waste vegetables, board, paper, etc.

Biomass sources

There are three main categories of biomass in India, which can be utilized for power generation. Table 1 shows the list of possible biomass materials which could be available for power generation .The largest quantum of all these is the biomass from agriculture ,which comprises primarily of crop residues

Table 1. Biomass Materials which could be used for power Production

Agricultural Residues	Agro-Industrial Residues	Forest and other Residues
Paddy Straw Pearl millet Stalks Sorghum Stalks Maize Stalks Maize Straws Sugarcane trash Coconut shells, fibre & pith Banana plant waste	RICE husk Bagasse De-oiled cakes Groundnut shells Castor/oilseed shells Tea/coffee weastes Cotton ginning waste	Deadwood from existing forests Wood from specially grown plantations Saw mill wastes Pulp wood wastes Road side bushes
Cotton Stalk Pulses-straw & stalks Oilseed straw Jute & Mesta Sticks Castor Stalks Mustard stalks	Cashew nut shell Coconut shell Coconut fibre Coconut pith	Wood from wastelands

Biomass is a poorly documented energy sources. The inability to fully address the indigenous biomass resource capability and its likely contribution to energy and development is still a serious constraint to the full realization of the energy potential As per one estimate, 1000 million tones (MT) of biomass are annually generated in India.

Table 2. Aggregate Biomass Generation in India

Source of biomass	Estimate of the Quantity generated, in MT
Agriculture/agro-industrial sugarcane derived materials	439.43
Sugarcane based materials including tops and trash	84.01
Roadside growths	10.74
Forest residues	157.18
Growths on west lands	27.12
Agro forestry waste	9.06
Dung live stock	267.76
Poultry droppings	4.86
Total	1000.17

Source: Upadhyay et.al (2005)

Table -2 provides aggregate of the production of all types of biomass in India. This works out to around 550 million tones every year. If used for power generation, only 25& of this biomass could:

- Save over 70 million tones of coal every year. Impact of this would become extremely significant in future when almost 80% of coal mined in India will be used for power generation and availability of coal could contain creation of new power capacity as well as operation of industries

- Generate additional employment of 20-30 crore mandays every year in rural areas through local collection storage handling and transportation of biomass for power projects

Although biomass is available in abundance, its low bulk density and bio-diversity, limit the scale of operation. In addition to the high transportation costs, the storage volumes required are also high, due to which some degree of fuel processing is absolutely essential. The degree of processing required can be determined depending on type of the end use in mind. The objective of processing is to make biomass easy to handle, with improved heating value or to convert to more suitable and usable forms like liquid or gaseous fuels. the conversion of biomass to gaseous or liquid fuels is accomplished mainly through two routes, viz., Biochemical and Thermo-chemical conversions. The biochemical conversion involves the microbial action for degradation of biomass to gaseous fuels (biogas) or to liquid fuels (like ethanol). The thermo-chemical conversion involves thermal degradation through directed chemical reaction under control reaction conditions.

Thermo-chemical Conversion of Biomass

The thermo-chemical conversion of biomass can be classified into four processes namely – Combustion, Gasification, Liquefaction and Pyrolysis. Each method gives different range of products, employs different equipment configurations and operates in different modes. different conversion technologies along with their primary product and applications are presented in Table 3. The primary product being converted to secondary product using 1994.

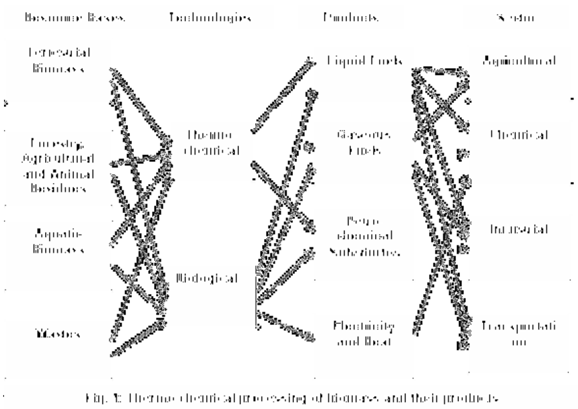

Fig. 1: Thermo-chemical processing of biomass and their products

Table 3: Thermo-chemical conversion technologies, primary products and application

Technology	Primary product	Application
Pyrolysis- • Fast or flash pyrolysis • Caboruzation • Slow pyrolysis	Liquid	Liquid fuel substitution, chemicals
	Charcoal	Solid fuel or slurry furl
	Gas	Fuel gas
	Liquid tar	Liquid fuel substitution, chemicals
	Solid char	Solid fuel or slurry fuel
Liquefaction	Liquid	Oil or liquid fuel substitution
Gasifaction	Gas	Synthesis gas or fuel gas
Combustion	Heat	Heating

Combustion involves direct burning of biomass to get heat. this is a process in which the biomass is degraded at higher temperature to clear and volatiles, which in turn are oxidized with the excess oxygen provided. A large amount of heat of reaction is released along with formation of carbon dioxide and water as gaseous emittants. With the present state of various technologies and with the niche scale of biomass power generation being 5-20MW, biomass combustion based steam power plants are still the most economical and popular route (Ganesh,2001).

Gasification is carried out in sub-stoichiometric oxygen atmosphere at temperatures ranging from 700^{o}C to 1000^{o}C. The final product, called as the "producer gas", is a low or medium calorific fuel gas, depending on the medium of gasification. Air gasification, that leads to a lower calorific value producer gas, is however most common, particularly in scales of economic operation. The gasifiers are used to substitute fuel oil in furnaces and in engine for power generation. With the diesel prices increasing steeply in the last two years in India, the gasification marker has seen a boom. Moreover, the development and subsequent availability of Spark Ignition Producer Gas Engine (SIPGE) will further boost the use of gasification for power generation – within the economic scale of operation with respect to the biomass availability, transportability and storability.

Biomass gasification offers several potential advantages over alternative approaches. First, conversion of the solid feedstock to a gaseous fuel significantly increases the opportunities for using biomass as

Table 4: Technology summary: biomass gasification

Energy services	Electricity	Shaft power	Cooking gas	Heat
Range of output	5 to 500 kWe	5 to 500 kW	10 to 1200 Nm3/hr	40–5,000 MJth/ hour
TECHNICAL PARAMETERS				
Basic equipment	Gasifier, gas cleanup, diesel engine		Gasifier, gas cleanup, gas distr., stove	Gasifier & furnace; or Gasifier, gas cleanup, furnace
Fuel inputs	Per kWh: 1-1.4 kg biomass + ~ 0.1 litre diesel (gives 60-70% diesel replacement)		Per MJth: 0.1 to 0.15 kg biomass	
Energy outputs	~ 1 kWh per (kg biomass + 0.1 litre diesel)		6 – 10 MJth/kg biomass	
Acceptable biomass	Wood chips, corn cobs, rice hulls, cotton stalks, coconut shells, palm nut shells, soy husks, saw dust, biomass briquettes			
Biomass requirements	Sized (10-150 mm, depending on gasifier design), dried (~5-20% moisture)			
Useful by-	products Waste heat, Mineral ash	Waste heat, Mineral ash	Mineral ash	Mineral ash
Key to good performance	Good gas cleanup (esp. tars), high capacity utilization			High capacity utilization
Special safety concerns	Leakage of (poisonous) carbon monoxide, exposure to (carcinogenic) tars			
Technology availability	From several multinationals and (in some countries) from domestic companies			
Difficulty of maintenance	Diesel engine maintenance	Low	Low	
Key cost factors	Capital, diesel fuel, operating Labor		Capital, operating labor	
Other attributes	Can operate exclusively on diesel fuel, if necessary			can burn gas in existing oil boilers + furnaces

a. Typical gas energy content is 4 to 5 MJ/Nm_3. Typical gas composition (volume%) is 20% CO, 10% CO_2, 18% H_2, 2% CH_4, 50% N_2.

b. Assuming an average input biomass energy content of 17.5 MJ per kilogram.

c. Systems are under pre commercial development at much greater scales as well, ranging up to 10s of MW.

an energy source. Since the gasification product is a fuel or synthesis gas rather than simply a stream of hot combustion products, the fuel can be used for different purposes. When sufficiently cleaned, the product gas can be used for applications such as:

- Powering higher-efficiency (~40%) conversion devices such as gas turbines
- Retrofitting existing oil- or natural gas-fired equipment to operate on biomass
- Providing fuel for fuel cells or other distributed generation technologies
- Synthesizing liquid fuels or chemicals

Gasification also offers potential environmental advantages when compared to combustion systems. The fuel gas produced by gasifiers is lower in both volume and temperature than the fully combusted product from a combustor. These characteristics provide an opportunity to clean and condition the fuel gas prior to use. Combustion of the resulting gaseous fuel can be more accurately controlled than combustion of the solid biomass. As a result, the overall emissions from gasification based power systems, particularly those of NO_x, can be reduced. The ability to produce clean energy potentially allows gasification to be used in other situations where combustion is unsuitable including:

- Facilities where stringent emission standards are enforced
- Locations where public perception of combustors is negative

These combined advantages of flexibility and environmental compatibility make gasification a significant option for new, high-efficiency electricity generation applications and for the synthesis of liquid fuels from biomass. Biomass gasification has been a subject of interest for many decades.

Pyrolysis is a versatile process wherein the thermal degradation of biomass (in absence of oxygen) takes place resulting in solid, liquid and gaseous products in the ratio corresponding to the operating parameters prevalent. Pyrolysis is a key process controlling all the thermo-chemical conversion process of biomass be it combustion or gasification.

Direct liquefaction of biomass involves and combustion are thermal decomposition processes, the major difference being the amount of oxugen used for the process. Read defines pyrolysis, gasification and combustion based on the amount of air supplied: pyrolysis, when air supplied is less than 1 kg/kg of biomass; gasification, when it is between 1 and 1.5 kg/kg of biomass; and combustion, when it is above 1.5 kh/kh of biomass (Read, 1985).

Gasification with internal combustion engines

Biomass, like coal, can be an unwieldy and inconvenient fuel because it is solid.

Converting biomass to a gas enables its use in a wider variety of energy devices. After appropriate treatment, biomass derived gas can be burned directly for cooking or heating, can be converted to electricity or mechanical work in a secondary conversion device such as an internal combustion engine, or can be used as a synthesis gas for producing higher quality fuels or chemical products such as hydrogen and methanol.

Table

The cost of delivering fuel gas, electricity, or shaft power with a gasification based system varies with the characteristics and requirements of a specific application. Capital investment is an important cost factor in all cases, especially where the capacity utilization rate is relatively low, as it often is in village applications. Operator costs are also important. When electricity is produced using a dual fuel (producer gas + diesel) engine, the cost of the diesel fuel generally is an important cost component as well. Since the electricity costs are generally higher than the cost of electricity generation from a new central station coal or natural gas facility, gasifier engine generators generally operate at sites where grid electricity is unreliable or unavailable. Thus an appropriate comparison is with the costs of central station power generation, including costs to extend the transmission and distribution system, or, alternatively, with pure diesel based generation. With sufficiently high capacity utilization, the gasifier engine generated electricity is easily competitive with the latter option, and it is likely to be competitive with the former under many conditions as well.

Biological Conversion:

In contrast to thermo-chemical conversion processes, biological conversion process are less energy intensive and take place at near atmospheric pressure at low temperatures (30 to 80 ^{o}C). Biological conversion entails an energy-yielding enzymatic breakdown of biomass by selected species of microorganisms. the product can be gaseous and liquid fuels, food, animal feed, fertilizers and other chemicals.

Anaerobic digestion/Bio-methanation:

Anaerobic digestion is an important biological conversion process yielding methane. It converts biomass in the absence of oxygen (by anaerobic digestion) to methane, popularly known as biogas, leaving a stabilized residue which makes an excellent organic manure. Traditionally in use for about a century, anaerobic digestion is a very complex process which only recently is beginning to be understood. Basically anaerobic digestion consists of three phases: the enzymatic hydrolysis of biomass, organic acid formation and methane generation. the total process requires a symbiosis of acid-forming and methane-forming microorganisms. the reactions of the two groups musty occur simultaneously; if these become unbalanced, the digestion process fails.

Methane production here is further influenced by three main factors- the nutrient components of the biomass substrate, the temperature and the pH. Carbon and nitrogen are essential for bacterial metabolism, so the suitability of the material for methane production is based on their carbon-nitrogen ratio, which should be around 30 for optimum production.

There are two types of methane forming bacteria, requiring temperatures for optimum growth. the mesophilic organism grow best around 35^{o}C, while the thermophilic organisms find an optimum temperature around 55^{o}C. Methane production decreases rather drastically as the temperature drops below level so that temperature control is a must for good yield. As a thumb rule, methane production drops by per 50 per cent for every 11oC decrease in temperature. A pH range of 6.7 to 7.6 is normally adequate.

Theoretically, in biogas plants, the fermentation of cellulose (the chief constituent of plant tissue), should give off equal amounts of methane and carbon dioxide, but actually, part f the carbon dioxide produced remains fixed on organic or mineral bases or remains dissolved in the water. Hence, biogas produced from farm residues consists of 55 to 65 per cent methane and 35 to 45 per cent carbon dioxide along with

0.3 per cent nitrogen, up to 1 per cent hydrogen, up to 1 per cent oxygen and traces of hydrogen sulphide. the biogas produced in a well functioning digester may have a heat value of 22.92 mega joules per cubic metre (compare the value for natural gas 39.58 mega joules per cubic metre). The energy value of the biogas can be increased by removing carbon dioxide by passing the gas through water. The gas may be used to provide heat in stoves or space heaters or for work in internal combustion engines.

If biogas is to be used in engines, hydrogen sulphide, the most corrosive component present in biogas of any origin, must normally be removed by the sponge iron process. the use of biogas as a diesel substitute has been successful by mixing 85 per cent biogas with 15 per cent diesel in engines to run tractors and other agricultural implements, this system has become popular among farmers.

When cow-dung is used in biogas plant, an output of 0.063 cubic metre of biogas per kg of cow-dung digested is possible. This is equivalent to 120 cubic metres of methane per tonne of volatile solids digested. Better outputs are reported from specially grown plants like water hyacinth. However for practical reasons the methane yields are normally within 100 to 140 cubic metres per tonne of volatile solids digested- an efficiency of about 20 to 25 per cent.

Besides animal dung, current research efforts are also being concentrated on other biomass materials such as rice husk, straws, aquatic plants etc. either alone or in mixtures. Digested biomass, an excellent manure and a good soil conditioner, contains 2 per cent nitrogen, 1 per cent phosphorus, 0.7 per cent potash and 50 to 70 per cent of organic humus.

Digestion of mixed residues (gobar, water hyacinth, algae, etc) gives greater overall efficiently, both in terms of energy recovery as well as the fertilizer value of the digested residue. A mixed residue resulted in a 2.3-fold increase in methane production as compared to cow-dung alone. The separation of acidogenic and methanogenic phases and the application of multi-reactor system have been demonstrated to provide even greater overall efficiency. A methane yield of 230 cubic metres per tonne of volatile solids digested, has been achieved in the latter as compared to 159 cubic metres per tonne of volatile solids digested mostly reported.

Biogas from anaerobic digestion as a cooking fuel and internal combustion engine fuel

The main application for which biogas systems have been disseminated is to supply cooking fuel for households, and there is considerable scope for further diffusion. Here, in addition to the use of biogas as cooking fuel, we discuss its use as a fuel for internal combustion engines.

Small scale digesters have been used extensively in India and China. Over 1.85 million cattle dung digesters were installed in India by the mid 1990s, but about one third of these were not operating in early 2000 for a variety of reasons, primarily inadequate maintenance, insufficient dung supply, and difficulties with the organization of dung deliveries. Some 7.0 million household scale digesters were installed in China as the result of a mass popularization effort in the 1970s. These digesters used pig manure and human waste as feed material. However, many failed to work due to insufficient or improper chemical compositions of the feed or poor construction and repair techniques. Some 3 to 4.5 million digesters were operating in the early 1980s. Since then, research, development, and dissemination activities have focused greater attention on proper construction, operation, and maintenance of digesters, and some 5 million household digesters were in working condition in China in the mid 1990s. In addition, China has some 500 large scale digesters operating at large pig farms and other agro industrial sites and some 24,000 digesters at urban sewage treatment plants.

Table summarizes the characteristics of anaerobic digestion systems

The cost of delivering fuel gas, electricity, or shaft power with a biogas system varies with the characteristics and requirements of a specific application. However, capital investment is an important cost factor in all cases, especially where the capacity utilization rate is relatively low, as it often is in village applications. Operator costs are also important. When electricity is produced using a dual fuel (Bio-gas + diesel) engine, the cost of the diesel fuel is also an important cost component.

Large scale industrial digesters have much lower costs per unit of gas production than do small digesters, in part because throughput rates are much higher. A recent estimate of the total cost of methane from a large scale digester (300,000 GJ/year capacity or larger) with a typical industrial feedstock is less than $2/GJ (less than $0.07 per litre of diesel equivalent) under European conditions and about $1/GJ under Brazilian conditions. Large scale digesters have thus become competitive with conventional fossil fuel options for grid connected power generation applications.

Compared with other biomass energy conversion technologies, anaerobic digestion has important, direct non energy benefits, which include pathogen destruction and production of a natural, nutrient rich fertilizer. For example, the slurry from a cattle dung digester contains essentially the same amount of nitrogen as the input dung, but in a form that is more readily usable by plants. Furthermore, dried digester effluent contains about twice the nitrogen of dried cattle dung, because more nitrogen is lost from dung than from digester effluent during drying. Digestion also provides for environmental neutralization of wastes by reducing or eliminating pathogens and by reducing the high chemical or oxygen demand (COD) or biological oxygen demand (BOD) of feed materials.[12] Significant declines in parasite infections, enteritis, and bacillary dysentery have been noted in some developing country regions following installation of small scale digesters.

Table 4: Technology summary: biogas from anaerobic fermentation

Scale of application	Household or Village		Industry or Municipality	
Energy services	Electricity or shaft power	Cooking gasa	Electricity	Fuel gas
Range of output	3-10 kWe	2 to 100 Nm3/day	500 - 15,000 kWe	10-200 1000Nm3/day
Scale of services provided	Village	Home or village	Industrial facility or electric utility grid	
TECHNICAL PARAMETERS				
Basic equipment	Digester, diesel engine, sludge filter/drier	Digester, sludge filter/drier, gas storage/distribution, burner/stove	Digester, gas cleanup, gas engine, sludge filter/drier	Digester, gas cleanup, storage, distribution, Sludge, filter/drier
Typical biomass inputs	Fresh animal or human manure, crop straws, leaves, grasses		Sewage sludge, food processing or food wastes, distillery effluents, animal manure	
Typical gas production	0.2-0.5 Nm3/day per m3 digester volume		4-8 Nm3/day per m3	
Inputs per unit outputb	14 kg fresh dung + 0.06 litres diesel fuel per kWh	30 kg fresh dungc + 30 litres water per Nm3 biogas	Varies with feedstock	
Gas required for cooking	---	~ 0.2 Nm3/capita/ dayd	---	
Useful by-products	Nitrogen fertilizer Pathogen destruction		Reduction of COD, BOD Fertilizer/irrigations	
Key to good performance	carbon: nitrogen in feedstock ~20:1 water: solids ~85:1 Internal temperature ~35oC		Temperature ~55oC	
Special safety concerns	Avoid build up of biogas in enclosed spaces (explosion or asphyxiation risk)			
Technology availability	Designs widely available can be built with mostly local materials.		Sold/made by companies in many countries	
Difficulty of maintenance	diesel engine maintenance	Low	Moderate	Moderate
Failure modes	Inadequate feed supply; social or organization problems (as with dung collection); lack of skilled labor for repairing structural damage (especially cracking of fixed dome units)			
Key cost factors	Capital, diesel fuel, operating labor		Capital	
Notes	Land area required for installation of digesters and sludge filtering			

Some precautions are needed in using biogas, particularly for household cooking. Biogas is not toxic, but an accumulation of gas in a closed living space presents explosion and asphyxiation risks. In practice, safety has not been a problem in the vast majority of cases where biogas has been used.

(ii) Fermentation

The process of alcohol production by fermentation using the enzymes of yeast is as old as human civilization. Alcohol was the fuel used when IC engine was invented. It was soon replaced by petroleum fuel which was available in abundance at much lower price. Gasohol, which is a blend of gasoline and alcohol, has been found to be a much cleaner fuel than gasoline and has been used extensively in automobiles without any modification in the combustion system of SI engines. It has higher octane value and antiknock properties than gasoline and burns slowly, coolly and resulting in reduced emissions. Brazil is a pioneer in blending up to 24% ethanol with gasoline.

Government of India has also implemented blending of 5% of ethanol with petrol used as automobile fuel. The world ethanol production in 2001 was 31 Gl. The major producers of ethanol are Brazil and US which account for about 62% of the world production. The major feedstock for ethanol in Brazil is sugarcane while corn grain is the main feedstock for ethanol in the US. Regardless of the raw material being used to produce alcohol, there are invariably four major steps involved:

1. Pretreatment: Raw materials rich in carbohydrates must in some way be converted into fermentable sugars.
2. Fermentation: The fermentable sugar is utilized by yeast (or possibly some other micro-organism) to produce alcohol and carbon dioxide.
3. Concentration: The alcohol produced during fermentation is concentrated by distillation to 100% alcohol.
4. By-product formation: The spent wash left, after the alcohol has been removed, is processed into a by-product.

While it is true that any biomass containing carbohydrates can be considered as feedstock for alcohol production, the yield of alcohol per tonne of individual feedstock varies considerably. Feedstock for alcohol production can be classified into 3 main categories:

i. Those containing starch
ii. Those containing sugar
iii. Those containing cellulose

The technology for ethanol production from starchy biomass such as corn grain is being widely practiced in US. Like-wise technology for ethanol production from sugarcane is also available and is widely used for production for fuel ethanol in Brazil. These technologies can be adopted easily. But sufficient land will have to be marked for this purpose.

Decentralized Energy Generation Strategy:

Agriculture is mostly dependent on energy. Lack of energy is therefore the single most important reason for decline of agriculture based activity and hence the economic activities in rural areas. A sustainable food and energy strategy for rural areas will therefore create new economic activities and can stop the desperate exodus to cities.

Sharan & Khosla (1996) have suggested the concepts of independent rural energy/power as an instrument for sustainable rural development. Authors suggest the need for creation of Independent Rural Power Producers (IRPP) to meet the power needs of small consumers in small town and villages. An IRPP should use energy resources that are renewable and locally available and operate on a commercially viable basis. While promoting sustainable development at the community level, it will also eliminate net CO2 emissions and thus automatically help reduce the risk of global climate change.

On this line, several NGOs and government aided centres and institutions have come up to work on generation of electricity through small units. Nimbkar Agricultural Research Institute (NARI), Phaltan (MS)as developed several technologies on commercial scale like Biomass Gasifiers and Plants for producing ethanol from sweet sorghum. The NARI provides a Thermal Gasifier of 800 kW capacities at the cost of Rs. 13 lakhs. Only 2 operations per shift are requires for running this gasifier. Here 20-24% of the fuel is converted into char which is a value added by-product.

As per news in *'Business in Development'*, Sept 16, 2004, Decentralized Energy Systems (India) or DESI Power had set up a power plant using agro-waste in Baharbari village in Bihar in 2001. DESI power installed a 50 kW Power Station in 2001 with energy produced from rice briquettes. In the beginning, farmers had no idea about the importance of electricity. However, today a cooperative oversees the growth of micro scale industries in this village which are alive with noisy electric pumps, battery charging stations, rice and flour mills and a briquetting press. The farmers now pay Rs. 35 to 49/- an hour for pumping water in their fields. As per the report, the power generated is cheaper than that from diesel generation. It is more reliable and cleaner than fossil fuels fired plants. It has promoted sustainable local livelihoods by creating jobs to operated the power plant and growing village industries. DESI Power builds and eventually transfers the plants to local ownership. As per news report, it has built nine plants in the states of Karnataka, Tamilnadu in the south, Orissa in the east, Bihar in north-east and Madhya Pradesh in central India, as well as one in Kenya. Such changes are a new hope for the country which has sufficient biomass well distributed all over the region and is available round the year.

Ravindranath et al (2004) made a case study on the performance and impact of a decentralized 20kW biomass gasifier-engine generator based power generation system in unelectrified Hosahalli village of Karnataka. This system is providing electricity successfully (population 218 in 2003) for lighting, piped drinking water, running irrigation pumps and flours mills for last 14years (1988-2004) and meeting allneeds of the village for over 85% of the days. The fuel, operation and maintenance cost ranged from Rs. 5.85/kWh at a load of 5 kWh to Rs. 3.34/kWh at a load of 20 kW.

The current advantage that fossil fuels, particularly coal, have over biomass in terms of market price would substantially diminish if the environment costs factored into the pricing of fuels. Given that one of the main reasons for the current level o interest in renewable energy is concern about the environment impact of large-scale fossil fuels use, it is not reasonable to exclude such concern from energy pricing, as is largely the case today. Most present day production and use of biomass for energy is carried out in a very unsustainable manner with great much negative environmental consequence. If biomass is to supply a greater proportion of the worlds energy need in the future, the challenge will be to produce biomass sustainably and use it without harming the natural environment. With fair pricing for energy, biomass-based generation would become viable in a wide range of situation, and the pace of commercialization for the technology would accelerate. In the near future, our concern over climate change and volatility in the world oil market will improve the prospects for renewable energy technologies.

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Integrated Nutrient Management Strategies for Enhancing Nutrient Use Efficiency in Different Crops/Cropping Systems

K. Sammi Reddy

Principal Scientist
Indian Institute of Soil Science, Nabibagh, Berasia Road, Bhopal – 462 038
Email: ksreddy_iiss39@yahoo.com

Therefore, enhancing nutrient use efficiency (NUE) in different cropping systems is relevant for sustainable crop production. The NUE is a measure of the extent to which fertilizers and management practices have worked together with the soil-climate complex in producing a high yield. Lot of research efforts have been made to develop improved agro-techniques for efficient fertilizer use such as use of hybrids/improved cultivars, suitable fertilizers, time and method of application, optimum rates of plant nutrients, nutrient-water interactions etc. Several reviews on these agro-techniques have been published earlier. Of late, whole cropping system is considered as a unit rather than an individual crop for developing fertilizer recommendations. Residual effects of nutrients applied to preceding crop and involvement of legumes in a cropping sequence were found to reduce the fertilizer nutrient requirement of subsequent crops. Conjoint application of organic/green manures with fertilizers not only supplies some nutrients but also enhance NUE by reducing nutrient fixation, improving soil physical condition, supplying secondary and micronutrients etc. In long-term studies, efforts have been made to identify the soil organic matter fractions that are responsible for nutrient fixation/release and to mobilize soil nutrients for plant availability. Consider these aspects, the strategies given below are gaining importance for improving NUE in different cropping systems; (i) Apportioning and application of the nutrients to crops in a cropping sequence taking into account the nutrient requirements of and the nutrient residues left by the previous crop(s), (ii) Modifying soil conditions by applying amendments for slowing down the nutrient fixing capacity of soils and for enhancing their nutrient supplying power, (iii) Integrated nutrient management strategies for different cropping systems as the organic manures are known to decreasing nutrient adsorption, increasing desorption, solubilization etc. , (iv) Arresting nutrient losses or fixation processes and to synchronize nutrient supply with demand by using special techniques or management practices, (v) Establishment of the role of soil organic matter fractions as source and ‘sink’ for plant – available soil nutrients and improvement in cycling of nutrients in the soil – plant system, (vi) Balanced fertilization of crops, and (vi) Soil test based fertilizer recommendation for different crops for efficient fertilizer use. The literature pertaining to these emerging strategies has been reviewed briefly and the salient findings were highlighted in this paper.

The Indian population, which increased from 683 million in 1981 to 1210 million in 2011, is estimated to reach 1412 million in 2025. To feed the projected population of 1.41 billion by 2025, India needs to produce at least 350 million tonnes of food grains. Fertilizers which contributed 50% towards improved food grain production were the fuel for the green revolution in the country. India produced about 218.2 million tonnes of foodgrains with the consumption of 26.5 million tonnes during the year 2009-10. Contrary to ever increasing demand for food, the yields of the crops grown in dryland areas remained very low (<1/ha) and the overall partial factor productivity of fertilizers to added fertilizers is declining year after year. The partial factor productivity of fertilizers decreased from 42 kg grain/kg NPK applied in 1975 to 18 in 1985, to 13 in 1995 and to 8 in 2010 (Fig. 1). Currently, the efficiency of fertilizer nutrients by different crops /cropping systems is very low (Table 1). Low nutrient recovery efficiency not only increases cost of crop production but also causes environmental pollution. The average efficiency of fertilizer nitrogen is only 30-40% in rice and 50-60% in other cereals, while the efficiency fertilizer P is 15-20% in most of the crops. The efficiency of K is 60—80% while that for sulphur is 8-12%. The recovery efficiency of micronutrients such as zinc hardly exceeds 5%. The decline in rate of response of crops to added fertilizer under intensive cropping systems has possibly resulted from deterioration in physical, chemical and biological health of soils. Due to low response of crops to added nutrients and the increased prices of fertilizers reduced the profitability of farmers. There is also very limited scope to increase the use of plant nutrients through classical sources like organic manures and biofertilizers (BF). Availability of organic manures, particularly cow dung, is a serious problem because of its greater demand for fuel (Dalal et al. 2003). Similarly, oilcakes have greater and better use as animal and poultry feeds. Moreover, very low nutrient content of organic manures and very slow release of plant nutrients render them unable to meet the quicker and higher needs of HYV cereals like rice, wheat etc. Biofertilizers have also their own limitation. Among BFs, only *rhizobium* has greater potential to fix atmospheric nitrogen. In view of the above, enhancing nutrient use efficiency (NUE) or fertilizer use efficiency (FUE) in different production systems becomes more relevant.

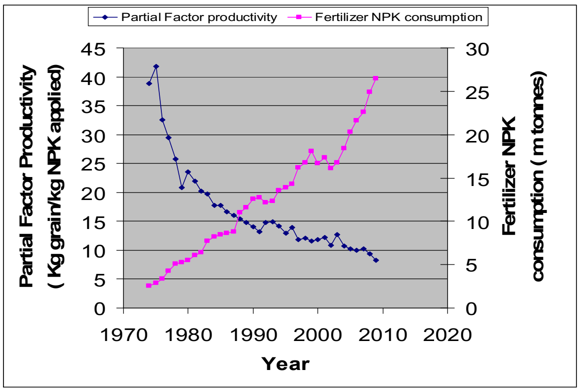

Fig. 1. Partial factor productivity of fertilizers over years in India (Source: FAI Fertiliser Statistics 2009-10)

Table 1. Current Status of NUE in India

Nutrient	Use Efficiency (%)
N	50-60
P	12-20
K	60-80
S	8-12
Micronutrients	< 5
NAAS (2006): Hegde et al. (2008)	

Concepts of Nutrient Use Efficiency/Fertilizer Use Efficiency

The nutrient use-efficiency (NUE) expressed in terms of agronomic efficiency, physiological efficiency, apparent nutrient recovery in different crops. Agronomic efficiency is the crop response to applied nutrients and expressed as kg grain/kg nutrient applied. Physiological efficiency is the crop response to amount of the applied nutrient taken up by the crop nutrient which is expressed as kg grain yield/kg nutrient uptake. Apparent nutrient recovery is the portion of the applied nutrient recovered by the crop which is expressed as per cent. FUE is a measure of the extent to which fertilizers and management practices have worked together with the soil-climate complex in producing a high yield (Tandon, 1983). NUE is very closely linked with the efficiency of the total yield of production system. Thus NUE rests heavily on the removal of constraints and on maximization of gains from the positive interactions. Nutrient Use Efficiency (NUE) and Fertilizer Use Efficiency (FUE) are used synonymously and interchangeably in the literature.

A lot of research efforts have been made to develop improved agro-techniques for efficient use of fertilizers which included selection of HYV and improved varieties, use of suitable fertilizer for different soils/crop situations, timely application of optimum rate of plant nutrients, nutrient-water interactions etc. These agro-techniques have been given lot of emphasis in several reviews published earlier (Tandon, 1980; Tandon, 1983; Tandon, 1989; Panda, 1989; Kanwar and Katyal, 1996; Kanwar and Sekhon, 1998). Of late, the subject of NUE is being viewed taking cropping system as a unit. In this approach the nutrient inputs and resources are considered together to attain maximum efficiency of different cropping systems. In this direction, concerted efforts have gone into developing a number of nutrient management strategies for efficient use of fertilizers. Among these, the following strategies are being emerged as the most important.

1. Apportioning and application of the nutrients to crops in a cropping sequence taking into account the nutrient requirements of and the nutrient residues left by the previous crop(s).
2. Modifying soil conditions (correcting soil reaction) by applying amendments for slowing down the nutrient fixing capacity of soils and for enhancing their nutrient supplying power.
3. Integrated nutrient management strategies for different cropping systems as the organic manures are known to decreasing nutrient adsorption, increasing desorption, solubilization etc.
4. Arresting nutrient losses or fixation processes and to synchronize nutrient supply with demand by using special techniques or management practices.
   a. Technologies for treating the soluble sources of N and P with cheaper amendments to convert them into slow release fertilizers,
   b. Improved fertilizer application techniques: Fertilizer placement to minimize fertilizer contact with soils for better nutrient availability, split application to match nutrient demand,
   c. Preferential application of fertilizer to crops in a cropping system *e.g.* applying fertilizer P to wheat in soybean-wheat system or rice – wheat system etc.
5. Establishment of the role of soil organic matter fractions as source and ‘sink’ for

plant – available soil nutrients and improvement in cycling of nutrients in the soil – plant system.

6. Balanced fertilization of crops
7. Soil test based fertilizer recommendation for different crops for efficient fertilizer use

1. Apportioning and Application of the Nutrients to Crops in a Cropping Sequence Taking into Account the Nutrient Requirements of and the Nutrient Residues Left by the Previous Crop(s).

Until recently the researches on fertilizer use in our country were mainly confined to individual crops and fertilizer recommendations formulated on the basis of their responses. It is a well-known fact that a crop is only a component of a cropping system and as such it has to be grown in some crop sequence. Consequently the fertilizer needs of a crop will vary depending upon the characteristics of the preceding crops in the rotation. There is a need for formulating fertilizer-recommendations for a cropping system rather than individual crops. In this context, it is also important to mention that besides the influence of preceding crops, the fertilizers applied to one-crop benefits to some extent the succeeding crops also because of their residual effects. Generally speaking it is also not taken into account and as such the present fertilizer recommendations are usually made for a single crop without considering the effect of preceding crop and the residual effect of applied fertilizers. This results in rather high and sometimes uneconomic use of fertilizers. For enhancing fertilizer use efficiency, it is almost obligatory to workout the fertilizer recommendation strategies by considering the role of preceding crops and also the residual affect of applied nutrients.

In Indian soils the deficiency of nitrogen is universal. The effect of directly applied nitrogen on crops has been most eye-catching, but the residual effect of fertilizer N is generally negligible. Use of nitrogen inhibitors along with nitrogen fertilizers can promote the efficiency of directly applied N and also the yield of succeeding crop due to its residual effect.

The beneficial effects of growing legumes in rotation in succession with cereal crops have been amply demonstrated through experiments in this country and abroad. Legumes are capable of fixing the atmospheric nitrogen to the maximum extent. Nitrogen is present in the atmosphere to the extent of 88000 tonnes in a column of air over an hectare of land. It has been estimated that out of 100 million tonnes of nitrogen fixed annually the largest part comes from symbiotic sources particularly through the nodules of legume plants (Donald, 1969). Several workers in India have reported beneficial effect of legumes on N status of soil. Beneficial effect of preceding legumes on the yield of succeeding maize crop at varying levels of N is very well demonstrated (Tiwari et al., 1980). Field experiments have clearly demonstrated the benefits of R*hizobium* inoculation to field crops not only by increasing the production of the crop but also by leaving behind substantial amount of residual nitrogen for the succeeding crops. Tiwari et al. (1980) reported that an inoculated crop of soybean resulted in a residual effect equivalent to 80 kg of applied nitrogen (Table2). Maximum increase of 65.9% per cent has been recorded in respect of grain yield of wheat after soybean.

Table 2. Effect of inoculation of soybean on the performance of subsequent wheat crop at two levels of directly applied N

Treatments	N applied to wheat (kg/ha)	Grain yield of wheat (q/ha)
Control	0	13.5
	120	39.1
Inoculation with nitrogen	0	22.4
	120	42.7
Soil application of nitrogen	0	23.5
	120	40.3

In order to maximize crop production per unit area per unit time, mixed cropping and intercropping of short duration quick growing crops in widely sown long duration crops assumes great importance. Usually no additional fertilizers are added to inter/mixed crops. In case of cotton by inter-cropping with groundnut, onion, soybean and pigeon pea, the main crop yields ranged from 62 to 95 per cent of the pure stand; however, additional gross income was 53, 12, 20 and 390 per cent, the highest being in pigeon pea (Mahapatra et al., 1974). The yield of wheat was increased when grown in association with gram, while the yield of gram was not affected (Tiwari et al., 1980). Also under mixed cropping system, wheat took up more fertilizer P from the 0-10 cm layer and gram was feeding a large amount even from the second layer (10-20 cm). Thus, there is a differential uptake from different depths making it most conducive for mixed cropping to be efficient from the point of view of fertilizer use efficiency.

Phosphatic and sulphatic fertilizers after application in the soil undergo change and enrich the soil unavailable pools, which in turn benefits the succeeding crops. In evaluating phosphatic fertilizers complimentary studies on the residual effects have been felt important and quite a large number of experiments to this effect have also been carried out. In a number of studies, significant increase in grain yield has been registered due to residual phosphate

Table 3. Effect of P applied at recommended level (PST) and residual P on soybean and wheat

Treatment (kg Pha^{-1})		Grain yield (qha^{-1})					
		1992-93		1993-94		1994-95	
Soybean	Wheat	Soybean	Wheat	Soybean	Wheat	Soybean	Wheat
Bhopal							
0	0	14.9	13.80	10.00	11.85	5.63	5.78
13	0	19.78	18.10	10.24	13.33	6.81	6.51
26	0	22.85	25.71	13.81	15.55	7.26	8.50
39	0	25.47	28.57	15.95	18.52	7.56	8.89
52	0	26.42	30.47	17.38	20.3	9.00	10.66
F	13	-	23.81	12.86	14.81	8.00	7.70
F	26	-	29.81	14.76	17.77	9.18	9.33
F	39	-	32.64	16.90	19.26	9.18	9.48
PST	39	-	-	18.81	31.12	16.74	26.07
CD (5%)	-	2.85	2.98	3.25	4.81	2.71	1.19

(Singh, 1985; Subba Rao et al., 1996; Sammi Reddy et al., 2003b). Recently, Sammi Reddy et al. (2003b) compared the residual effect of P applied to soybean on subsequent wheat and soybean with that freshly applied P to these crops. The P applied at 39 kg/ha to first soybean in soybean-wheat system on a Vertisol had significant residual effect on the yields of subsequent wheat (2nd crop) and soybean (3rd crop) (Table 3). Ganeshmurthy and Takkar (1997) reported that the rate 80 kg S/ha applied to soybean shown residual effects in 2 succeeding crops, while 60 kg S/ha applied to soybean or wheat showed residual effect in only 1 succeeding crop. Keeping in view of large residual effects of fertilizers, Kanwar and Sekhon (1998) stressed the need to determine adequately the discount rates for previous fertilization for the individual crops in all dominant cropping sequences in a soil climatic zone. By considering cropping system as a whole the fertilizer management strategies for major cropping systems grown in various agro-climatic zones have been worked out and presented in (Table 4).

2. Modifying soil Conditions by Applying Amendments for Slowing down the Nutrient Fixing Capacity of Soils and for Enhancing their Nutrient Supplying Power

(i) Acid soils

Nutrient imbalance is one of the main reasons for low productivity in acid soils. Solubility of Al, Fe and Mn being high in acid environment, these elements are available quite in excess at times causing toxicity. At below pH 5.4, Al and Mn concentrations hinder plant growth. High concentrations of Fe in the water-logging environment develops iron toxicity even for rice. Soil acidity causes shortage of Ca and Mg. Available B in acid soils is affected by (i) formation of Fe and Al oxy and hydroxy compounds (ii) broken Si-O and Al-O bonds at edges of alumino-silicate minerals and (iii) amorphous hydroxide structure. It is also affected by H+ and CO_2 in the root. Ordinarily, B should be available under acid conditions but porous nature of topsoil allows the soluble B to leach down in the profile beyond the reach of the plant roots (Panda, 1998). In light textured soils, Zn becomes deficient. At mildly acidic conditions availability of P increases but with further increase in acidity P reacts with active Fe and Al to form insoluble form. It has been reported that 86% of P in super phosphate got converted to unavailable form within 15 days of application (Mandal and Khan, 1972). Excess of Al in soil solution reduce the uptake and transport of P in plants. In general, the availability of nutrients present in cationic form increases with increase in soil acidity, while those present in anionic form mainly Mo and B decreases.

Management of acid soils should aim at realization of production potential either by addition of amendments or to manipulate agricultural practices to enhance fertilizer use efficiency and higher crop yields under acidic condition. Application of lime as amendment to neutralize the exchangeable Al to a certain extent has been found effective. Liming improves the base status, inactivates Fe, Mn and Al in soil solution and thus reduces P fixation. Further, liming stimulates microbial activity in soil leading to mineralization of organic N in soil and fixation of atmospheric N. Improvement in the availability of soil and fertilizer P by liming the acid lateritic soils have been reported (Panda and Mishra, 1970). In Orissa, application of lime at the rates 1000 kg $CaCO_3$ equivalent per hectare sustained a pH of 5.0 for 2 years. Different doses of lime starting from 1/20 lime requirement to full lime requirement was found superior to increase grain yields of pulse and oil seed crops (Mathur, 1992). Other strategies for enhancing P utilization efficiency in different cropping systems on acid soils are presented in Table 5.

Table 4. Fertilizer management strategies for major cropping systems by taking into account the residual effects of nutrients applied to preceding crops

Cropping System	Agro-climatic Region/state	Strategy
Potato-wheat	Upper Gangetic Plains	Wheat requires 25-50% less fertilizer N, when preceding potato receives recommended fertilizer dose. The residual effect of P an K applied at recommended rates to potato obviate the nee of fresh application of these nutrients.
Maize-Rice-Mustard	Upper Gangetic plain	Reduce 25% fertilizer NPK dose in mustard when previous crop of maize or rice is fertilized with recommended NPK.
Cotton-Wheat	Trans-Gangetic Plain	In cotton grown after well fertilized wheat, apply 100-150 kg N/ha. Residual effect of 60 kg P_2O_5 and 60 kg K_2O/ha applied to wheat can also meet P and K demands of the cotton crop.
Soybean-Wheat	Eastern Plateau & Hills region; Southern Plateau & Hills region; Gujarat Plain & Hills region	Application of 30 kg P_2O_5/ha instead of 60 kg P_2O_5/ha to each soybean and wheat or 60 kg P_2O_5/ha only to wheat every year helps in saving of 60 kg P_2O_5/ha fertilizer.
Pulse based systems	Eastern Plateau & Hills region; East Coast Plains & Hills region; West Coast Plains & Ghats; Western Dry zone	Apply P fertilizers for the first and second crop in a cropping system and grow the 3rd (pulse) crop without P application to encash the residual effect.
Rice based systems	Central Plateau & Hills region; East Coast Plains & Hills region; West Coast Plain & Ghats	In rice based cropping systems if preceding crop receives recommended dose of P fertilizer, P application to next rice can be omitted.
Soybean-gram	Central Plateau & Hills region	Apply 20-40 kg S/ha in addition to recommended dose of NP at the time of sowing in either soybean or gram.
Soybean-wheat	Western Plateau & Hills region; Gujarat Plain & Hills region	i. Application of 45 kg P_2O_5/ha to each soybean and wheat or 90 kg P_2O_5/ha only to wheat every year helps in saving of 30 kg P_2O_5/ha ii. Apply 20-40 kg S/ha in addition to recommended NPK at the time of sowing in soybean or wheat crop in alternate years.
Maize-groundnut Wheat-groundnut Mustard-groundnut	Gujarat Plains & Hills region	Application of 75% of recommended NPK fertilizer to both crops is sufficient
Rice-rice	Karnataka, Orissa, Kerala	i. Apply 75% of recommended NPK to both kharif and rabi rice. ii. Apply 25% of recommended NPK to kharif rice and full dose to rabi rice
Rice-wheat	Uttar Pradesh, Madhya Pradesh	Apply 75% of recommended NPK to rice in kharif and full dose of NPK to wheat in rabi

Source: Pandey et al. (1999); Acharya et al. (2003)

Table 5. Strategies for enhancing P use efficiency in crops in acid soils

Cropping System	Agro-climatic zone	Strategy
Maize-wheat	Western Himalayan region (pH <6.0)	Apply 60 kg P_20_5/ha as a mixture of SSP and rock phosphate in a ratio of 1:2 to maize. However, apply SSP to following wheat for higher NUE.
Rice-rice	Eastern Himalayan region (pH<5.1)	Apply 30 kg P_2O_5/ha to summer as well as monsoon rice in the form of rock phosphate or a mixture of SSP and RP in 1:1 ratio.
Rice-rice	Brahmaputra Valley	Apply MRP at 40 kg P_2O_5/ha at 20 day before rice transplanting.
Rice-rice	Lower Gangetic Plain region	Use SSP and rock phosphate in 1:2 ratio as basal dressing for higher P use efficiency.
Rice-rice	Central Plateau & Hills region	Recommended P dose is 60 kg P_2O_5/ha as rock phosphate.
Pulses	Southern plateau & Hills region	I. Rhizobium inoculated seed should be treated with 1.5 kg of finely powdered lime (300 mesh). II. Liming rate should be determined by soil test method and the rate should be that it can only upset the Al toxicity and does not impair the K and Ca balance.
Rice-rice	East Coast Plains & Hills region West Coast Plains & Hills region	Apply 60 kg P_2O_5/ha as rock phosphate 3 weeks before transplanting.

Table 6. Effect of integrated nutrient supply through fertilizers and FYM on the grain yield of crops in different cropping systems

Treatment		Grain yield (t/ha)		
Kharif	Rabi	Kharif	Rabi	Total
Karamana (Rice-Rice) mean of 6 yrs				
100% NPK	100%NPK	3.49	3.21	6.70
50%NPK + 50% N (FYM)	100% NPK	3.73	3.47	7.21
75%NPK +25% N (FYM)	75% NPK	3.61	3.22	6.83
Palampur (Rice-wheat) mean of 6 yrs				
100% NPK	100%NPK	3.14	2.08	5.21
50%NPK + 50% N (FYM)	100% NPK	3.08	2.28	5.35
Parbhani (surghum-wheat) mean of 7 yrs				
100% NPK	100%NPK	2.97	2.64	5.62
50%NPK + 50% N (FYM)	100% NPK	2.85	2.78	6.53
Hanumangarh (Pearlmllet-wheat) mean of 5 yrs				
100% NPK	100%NPK	2.72	3.61	6.33
50%NPK + 50% N (FYM)	100% NPK	2.56	3.82	6.38
Ranchi (Maize-wheat) mean of 8 yrs.				
100% NPK	100%NPK	2.92	2.71	5.63
75%NPK + 25% N (FYM)	75% NPK	3.30	2.40	5.70
Kathalagere (Rice-Maize) mean of 3 yrs				
100% NPK	100%NPK	5.06	3.94	9.00
50%NPK + 50% N (FYM)	100% NPK	5.11	4.83	9.95

Table 7. Apparent phosphorus recovery (APR) of fertilizer P in soybean and wheat (mean of 5 years)

Manure dose (t/ha)	Rate of fertilizer P (kg P/ha)							
	0	11	22	44	0	11	22	44
	APR by soybean (%)				APR by wheat (%)			
0 (0)	-	36.6	30.0	19.0	-	35.1	27.8	17.7
4 (5.6)	-	44.1	31.8	19.1	-	33.4	32.8	19.2
8 (11.2)	-	46.5	35.2	22.7	-	35.9	33.9	23.1
16(22.4)	-	47.0	35.8	23.2	-	40.3	38.5	26.9
Mean	-	43.6	33.2	21.0	-	36.2	33.2	21.6

Figures in parenthesis are P applied through manure

3. Integrated Nutrient Management Strategies for Different Cropping Systems as the Organic Manures are known to Decreasing Nutrient Adsorption, Increasing Desorption, Solubilization etc.

The basic concept underlying the principle of integrated nutrient management (INM) is to maintain or adjust plant nutrient supply to achieve a given level of crop production by optimizing the benefits from all possible sources of plant nutrients. The basic objectives of INM are to reduce the inorganic fertilizer requirement, to restore organic matter in soil, to enhance nutrient use efficiency and to maintain soil quality in terms of physical, chemical and biological properties. Bulky organic manures may not be able to supply adequate amount of nutrients, nevertheless their role becomes important in meeting the above objectives. Long-term studies being carried out under AICARP (Hegde, 1992) have indicated that it is possible to substitute a part of fertilizer N needs of kharif crop by FYM without any adverse effect on the total productivity of the system in major cropping systems such as rice-rice, rice-wheat, maize-wheat sorghum-wheat, pearlmillet-wheat, maize-wheat and rice-maize (Table 6). Organic manures alone cannot supply sufficient P for optimum crop growth because of limited availability and low P concentration. The organic manures are known to decrease P adsorption/fixation and enhance P availability in P-fixing soils (Reddy et al. 1999b). Organic anions formed during the decomposition of organic inputs can compete with P for the same sorption sites and thereby increase P availability in soil (Iyamuremye et al. 1996) and improve utilization by crops. Reddy et al. (1999c) observed higher apparent P recovery by soybean-wheat system on Vertisol with a combination of fertilizer P and manure (Table 7). Therefore, it is necessary to popularize the INM strategies for different cropping systems for achieving higher crop yields and fertilizer use efficiency. The INM strategies developed for different cropping systems all over the country are compiled and presented in the Table 8.

4. Arresting Nutrient Losses or Fixation Processes and to Synchronize Nutrient Supply with Demand by Using Special Techniques or Management Practices

(i) Techniques for treating the soluble sources of N and P with cheaper amendments to convert them into slow release fertilizers

Several experiments have been conducted on the use of various nitrification inhibitors to reduce the dissolution of urea fertilizer and prolong N availability to plants, mostly rice. Coating of urea with neem-based materials, such as nimin, neemix, neem cake etc. also checks nitrification and thus helps in reducing N losses. Nimin coated urea @ 70 kgN/ha gave similar yield of maize as with 100 kg N/ha of uncoated urea by significantly lowering levels of nitrification for at least one month (Vyas et al., 1991). In an experiment at Ranichauri in Uttaranchal, various modified urea formulations were tested on maize (Table 9). Sulphur coated urea maintained the highest available N in soil throughout the crop growth period and resulted in the highest grain yield, N use efficiency and N uptake efficiency. Coating of urea with lac,

Table 8. INM strategies for different cropping systems under various agro-climatic regions

Agro-climatic Region	Cropping system	INM strategy
Western Himalayan Region	Rice – wheat	Green manuring of rice with sunnhemp equivalent to 90 kg fertilize N along with 40 kg N/ha produces yield equivalent to 120 kg N/ha. In an acid Alfisol soil, incorporation of lantana camera 10-15 days before transplanting of rice helps to increase the N use efficiency.
Eastern Himalayan Region	Rice – rice	Use of organic sources, such as FYM, compost, green manure, azolla etc. meet 25-50% of N needs in *kharif* rice and can help curtailing NPK fertilizers by 25-50%.
	Rice- mustard	If rice receives 10 t FYM/ha along with recommended NPK fertilizer, use of 20 kg N, 10 kg P_2O_5 and 25 kg K_2O/ha is sufficient for mustard.
Lower Gangetic Plains	Rice – Wheat	Application of 75% of recommended NPK and 25% N through organic sources viz., FYM, green manure etc. not only increases rice yields but also saves 25% NPK in succeeding wheat.
	Rice-potato-groundnut	Use 75% NPK with 10 t FYM/ha in rice and potato.
	Jute based cropping systems	Use of 10 t FYM/ha enhances fertilizer use efficiency in jute and saves 50% NPK.
Middle Gangetic Plains	Rice – wheat	Application of FYM to substitute 25% of recommended NPK in rice improves fertilizer use efficiency to the extent that 25% of recommended NPK can be saved both in rice and following wheat. Combined use of FYM and blue green algae with fertilizer improves nutrient use efficiency by 30-45% over chemical fertilizer alone.
Upper Gangetic Plains	Rice – wheat	i. Summer geeen manuring of *sesbania* improves N use efficiency leading to saving of 25% of NPK in rice as well as wheat. ii. Application of 12 t FYM/ha in rice results in yield improvement equivalent to 60 kg N/ha, besides increasing the yield of succeeding wheat by 15%.
	Sugarcane – wheat	Combined use of 10 t FYM/ha and recommended NPK increases the cane productivity by 8-12 t/ha over chemical fertilizer alone.
	Maize – wheat	Apply 50% recommended NPK as fertilizer and 50% of N as FYM in maize and 100% of recommended NPK as fertilizer in wheat.
	Mustard – maize or rice	Reduce 25% NPK in mustard, if previous rice or maize is fertilized with 50% of recommended NPK + FYM at 50% of recommended N.
Trans-Gengetic Plain	Rice – wheat	Combined application of 12 t FYM/ha and green manuring can meet the entire N requirement of the high yielding rice. It also increases the yield of following wheat by 10-15% due to residual effect.
	Pearl millet – wheat	Application of 50% recommended NPK as fertilizer + 50% N through FYM to kharif pearl millet followed by 100% NPK to wheat improves yields of both crops and NUE.
Eastern Plateau and Hills	Soybean – wheat	To get 2 t soybean and 3.5 t wheat, apply 8 t FYM/ha to soybean and 60kg N+11 kg P/ha to wheat or apply 4 t FYM + 10 kg N+ 11 kg P/ha to soybean and 90 kg N+22 kg P/ha to wheat.
	Pulses	Integrated use of FYM at 2.5 t/ha and 50% recommended NPK fertilizers plus rhizobium inoculation helps in saving of 50% chemical fertilizers.
Central Plateau and Hills	Soybean – wheat	To get 2 t soybean and 3.5 t wheat, apply 8 t FYM/ha to soybean and 60kg N+11 kg P/ha to wheat or apply 4 t FYM + 10 kg N+ 11 kg P/ha to soybean and 90 kg N+22 kg P/ha to wheat.
	Rice - wheat	(i) Integrated use of 80 kg N/ha and 12 t FYM/ha enhances N use efficiency over inorganic N alone. Moreover FYM will also have residual effect on the following crop. (ii) Apply 75% NPK + 25% NPK through green manure or FYM at 6 t/ha to rice and 75% NPK to wheat. (iii) Inoculation of BGA @ 10kg/ha provides about 20-30 kg N/ha.
	Mustard	Substitute 25-50% of chemical fertilizer through 10 t FYM/ha to get higher yield and NUE.
Western Plateau and Hills	Soybean – wheat	To get 2 t soybean and 3.5 t wheat, apply 8 t FYM/ha to soybean and 60kg N+11 kg P/ha to wheat or apply 4 t FYM + 10 kg N+ 11 kg P/ha to soybean and 90 kg N+22 kg P/ha to wheat.
	Sorghum	Substitute 60 kg N through FYM or green *Leuceana leaucocephala* loppings to get higher yields and NUE.
	Cotton	50% of recommended NPK can be replaced by 5 t FYM/ha.
Southern Plateau and Hills	Rice – rice	Apply 75% NPK + 25% NPK through green manure or FYM at 6 t/ha to *kharif* rice and 75% NPK to *rabi* rice.
	Sunflower	Application of 5-10 t FYM/ha in conjunction with 50% recommended dose of NPK, offer enhanced yield and nutrient use efficiency.
	Pulses	Integrated use of FYM or compost or biogas slurry at 2.5 t/ha with 50% recommended NPK helps in saving of 50% of chemical fertilizers.
East Coast Plains & Hills Region; West Coast Plains & Hills Region	Rice - rice	i. Integrated use of 80 kg N/ha and 12 t FYM/ha enhances N use efficiency over inorganic N alone. Moreover FYM will also have residual effect on the following rice crop. ii. A successful inoculation of blue green algae @ 10 kg/ha provides about 20-30 kg N/ha.
Gujarat Plains and Hills	Mustard	Substitute 25-50% of chemical fertilizer through 10 t FYM/ha to get higher yield and NUE.
Western Dry Region	Pearl millet	Combined use of N @ 20 kg/ha, 2 t clusterbean crop residue and 2 t FYM/ha increases NUE in pearl millet – legume system.

Source: Subba Rao et al. (1995), Mondal and Chettri (1998); Acharya et al. (2003)

coaltar, resin (*lisa*) and wax was also found superior to uncoated urea fertilizer. However, these slow release urea fertilizers have not found much favour with the farmers because of the practical difficulties in their availability and application as well as their high cost. Volatilization loss of 6% in acid soil was reported but it was 50% in alkaline soil where ammonium sulphate was applied (Panda, 1998). Where urea was mixed with rice straw before application, recovery went up to 52.5%. Urea incubated with dry soil for 72 hours was much better than uncoated urea. Superiority of USG and briquettes of varying weights proved their efficiency which could be due to slower rate of enzymatic hydrolyses of urea or increase in the vertical diffusion of NH_3 form on account of increase in the concentration gradient (Panda, 1998). Urea coated with powdered rock phosphate was proved efficient for rice in acid soils.

Table 9. Effect of different modified urea formulations on grain yield and nitrogen use efficiency of maize at Ranchauri in Uttaranchal

Treatments	Grain yield (t/ha)	Nitrogen use efficiency (kg grain/kg N applied)	Physiological efficiency (kg N uptake/kg N applied)
Control	0.85	-	-
Prilled urea	2.13	26.7	1.00
Sulphur coated urea	3.66	45.8	1.60
Urea super granules	2.62	32.8	1.15
Lac coated urea	3.30	41.1	1.45
Lisa coated urea	2.74	34.1	1.15
Coaltar coated urea	2.81	35.0	1.25
Neem oil coated urea	2.29	28.6	1.05
Wax coated urea	2.27	34.6	1.30
Kerosene coated urea	2.63	32.8	1.20

Source: Pal (1996)

The water-soluble form of P is readily available to plants. The efficiency of P sources varies depending upon (i) proportion of water soluble P (WSP), and (ii) soil reaction. Generally, in neutral to alkaline soils, materials containing WSP are more efficient than materials containing P as citric acid soluble or water plus citric acid insoluble while in acid soils the latter materials can become equally efficient. When WSP fertilizers are added to soil, reactions takes place between the soil constituents and the fertilizer solution. Consequently the soil solution gets enriched with one or more P compounds and results in the precipitation of the reactions products. As a result the P fertilizer use efficiency never exceeds 20%. Several indigenous techniques were developed for regulating the P release from WSP fertilizers to enhance the utilization of applied P by wheat – green gram cropping system (Kanwar et al., 1982). Slurry coated SSP was found an effective treatment for increasing the P utilization by wheat in sandy loam soil while SSP applied with sodium silicate was so in clay loam soil. In the sandy loam soil, SSP with sodium silicate resulted in the highest utilization of applied P with an increase of about 9% over SSP alone (Table 10).

Table 10. Effect of different treatments on P utilization (%) by wheat

Treatment (kg P_2O_5/ha)	30	60	90	Mean
SSP	11.2	10.1	13.6	11.6
Slurry coated urea	13.7	13.1	16.4	14.4
Dung coated urea	12.8	13.6	17.7	14.7
Pelleted SSP	8.5	6.5	9.4	8.1
$MgSO_4$+SSP	15.2	14.2	12.9	14.1
Silicate+SSP	25.3	16.9	19.2	20.5

Rock phosphate (RP) as P fertilizer is a problematic product and its use as such may be only 20-35% as effective as processed phosphate even in acid soils (Marwaha, 1994). To get better response from its application, the finely ground RP should be applied 15-30 days before crop sowing by broadcast and thoroughly worked into the soil at about 150% dose of P requirement of a crop in medium to strongly acid soils. In slightly acidic, neutral and alkaline soils, however, modified rock phosphates, namely, (i) partially acidulated RPs (PARPs), (ii) RP enriched with SSP, (iii) RP in conjunction with phosphobacterin, and (iv) RP admixtured with pyrites or gypsum were found better. Wheat, potato and peas exhibited good response to 10% PARP in comparison with other RP based treatments in an acid Alfisol (Table 11, Marwaha, 1981). RP-super phosphate mixture often gives desirable results for a wide variety of crops. Thus, 25-50% of WSP requirement could safely be substituted by RP (Marwaha, 1994).

Table 11. Agronomic effectiveness of partially acidulated rock phosphate (PARP) relative to RP based treatments in an Alfisol

Treatment	Agronomic effectiveness in relation to SSP (%)			
RP alone	23.7	32.7	3.2	48.7
RP+pyrites (1.3, wt/wt)	18.0	25.7	4.1	51.8
RP+SSP (80:20, P_2O_5 basis)	97.1	84.8	57.8	70.1
RP+SSP (60:40, P_2O_5 basis)	99.3	108.9	74.8	84.6
PARP (10%)	111.4	99.4	64.7	96.4

(ii) Improved fertilizer application techniques

(a) Nitrogen

Fertilizer nitrogen use efficiency is very low in different cropping, particularly in rice, due to several losses. Among the mechanisms of N loss, ammonia volatilization, leaching, de-nitrification, runoff are very important. A large number of soil, climatic and management factors affect the amount of N lost through any given channel (Tandon, 1989), for example, 26 factors have been identified through which ammonia volatilization losses can take place from the soil (De Datta, 1981). Keeping these factors in views, several experiments have been conducted to develop appropriate method of application for different cropping systems. Among these split application comes out as a key feature of N management strategies. This invariably leads to lower losses of N and better N use efficiency. The schedule of split application (number and timing of splits) is not the same for all soil-crop conditions. The number of splits needed usually increases in (i) coarse textured sandy soils, particularly under flood irrigation a high rainfall, (ii) where large amounts of N/crop are to be applied and (iii) where the

Table 12. Strategies for split application of N to different cropping systems

Agro-climatic region	Crop	N dose (kg/ha)	Application strategy
Western Himalayan	Rice	80	1/3 basal, 1/3 at tillering, 1/3 at panicle initiation
Eastern Himalayan	Rice	60-100	½ basal, ½ two weeks before heading
	Wheat	60-80	½ basal, ½ two weeks before heading
Middle Gangetic Plain	Wheat	100	½ at sowing, ½ at crown root initiation
Upper Gangetic Plain	Wheat with conventional tillage	120	1/3 at sowing, 1/3 at first irrigation, 1/3 at second irrigation
	Wheat with zero tillage	150	½ at first irrigation, ½ at third irrigation
	Rice	120	Apply urea super granules at root zone with an applicator
Trans-Gangetic plain	Rice without green manuring	180	1/3 at transplanting, 1/3 at 21 DAT, 1/3 at 42 DAT
	Rice with green manuring	120	½ at 21 DAT, ½ at 42 DAT
	Wheat	180	½ at sowing, ½ at first irrigation on medium textured soils 1/3 at sowing, 1/3 at first irrigation, 1/3 at third irrigation on coarse textured soils.
	Rice on alkali soils	150	at transplanting, 1/3 at 20 DAT, at 40 DAT, at 60 DAT
	Wheat on alkali soils	150	at sowing, 1/4 at first irrigation, at second irrigation, at third irrigation
	Pearl millet	60	½ with last ploughing, ½ one month later when rainfall occurs
Eastern Plateau and Hills	Irrigated rice	80-120	½ basal, after final puddling, at tillering
	Rainfed upland rice	40-60	½ at 2-3 weeks after germination, ½ at 4-5 weeks after germination coinciding with pancle initiation stage
	Lowland rice	60	½ at final puddling, at 21 DAT, 42 DAT
Eastern Plateau and Hills	Medium-deep waterlogged and deep water rice	40-60	Apply entire N in shallow furrows behind plough and sow seeds
	Wheat	120	½ basal, at 20 DAS, at 40 DAS
	Pulses	15-20	At the time of sowing
Central Plateau and Hills	Soybean	20	At the time of sowing
	Wheat	120	½ basal, at 20 DAS, at 40 DAS
	Rice	80-120	(i) 1/3 at transplanting, 1/3 at tillering, 1/3 at panicle initiation (in case of urea) (ii) Point placement of entire dose of N as USG at 5-10 cm depth
	Gram	15-20	At the time of sowing
Western Plateau & Hills	Wheat	120	½ basal, at 20DAS, at 40 DAS
	Pigeon pea	15-20	At the time of sowing
Southern Plateau & Hills	Rice	80-120	1/3 at transplanting, 1/3 at tillering, 1/3 at panicle initiation
	Groundnut	10-20	Entire dose in furrows at sowing
	Sunflower	40-60	½ at sowing, at button stage, at flowering
	Cotton (improved varieties)	40-90	½ at squaring, ½ at flowering in case of improved varieties
	Cotton (hybrids)	100-150	½ basal, remaining half in 3 equal splits at 30 days interval
East Coast Plains and Hills	Rice	90-120	1/3 at transplanting, 1/3 at tillering, 1/3 at panicle initiation
	Pulses	15-20	At the time of sowing
West Coast Plains and Hills	Rice	90-120	1/3 at transplanting, 1/3 at tillering, 1/3 at panicle initiation
	Pulses	15-20	At the time of sowing
Gujarat Plains & Hills	Groundnut	10-20	½ basal, ½ at 25 DAS
	Castor	20-60	2/3 basal, 1/3 one month after sowing
	Wheat	120	½ basal, at 20DAS, at 40 DAS

Source: Acharya et al. (2003)

crop is of a longer duration. The strategies of methods of application of N to different cropping systems under various agro climatic zones are given in Table 12.

(b) Phosphorus

Many factors must be considered while applying phosphatic fertilizers including soil fertility levels, crops to be grown, tillage practices, equipment, timing, and other management factors. Phosphorus fixation is an important point to consider while deciding on mode of P application. Crops usually respond more to banded than to broadcast P on low fertility soils. Fixation is greater when P containing fertilizer is broadcast. Further, banding puts a readily accessible P source in the root zone, making it positionally more available. Banding also helps in reducing fixation reactions and thus causes enhanced P uptake.

For maximum efficiency from P fertilizer, band application is the best. But as fertility levels increase, the banding advantage disappears. So whether to band or broadcast depends greatly on the management philosophy of the grower. Banding does offer the following advantages (Tiwari, 2001):

- May allow use of lower rates than broadcast to achieve the same yield.
- Reduces fixation of P.
- Places the P so that it becomes positionally available to the young, restricted root system.
- Provides an opportunity for enhanced use efficiency of P and at the same time increases yields by combining placement and recommended rates.

Since in acid soils, water insoluble sources can be used with advantage, therefore, in that case, to maximize soil and fertilizer contact, it has been recommended to broadcast P fertilizer especially citric acid soluble sources followed by incorporation in the soil.

In methods of P application to crops, three additional practices reported in literature where some success has been obtained are:

- Dipping seedlings' roots in phosphate slurry.
- Soaking of potato tubers in 1.5% single superphosphate solution for 6 hours.
- Coating of P fertilizer with bio-gas slurry.

(c) Potassium and other nutrients

Other fertilizer nutrients, namely, potassium, sulphur, and zinc are preferred to apply as basal dose to different crops (Acharya et al., 2003). However, some exceptions are there depending upon the soil type and other crop situations. In Jharkhand, application of potassium to rice in 2 splits (3/4 at final puddling and at panicle initiation) has been found effective in increasing grain yield as compared to basal application (Acharya et al., 2003). In coarse textured K deficient soils, it is better to apply K to rice in 2 equal splits one at transplanting and another at tillering stage for higher utilization.

(iii) Preferential application of fertilizer to crops in a cropping system

Nitrogen removal by crops under different cropping systems varies greatly which in turn influences the fertility status of the soils. Cereal crops have been reported to deplete the soil fertility to a relatively greater extent (Tiwari et al., 1980). On the contrary, a restorative crop of legumes enriches it somewhat. Among the various cereal crops, exhaustive crop of sorghum impoverishes soil much more than a crop of maize (Mahapatra et al. 1974). Sadanandan and Mahapatra (1973) observed negative balance of N in all multiple cropping systems but the extent of deficit was less in groundnut-jute-rice rotation. Tiwari et al. (1980) opined that a positive balance of nitrogen could be maintained favourably by judicious application of nitrogen to the cereal crops in double cropping systems. The comparative economics of fertilizer use in the case of different cereal crops clearly shows that the application of N fertilizers is most profitable to wheat followed by rice, maize, jowar and bajra. Consequently, when a farmer wants to apply N fertilizers in kharif under irrigated conditions he should prefer the growing of rice to that of maize and sorghum. On the other hand, wheat is the only choice under irrigated conditions in rabi season.

Plant species have different capacities to utilize native and applied P and the residual effect of applied P will also differ. Therefore, attempts are being made to recommend a dose of fertilizer P for a cropping system rather than one crop. Available evidence on differences in the extractability of various P fractions by different crops has been compiled by Tiwari et al. (1980) (Table 13). Singh (1974) observed that in a rice-wheat rotations, Ca-P was built up by 49.9 kg/ha and Al-P was depleted by 28.8 kg/ha, while in case of moong-rice-wheat rotation, the built up in Ca-P & Al-P was 68.8 and 15.5 kg/ha, respectively. Therefore choosing compatible crops in the sequence on this basis will keep a favourable balance between different forms in the soils. Singhania and Goswami (1974) observed that there was little residual effect on wheat of the P applied to preceding rice crop and accordingly they suggested that in rice-wheat sequence fertilizer-P applied to wheat only taking advantage of the residual effect on rice. To substantiate this recommendations they advanced reasons that (i) wheat removes higher amount of fertilizer P than rice, (ii) wheat can't utilize the residual P in the Fe-P, and (iii) rice utilize residual-P in the form of Fe-P and Al-P. Based on the degree of response shown by different crops to potassium application, Zende (1976) arranged them in the descending order as rice>nagli>kharif jowar>rabi jowar>wheat (irrigated)>groundnut>cotton>wheat (unirrigated) >bajra>gram>linseed. In jute growing areas, jute-paddy-wheat and jute-paddy-potato being most sensitive to potassium deficiency it will be more profitable to fertilize this crop with potassic fertilizers and jute crop will be beneficial with the residual potassium in the soil. From the literature it appears that the preferential application of fertilizer to crops in a cropping system mainly depends upon the (i) nutrient requirement of individual crops (ii) the extent of response of crops to a particular fertilizer nutrient and (iii) the capacity of crops to utilize the residual fractions of soil nutrients. Based on this hypothesis several experiments have been conducted to develop strategies of preferential application of fertilizer nutrient to crops in a cropping system for attaining maximum fertilizer utilization efficiency through higher crop responses (Table 14).

Table 13. Soil phosphorus fractions in relation to phosphorus uptake by crops

Crop	Soil P-fraction
Maize	Al-P, Fe-P Adsorbed – P
Bajra	Fe-P
Wheat	Ca-P, Al-P
Rice	Fe- P, Fe- P, Al- P
Jute	Fe- P
Cowpea	Al- P, Ca-P
Urd	Al- P, Ca-P
Jowar	Adsorbed – P
Compiled by Tiwari et al. (1980)	

Table 14. Preferential application of fertilizer nutrients to crops in a cropping system

Cropping sequence	Strategy
Rice-wheat Pearlmillet-wheat Soybean-wheat	Apply phosphorus to wheat (rabi) and skip P application to kharif crops
Maize-wheat Sorghum-wheat	Prefer to apply P to wheat
Gram-rice	Apply superphosphate to gram and harness the residual effect on rice
Sorghum-castor	Apply P at recommended dose to sorghum and castor crop may be given the reduced dose
Potato based cropping system	P should be applied to potatoes in crop rotation
Groundnut-wheat	Apply recommended dose of P to wheat and skip P application to groundnut
Rice-wheat	Use of potassium may be preferred in the rice crop
Jute-paddy-wheat	Apply K to paddy and wheat and harness the residual effect on jute
Jute-paddy-potato	Apply K to potato and paddy and grow jute on residual effect

Source: Acharya et al. (2003)

5. Establishment of the Role of Soil Organic Matter Fractions as Source and Sink for Plant Available Soil Nutrients and Improvement in Cycling of Nutrients in the Soil – Plant System

In most soils, about 95-98% of total N is bound in organic compounds, and the rest is in inorganic forms which, except in soils containing much fixed ammonium, are easily available to plants (Stevenson, 1982). Similarly organic P can account for 20-80% of the total P in most mineral soils (Sharpley, 1985). Perhaps 95% or more of the total S in arable soils is in organic form (Sammi Reddy et al., 2001). In tropics available N, P and S are rarely adequate for plant growth unless they are replenished by mineralization of organic pools. Continuous application of inorganic fertilizer (N, P, & S) with or without organic manures to different cropping systems grown on varying soils can result in accumulation as residual forms in various organic and inorganic fractions of soil nutrients (Reddy et al., 1999a; Sammi Reddy et al., 2001; Sammi Reddy et al., 2002; Sammi Reddy et al., 2003b) where soil organic matter plays an important role. Therefore, it is essential to identify the soil organic matter fractions that may act as “source” and “sink” for available plant nutrients to improve their cycling in soil –plant system. Such information is also essential for modeling nutrient dynamics in the soil-plant system, and thereby, to resolve the nutrient management conflicts between loss of applied plant nutrients from the soil and poor fertilizer use efficiency. The C and N contents of humic acids from surface soils were higher than those from subsurface with more content of functional groups in forest soils (Joshi and Saxena, 1971). Joshi and Saxena (1971) studied the interaction of urea and ammonia with humic acid and found that considerable amount of N had been fixed by fulvic acid and more fixation occurred in case of urea. Maximum amount of N in soils of Rajasthan (Joshi and Saxena, 1971) was associated with FA (7-20%), followed by B-humus (6-15%), humin (5-15%), HA (3-7%) and hymetamelanic acid (traces- 1.3%). Long-term experiments on different soils revealed that the continuous application of NPK fertilizers at graded rates with or without FYM resulted in a marked accumulation of applied N mainly in hydrolysable N pools in surface soils. The incorporation of FYM with recommended rates of inorganic fertilizers resulted in greater contents of soil mineralizable N as compared to inorganic fertilizers alone (Sammi Reddy et al. 2003a).

Joshi and Saxena (1972) found that in Rajasthan soils maximum amount of organic P was associated with non-humic fraction (31-86%) followed by B-humus (12-24%), fulvic acid (10-25%) and humic acid (3-12%). Humin did not contain phosphorus. Recently Hedley et al. (1982) developed sequential extraction scheme to quantify various labile and stable organic P pools associated with different organic matter fractions in soil. Beck and Sanchez (1994), using path analysis, showed that inorganic P extracted

Table 15. Critical areas of imbalances in fertilizer consumption

Sl. No.	Agro ecological region	N	P_2O_5	K_2O	N: P_2O_5	Crops/ cropping system	N	P_2O_5	K_2O	N: P_2O_5
4.	N_8D_2	34.0	9.6	1	3.6	Rice-wheat	205.0	47.0	1	4.35
9.	N_8C_3	23.5	4.7	1	5.0	Maize-wheat	34.0	4.9	1	3.61
14.	O_8C_4	17.3	3.4	1	5.1	Rice-pulse	7.4	2.1	1	3.47
15.	$A_{15}C_4$	14.5	2.5	1	5.7	Potato-wheat	14.5	2.5	1	5.73
18.	D_2A_5	11.4	2.9	1	3.9	Sugarcane	21.1	4.2	1	5.00

Table 16. Effect of balanced (NPK) fertilization on agronomic efficiency of nitrogen (AE_N)

Crop	Control yield (kgha^{-1})	N applied (kgha^{-1})	AE_N (kg grain kg N^{-1})		Increase in AE_N (%)
			N alone	PK	
Rice (wet season)	2,740	40	13.5	27.0	100
Rice (Summer)	3,030	40	10.5	81.0	671
Wheat	1,450	40	10.8	20.0	85
Pearl millet	1,050	40	4.7	15.0	219
Maize	1,670	40	19.5	39.0	100
Sorghum	1,270	40	5.3	12.0	126
Sugarcane	47,200	150	78.7	227.7	189

Source: Ram (1998)

with NaOH was a major sink for added P in fertilized soil and organic P was a major source of labile P in unfertilized soil during 18 years of crop production. Tiessen et al. (1984) effectively explained differences in interactions among the P fractions in soils of Brazil. They found that labile P in Mollisols associated with inorganic bicarbonate and hydroxide extractable P. In Ultisols, they found that labile P was largely from organic P (Po). Under laboratory conditions, Sammi Reddy et al. (1996) reported that when inorganic P applied alone to a Vertisol, the P accumulated predominantly as labile inorganic P (NaOH-Pi), moderately labile inorganic ($NaHCO_3$-Pi) and calcium bound inorganic P (HCl-Pi). While application of farmyard manure with fertilizer P enriched long-term P fertility through accumulation in $NaHCO_3$-Po and NaOH-Po and a short-term P supply through HCl-Pi. Reddy et al. (1999a) observed similar changes in labile and moderately labile organic and inorganic P fractions with the application of FYM and fertilizer P to soybean-wheat system under field conditions except that there was no significant change in HCl-Po and –Pi fractions. The changes in $NaHCO_3$-Pi and -Po, NaOH-Pi and -Po were significantly correlated with the apparent P balance and were thought to be biologically active dynamic soil P pools and act as major source and sink of plant available P. In Typic Hapludalf, Zhang and MacKenzie (1997) reported that in the manure –inorganic system, soil organic P (Po) accumulated finally as Resin-P through NaOH-Po. Further, Resin-P along with

Table 17. Results of on-farm trials with wheat, pearlmillet and mustard at New Delhi

Crops	Treatment	Nutrient dose (kg/ha)			Yield (kg/ha)
		N	P_2O_5	K_2O	
Wheat	STCR target 5 t/ha	126	41	49	4887
	State Recommendation (SR)	120	40	60	4567
	Farmers' Practice (FP)	80	0	57	3662
Pearlmillet	STCR target 5 t/ha	100	43.5	42	2540
	SR	80	40	40	2020
	FP	46	0	23	1360
Mustard	STCR target 2.55 t/ha	97	35	75.5	2281
	SR	100	40	40	1890
	FP	60	0	57	1312

Source: Sharma et al. (2003)

NaOH extractable inorganic P (Pi) acted as major sink of the added P. A significant part of the added P was found as bicarbonate-Pi, which was assumed to constitute the immediate source of plant available P. In the inorganic system without manure, most bicarbonate-Pi was indirectly supplied from fertilizer P through labile NaOH-Pi.

Somani and Saxena (1976) observed that the highest amount of organic S was associated with HA (11-31%) followed by fulvic acid (4-32%) and humin (7-12%). 56-75% of organic S was present in humus fraction and remaining should be accounted for by the non-humic matter. Similar to P, $NaHCO_3$ and NaOH reagents are being used to extract not only readily soluble and adsorbed soil S but also to extract labile organic S associated with HI-reduced and C-bonded organic S from humic and fulvic acids (Bettany et al., 1980). Sulphur transformation studies under long-term trials on Vertisol and Alfisol soils revealed that the application of fertilizers (NPKS) and FYM increased the $NaHCO_3$ and NaOH extractable inorganic and organic S fractions. The significant correlation between soil mineralizable S and $NaHCO_3$ and NaOH extractable inorganic and organic S fractions suggested that these organic S fractions are highly mobile and could be available to plants over a short time (Sammi Reddy et al., 2001; Sammi Reddy et al., 2002).

6. Balanced Fertilization of Crops

It is being increasingly appreciated that balanced fertilization is a primary step towards improving NUE (Tandon, 1983, Acharya et al. 2003). In an era of multiple nutrient deficiencies a single nutrient approach can lower NUE. Balanced nutrition implies that there are no deficiencies, no excesses, no antagonisms and no negative interactions. All nutrients be at an optimum by themselves and in relation to each other enabling positive interactions to enhance yields.

Experimental results on the benefits of balanced fertilizer use are numerous. Yet fertilizer consumption in India is grossly imbalanced since beginning. It is tilted more towards N followed by P. This has serious implication on the yield response to fertilizers under farmers' field, decreases crop quality, affects adversely the availability of other nutrients, deteriorates soil fertility and degrade environment thus ultimately results in poor NUE. Some critical areas of imbalances in fertilizer consumption are presented in table 16 (Swarup, 1998). There is wide variation in the ($N:P_2O_5:K_2O$) consumption ratio of fertilizer from region to region and cropping system to system. A $N:P_2O_5$ beyond 3.5 is dangerously wide. The recent survey conducted in Vidisha and Rajgarh districts of M.P. showed that farmers are applying widely imbalanced fertilizer doses to major crops (Dalal et al., 2003). In other areas also imbalanced fertilization is the root cause for poor crop yields and soil fertility status. Table 17 clearly shows the importance of balanced P and K application in increasing the agronomic efficiency of N (AE_N) in a number of crops. Apart from NPK nutrients Zn, Fe, Mn, S & B have assumed importance due to their emerging deficiencies (Swarup and Ganeshamurthy, 1998). Long term field experiments revealed that the yields of different cropping systems increased significantly with the balanced application of NPK, Zn, & S as compared to N, NP and NPK treatments (Swarup, 1998). Studies conducted at Pantnagar and Modipuram also revealed that rice-wheat yield could be increased significantly by the application of Zn along with NPK as compared to NPK alone (Sharma, 2000)**.** Therefore, it is necessary to promote the balanced fertilization among the farmers to achieve higher NUE and crop yields while sustaining soil fertility.

7. Soil Test Fertilizer Recommendation for Efficient Fertilizer Use

General blanket fertilizer recommendations are static and can't commensurate with variability and changes in soil nutrient status, crop demand and crop management. Therefore, an alternative approach could be that fertilizer is applied based on recommendations emanating from Soil Test Crop Response Correlation (STCR) data. Among the various methods, the one based on yield targeting is unique in the sense that this method not only indicates soil-test based fertilizer dose but also gives the level of yield the farmer can hope to achieve if good agronomic practices are followed in raising the crop. The essential basic data required for formulating fertilizer recommendations for targeted yield are (i) nutrient requirement in kg/q of produce, grain or other economic produce, (ii) the percent contribution from the soil available nutrients, and (iii) the percent contribution from the applied fertilizer nutrients. All aspects of the target yield concept have been discussed (Subba Rao a nd Srivastav, 2001). Adjustment equations for desired yield targets for different crops growing on various soils have been worked out from basic data derived from several field experiments (Subba Rao and Srivastav, 2001). The STCR approach allows balanced fertilizer use under resource constraints and helps in maintaining soil fertility. When fertilizer availability and resources of the farmers are limited, planning for low yield target (but higher than the yield levels normally obtained by farmers) ensures efficient and economic use of available fertilizers. Data of the on-farm trials comparing the responses to applied fertilizer as per yield target vis-à-vis state recommendations and farmers' practice (FP) (Table 18) indicates that state recommendation (SR) gives much lower yield as compared to the fertilizer application as per yield target. Despite good research efforts on soil testing and expansion of soil testing advisory service through 514 soil testing laboratories in the country, the farmers have hardly taken advantage of it. By and large the farmers of most undeveloped states know well that food security and prosperity lie with the use of adequate amount of mineral fertilizers, but they are unable to go in for it due to resource constraints and lack of other facilities. Both private and government organizations should provide facilities of farm clinics/ diagnostic centers to the farmers so that their specific problems of poor crop performance due to inadequate and imbalanced use of fertilizer can be solved rapidly.

A fair amount of information is available on the nutrient management strategies for enhancing NUE in different cropping systems which if utilized can increase the NUE in large parts of the country.

Future Lines of Research

- Nutrients from manures are released over a number of seasons, and thus the nutrient contribution of manures must be worked out over a number of seasons for discounting them in working out the appropriate fertilizer doses. Therefore, there is a need to develop nutrient availability constants through decay series approach for manures of different quality. Subsequently, these availability constants are needs to be calibrated against field studies using Fertilizer Equivalence Approach.

- Studies on mobilization of P, Zn, Cu etc. from soil trough organic manures application are needed.

- Even though some research has been carried out to identify the soil organic matter fractions acting as source and sinks for available plant nutrients, the effect of different management practices on the mobilization of these nutrients need to be studied further.

- There is enormous potential of using crop residues as organic manures. Field data on *in-situ* decomposition of crop residues in relation to soil properties and crop productivity are needed.

- As the quality of organic manures at farmers' fields assumes great importance, On-farm programmes should include demonstration of modern scientific technology for preparation of quality manures.

- Even though few investigations were carried out on the residual effect of P on subsequent crops, more field studies are needed to quantify the effectiveness of residual P and S in different cropping systems.

- Coating of soluble phosphates with organic matter, and application of silicates and magnesium in conjunction with superphosphate or diammonium phosphate has been found useful but more conclusive data from field experiments are required.

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Lac Production- An Approach towards Natural Resource Management

Moni Thomas

Principal Scientist
Directorate of Research Services
JN Krishi Vishwa Vidhyalaya, Jabalpur – 482004 (M.P.)

Resource management is the most important component for production management in almost all the production system. Management of a robust resource inventory is the core area of many commercial production systems. Resource includes both Man and materials. The production system that neglects the former usually end up in a loss, thus Human resource management has given due to importance .This because of the reason that it is Man who puts the resources available for delivering the best output and company profits. Unfortunately, in many of the land based production system we often stress less on the human resource management.

The success of promotion of Lac production in Madhya Pradesh was due to stress Human resource management. Lac production is a natural resource based livelihood enterprise. Thus it is a combination of natural resource and human resource management for sustenance. We will discuss Human resource, natural resource and both tangible and intangible benefits due to promotion of Lac production.

Human resource

As Man manages the resources around him for production and development it is very important to train him pass the skill required in the most effective way and constantly upgrade and update his knowledge.

Skilled based training

Knowledge is the key to any production system. Flow of knowledge has to be smooth and in such a way that it is easily absorbed by the target beneficiaries. In a production system the target group subjected to skill based training. Skill based training is quite different from the traditional lecture based training where an expert delivers his lecture and moves on.

Skill based training is a slow process of transfer a knowledge through operational activities to a small group. Lac production involves ten operations throughout the crop season right from the identification of site, host trees to harvest of Lac. Thus the skill based training programme on Lac production is stretched to the entire four to five month period. As on date there were nearly 600 training touching 22046 people organised since year2000.

Demonstration

Most of the training was followed by demonstration of technology in the field in a participatory mode. In a participatory mode of technology demonstration, field, trees, manpower and inputs belongs to the participating farmers while the trainer helps them to practice the production operation step wise till the harvest of the Lac crop. This helped the trainees to learn by doing and correct their mistakes themselves through consultation. The demonstration is carried out in a farmer's field or on his trees but the rest of the trainees followed it on their host trees. This was successful and communication is always established to facilitate them to discuss their doubts if they find any difficult later. Skill based training and simultaneously demonstrating the technology helps them to practice what they learnt on the training day.

Sharing of experience

It is a human psychology to get excited during a success or a failure. Both teach many lessons if one analyses the process that has lead to a success or a failure. Farmers are keen observers of the events happening in their field or on their crop, therefore if facilitated to speak on their observation they come out with their experiences. And this is very important.

Encouraging to share the farmers experience was the backbone of success of the promotion of Lac production in MP. On a keen hearing one will realise not only their observations but also where they committed mistakes in the adaptation of a particular part of the production technology. Usually sharing of experience should always be in a group where each participant is given equal chance to speak. Thus sharing of experiences benefits all and rectification of mistakes also applies to all. Sharing is also a learning experience. After a couple of such sharing of experiences any new Lac grower gradually overcomes his shyness to communicate, develops confidence in himself and improves his expression and finally he turns to an agent of change.

Trainee to trainer

Technology is best absorbed if it is propagated by the local and in his local language. It is always thought that a Scientist knows more and therefore can communicate better, unfortunately in field it is otherwise.

Success of promotion of Lac production in MP was mainly due to facilitation of the Trainee to become Trainer. The trainee in during the skill based training, participatory demonstration and through sharing of experience turns out to be a promoter of the technology. Such individuals when identified and given few more strokes of training tips and skills turn out to be a Master Trainer. As he is well verse with the local dialect and understands the social as well as the geographical landscape of his village and neighbouring villages this person happens to be the best promoter of Lac production. In MP we have many such village Lac promoters who are volunteering to promote the enterprise.

Natural resource

Availability of host trees of Lac insect is a prerequisite for Lac production. Besides other natural resources that play an important role is soil type and soil moisture.

Although there are over 114 host trees of Lac insect but for commercial production Palash (*Butea monosperma*),Ber(*Zizyphus mauritiana*),Ghont(*Z xylophora*) Semialata (*Flemmingia semialata*) and Kusum(*Schleichera oleosa*) are chiefly utilized.

In MP *B monosperma* is widely distributed along field bunds, wasteland and forests and unutilized, but susceptible to felling to address the fuel, fencing and thatching needs of villagers. Similarly *Z mauritiana* is found in the backyards and field bunds. Lac production on these natural resources for a cash crop –Lac has translated the rural economy and environment in many villages in MP in the recent years.

As a *B monosperma* trees produces a minimum of two to three kilogram of Lac, a lac grower gets Rs150 to 200per tree. As a result of this income generation from *B monosperma* there is a social protection of this tree in the lac growing villages. Conservation of trees has lead to control soil erosion and soil moisture conservation.

Benefits from Lac production

There are both tangible and intangible benefits from any enterprises. Therefore each has to be looked differently.

Tangible

Tangible gains are immediate and visible gains. It is very important to have tangible gains to attract new entrants to the enterprise. Getting something like about Rs150 to 200 per *B monosperma* tree which was earlier considered of little value was a greater motivator. Economic gain attracts especially people in the rainfed areas where there a deficit of cash inflow during the agricultural season and long lean period.

A cash crop matters too much in Rainfed areas. It has been observed there have been increased investments in agriculture, children education and diversification in the Lac growing areas. Farmers are willing to adopt technologies and invest in inputs if there is surplus money at their disposal. Thus, lac production is resulting to an increase in the agricultural production in many areas.

Intangible

Conservation of *B monosperma* tree in the lac growing areas has resulted in an increase in the green cover and reduced the scale of deforestation due to constant vigil by the members of *Gram Surakhsha Samities* engaged in Lac production. *B monosperma* shed its leaves during February which either decompose or are ploughed during summer ploughing . This is helping in improving the soil flora and fauna.

There has been a development of leadership among Lac growers. In the village Mediaraas , Anuppur district the Sarpanch and almost all the ward members are Lac growers. Similarly the *Zila Panchayayt Adhyaksha* also happens to be associated with lac .There are many examples to quoted on the capacity building and empowerment of Lac growers. Village level volunteers promoting lac are also an example of new responsibilities that they are willingly delivering to the public at large.

Insect Pollinators and their Conservation

S.B.Das[1] and O.P. Veda[2]

[1]Professor
[2]Professor & Head (Entomology) and Director of Instruction
J.N. Krishi Vishwa Vidhyalaya, Jabalpur – 482 004 (M.P.)

Pollination is the transference of pollen grains from the anther of a flower to the stigma of the same flower or of another flower of the same or sometimes allied species.

Pollinations are of two kinds and both the methods are widespread in nature:

1. Self – Pollination or Autogamy: Self - pollination is the transference of pollen grains from the anther of a flower to the stigma of the same flower evidently bisexual. In self – pollination only one flower is concerned to produce the offspring.

The self-pollinated crop species occupy less than 15%. The self-pollinated crop species also benefit from cross pollination and hybrids grown these days require pollination in order to bear satisfactory marketable crops.

2. Cross – Pollination or Allogamy: Cross-pollination is the transference of pollen grains from one flower to another flower borne by the same plant or by two separate plants of the same or allied species irrespective of whether the flowers are bisexual or unisexual. Here two flowers are involved and, therefore a mingling of two sets of parental characters takes place resulting in better offspring.

The cross-pollinated crop species occupy more than 85%. Some crops also exhibit often cross pollinated nature. The genetic architecture of such crops is intermediate between self- and cross-pollinated species.

Cross - pollination is brought about by external agents:

A. Abiotic agents:

(a) Wind: Pollination aided by wind is known as Anemophily. Important features of anemophilus plants are **–**

- **(i)** Flowers are small , inconspicuous and unattractive
- **(ii)** Pollen are dry and light in weight
- **(iii)** Stigma is feathery with large surface area *eg.* maize, barley, wheat, sugarcane

(b) Water: Water carries pollen from one plant to other and helps in pollination, is known as Hydrophily.

B. Biotic agents: Birds, bats and insects are important biotic agents helping in pollination. Humans also can be pollinators, as the gardener who hand pollinates his garden blossoms, or the farmer, who climbs his date palms to pollinate them.

(a) Zoophily: Birds, squirrels, bats, snails *etc.*, act as useful agents of pollination.

Bats are important pollinators of some tropical flowers. Birds, particularly hummingbirds, honeyeaters and sunbirds also accomplish much pollination, especially of deep-throated flowers. Other vertebrates, such as monkeys, rodents and lizards have been recorded pollinating some plants.

(b) Entomophily: Pollination by insects is of general occurrence among plants. Entomophilous or insect – loving flowers have various adaptations by which they attract insects and use them as conveyors of pollen grains from one flower to another for the purpose of pollination. Principal adaptations are colour, nectar and scent. Besides these there are also some special adaptations in certain flowers, such as: overall flower size, the depth and width of the corolla, amount of nectar, composition of nectar, *etc.* For example, birds visit red flowers with long narrow tubes and lots of nectar, but are not as strongly attracted to wide flowers with little nectar and copious pollen, which are rather more attractive to beetles.

When we talk about insect pollinators immediately that comes in mind are honey bees and butterflies, but there are also many other insects that perform this job for flowering plants, as well.

In fact, of the total pollination activities, over 80% is performed by insects and bees contribute nearly 80% of the total insect pollination, and therefore, they are considered the best pollinators.

Types of Insect Pollinators:

1. Order: Lepidoptera:

Lepidopterans (butterflies and moths) also pollinate to a small degree. They are not major pollinators of our food crops, but various moths are important for some wildflowers, or other commercial crops such as tobacco.

Butterflies and Moths

Wings covered with tiny scales; mouth parts are coiled tube. Moths have feathery antennae and are often seen at dusk; butterflies have club-shaped antennae.

A. Butterflies:

a. Family: Papilionidae: Swallowtails

Large and stunningly beautiful; black and yellow or black, yellow, orange and iridescent blue.

b. Family: Pieridae: Whites and Sulphurs

Very common; white, orange, or yellow; medium-sized.

c. Family: Lycaenidae: Gossamer-winged butterflies

Blues and Hairstreaks. Gray hairstreak, most common hairstreak in the gardens. Western pygmy-blue, one of the world's smallest.

d. Family: Nymphalidae: Brushfoot butterflies

Diverse group of brightly colored small and large butterflies. Appear to have only 4 legs–the front pair is reduced and held close to the body.

e. Family: Hesperiidae: Skippers

Common checkered skippers, Northern cloudywings, Pahaska skippers in the gardens.

B. Moths:

a. Family: Sphingidae: Sphinx or Hawk moths

Often mistaken for hummingbirds due to size, shape, and hovering while nectaring. Mostly seen pollinating night-blooming flowers like *datura* and cactus.

2. Coleoptera:

Beetles:

Thick front wings (elytra) join in a straight line down the back. With over 300,000 species, beetles are the most diverse animal family in the world.

a. Family: Scarabaeidae: Flower scarabs

Bee-like; *Trichiotinus* sp. commonly seen with its head buried in thistle flower and fury abdomen sticking up.

b. Family: Cantharidae: Soldier beetles

Long, narrow; yellow, orange, or red with black markings. Commonly seen in late summer on yellow flowers of the sunflower family.

c. Family: Mordellaidae: Tumbling flower beetles

Tiny; "Volkswagen Bug"-shaped. Common on white and yellow flowers.

d. Family: Buprestidae: Metallic wood-boring beetles

Elongated; with distinctive yellow & black markings.

e. Family: Curculionidae:

Weevil, *Elaeidobius kamerunicus* pollinating oil palm.

3. Diptera: Green bottle or carrion flies are important for some flowers, usually for thgose ones that exude a fetid odor. Some male *Bactrocera* fruit flies are exclusive pollinators of some wild *Bulbophyllum* orchids that have a specific chemical attractant present in their floral fragrance. Some Dipterans (flies) may be the main pollinators in higher elevations of mountains.

Flies: One pair of wings, held horizontally rather than folded; mimic bees and wasps; large, prominent eyes; short antennae.

a. Family: Stratiomyidae: Soldier flies

Small, colorful flies with Y- or T-shaped antennae.

b. Family: Bombyliidae: Bee flies

Ornately patterned wings; covered with fine hair; many with fuzzy, striped abdomen similar to bees; wings held horizontally rather than folded like a bee.

c. Family: Syrphidae: Flower Flies

Syrphid flies, also known as hover flies for their ability to hover in flight, are common predators of aphids and other soft bodied insects. Because Syrphid flies feed on pollen, nectar, and aphid honeydew, they also act as pollinators and pollinate Lady's finger, carrot, pulses *etc.*

Colorful mimics look like bees and wasps as a protective strategy; large black flower fly is common in the gardens.

d. Family: Tachinidae: Tachinid flies

Most of them are robust with spiny abdomens. Highly diverse and important pollinators; often confused as house flies.

4. Hymenoptera:

Bees and Wasps

Two pair of wings. Young bees feed on plant food; young wasps on animal food.

A. Bees:

a. Family: Andrenidae: Mining bees

b. Family: Halictidae: Sweat bees

Small to medium-sized; frequently glittering green, copper, or gold.

c. Family: Megachilidae: Megachilid bees

Leafcutter, Mason and Resin bees; carry their pollen on "pollen brushes" under their abdomen rather than in "baskets" on their legs.

d. Family: Apidae:

Carpenter bees, large, hairy black bees, Honey bees, social bee; has become one of the most common bees in the country; tawny colored back, black and white striped abdomen.

Digger bees- hairy, robust; large range of size.

B. Wasps:

Wasps are important pollinators of some plants.

a. Family: Sphecidae: Sphecid Wasps

Solitary wasps: mud daubers, sand wasps, hunting wasps. Wings folded over backs; generally hairless; brightly colored.

b. Family: Scoliidae: Scoliid wasps

Large and hairy; most common Scoliid species are black with a hairy, red abdomen.

c. Family: Pompilidae: Spider wasps

Tarantula hawk wasp is most common, very large with blue-black body and scarlet wings.

d. Family: Vespidae: Vespid wasps

Paper wasps, yellowjackets, hornets, mason, and potter wasps. Wings folded lengthwise at rest.

e. Family: Agaonidae:

Fig wasps, *Blastophaga psenes* pollinating Fig (both Smyrna and Capri fig).

1. Bees:

The most recognized pollinators are the various species of bees, which are plainly adapted to pollination. Bees typically are fuzzy and carry an electrostatic charge. Both features help pollen grains adhere to their bodies, but they also have specialized pollen-carrying structures; in most bees, this takes the form of a structure known as the scopa, which is on the hind legs of most bees, and/or the lower abdomen (*e.g.* of megachilid bees), made up of thick, plumose setae. Honey bees, bumblebees and their relatives do not have a scopa, but the hind leg is modified into a structure called the corbicula (also known as the "pollen basket"). Most bees gather nectar, a concentrated energy source, and pollen, which is a high protein food, to nurture their young, and inadvertently transfer some among the flowers as they are working. Euglossine bees pollinate orchids, but these are male bees collecting floral scents rather than females gathering nectar or pollen. Female orchid bees act as pollinators, but of flowers other than orchids. Eusocial bees such as honey bees need an abundant and steady source of pollen to multiply.

a. Honey bees:

Among insects, honey bees play major role in pollination. Honey bees and flowering plants have co-evolved in the evolutionary process. True honey bees belong to *Apis* spp. They are the most valuable pollinators of commercial crops.

Honey bees travel from flower to flower, collecting nectar (later converted to honey), and pollen grains. The bee collects the pollen by rubbing against the anthers. The pollen collected on the hind legs, in the "pollen basket". As the bee flies from flower to flower, some of the pollen grains are transferred onto the stigma of other flowers. Nectar provides the energy for bee nutrition; pollen provides the protein. When bees are rearing large quantities of brood , bees deliberately gather pollen to meet the nutritional needs of the brood. A honey bee that is deliberately gathering pollen is up to ten times more efficient as a pollinator than one that is primarily gathering nectar and only unintentionally transferring pollen.

It is estimated that 60-80 percent of the grain crops are pollinated by insects, bulk of it by bees. Every time the bees collect Rs. 100/- worth of honey, they make Rs 2000/- worth seeds and fruits by pollinating the flowers.

b. Bumble Bees:

Bumble bees are excellent pollinators, and are generalist foragers that visit a diversity of flowers a few groups of flowers, such as willows and lupines, are particularly important to them. Bumble bees practice what is called ‘buzz pollination’ where they grab onto the anthers, the pollen-bearing structure, of certain flowers and buzz their flight muscles to release the pollen. This behavior is especially important in pollinating tomatoes.

Bumble bees are social insects that build their nests in the ground, often in abandoned mouse burrows, empty bird nests, and under fallen grass. The mated queen over winters in the soil while the rest of the colony dies at the onset of cold weather. In early summer, the queen establishes a new nest and rears the first worker brood. These workers are small, sterile females that enlarge the nest, forage, and tend to the next generation of workers. These are larger bees, due to changed nest conditions, such as increased temperature, cell size, and food availability. The fertile females (next year’s queens) and males (called drones) are produced in the late summer and the sole function of the latter is to fertilize the queens before dying.

c. Sweat Bees:

Sweat bee is the common name for bees in the Halictidae family, and they are named for their attraction to the salts in human perspiration. Most sweat bees are small to medium in size, 1/8 to 3/8 of an inch long. They are generally black or metallic, and some are bright green or brassy yellow. Sweat bees are among the most common bees.

All species nest in the ground. Halictids have a range of nesting habits, from dispersed solitary nests, to densely situated ones with individual bees sharing common entrance ways, to primitive social arrangements. Halictid bees are common insects and good general pollinators.

d. Mining Bees:

Andrenid bees, commonly called mining or digger bees, are another common pollinator. They resemble the typical honey bee in shape and size. Their bodies are dark in color and covered with fine, light brown or yellow hairs.

Andrenid bees have chewing-lapping mouthparts used to manipulate and collect nectar and pollen. The protruding, 'lapping' mouthpart is shorter in mining bees than honeybees, giving them the common name of short-tongued bees. As their name suggests, mining bees dig single nests in the soil. Mining bees are solitary and do not form large, socially organized nests. However, thousands of individuals may nest in a general area with good nesting habitat.

e. European / Indian Honey Bees:

European / Indian honey bees play a critical role in pollinating crops. They are the pollinator we know how to best manage and move for agriculture. However, in recent years they have been plagued by pests and diseases.

2. Wasps:

Like bees, yellow jackets and hornets belong to the insect order Hymenoptera. These species are beneficial to humans for pest control and some pollination. In addition, thousands of small wasp species are parasites of other insect pests, particularly aphids and caterpillars. Without parasitic wasps, pests would overtake most crops.

a. Yellow jackets:

Yellow jackets can be both beneficial and problematic wasps. They are important predators and scavengers, helping to control pests and recycle organic materials, but can also be a threat to humans due to their ability to sting repeatedly in defense of their nests. Yellow jackets are relatively short and stout, holding their legs close to their body compared with other wasps. Paper wasps, for example, are more slender and have long, dangling legs. All yellow jackets are striped either black and white or black and yellow. They are rapid fliers, and are more aggressive than other types of wasps. Their nests are always enclosed with a papery envelope and can be found in the ground, hanging from leaves or tree branches, and occasionally in wall voids.

b. The Bald or White Faced Hornet:

The Bald or White Faced Hornet is scientifically not considered to be a hornet, but a large wasp. Its coloration is black and white. Their nests are found in trees or shrubs and they become very large by summer's end. The size of the nest, number of individuals in a colony, and the active time beyond summer all depend on the species.

5. Other insects:

Midges and even thrips or ants can sometimes pollinate flowers. Other insect orders are rarely pollinators, and then typically only accidentally (*e.g.*, Hemiptera such as Anthocoridae, Miridae).

Insect Pollination Types:

The pollination types are classified based on the insect groups that pollinate the crops and below is the list of pollination classes:

Table1: Insect pollination types

Insect group	Pollination Type
Bees	Mellitophily
Beetles	Cantharophily
Butterflies	Psychophily
Carrion flies	Saprophily
Hawk moths	Sphingophily
Small moths	Phaleophily
Syrphid and Bombylid flies	Myophily

Installation of bee hives in various crops:

Number of bee hives to be installed in various crops are listed below:

Table 3: Number of bee hives installed in various crops

Common Name	Number Of bee hives per hectare
Almonds	2-3
Apples (dwarf)	3
Apples (normal size)	1
Apples (semi dwarf)	2
Apricots	1
Buckwheat	0.5 - 1
Clovers	1 - 2
Cucumbers	1-2
Lucerne	3-5
Muskmelon	1-3
Peaches	1
Pears	1
Plums	1
Pumpkins	1
Raspberries	0.7 - 1.3
Squash	1-3
Strawberries	1 - 3.5
Sunflower	1
Watermelon	1-3

Table 2. Various crops pollinated by insect pollinators

Common name	**Scientific name**	**Pollinator /s**
Condiments and Spices		
Cardamom	*Elettaria cardamomum*	Honey bees, Solitary bees
Chile pepper, Red pepper, Bell pepper, Green pepper	*Capsicum annuum, C. frutescens*	Honey bees, stingless bees (*Melipona* spp.), bumblebees, solitary bees, hover flies
Coriander	*Coriandrum sativum*	Honey bees, Solitary bees
Fennel	*Foeniculum vulgare*	Honey bees, Solitary bees, flies
Tamarind	*Tamarindus indica*	Honey bees (*Apis dorsata*)
Fibre Crops		
Cotton	*Gossypium spp.*	Honey bees, Bumblebees, Solitary bees
Jute	*Corchorus capsularis*	Bees
Sunhemp	*Crotalaria juncea*	Honey bees, other bees
Fodder Crops		
Alfalfa, Lucerne	*Medicago sativa*	Alfalfa leafcutter bee, Alkali bee, Honey bees
Chestnut	*Castanea sativa*	Honey bees, Solitary bees
Clover (not all species)	*Trifolium* spp.	Honey bees, Bumblebees, Solitary bees
Red clover	*Trifolium pratense*	Honey bees, Bumblebees, Solitary bees
Fruit Crops		
Almond	*Prunus amygdalus*	Honey bees, bumblebees, Solitary bees , flies
Apple	*Malus domestica, or Malus sylvestris*	Honey bees, orchard mason bee, Bumblebees, Solitary bees (*Andrena* spp., *Halictus* spp., *Osmia* spp., *Anthophora* spp.), Hover flies (*Eristalis cerealis, E. tenax*)
Apricot	*Prunus armeniaca*	Honey bees, Bumblebees, Solitary bees, flies
Avocado	*Persea americana*	Honey bees, Stingless bees, Solitary bees
Banana	*Musa* spp.	Bees
Carambola	*Averrhoa carambola*	Honey bees, Stingless bees
Cashew	*Anacardium occidentale*	Honey bees, Stingless bees, bumblebees, Solitary bees (*Centris tarsata*), Butterflies, flies, hummingbirds
Cherry	*Prunus avium , P. cerasus*	Honey bees, Bumblebees, Solitary bees, flies
Citrus	*Citrus spp.*	Honey bees, Bumblebees
Custard apple	*Annona squamosa*	Nitidulid beetles
Falsa	*Grwia asiatica*	Honey bees , flies, wasps
Fig	*Ficus spp.*	Fig wasps (*Blastophaga psenes*)
Grape	*Vitis spp.*	Honey bees, Solitary bees, flies
Guava	*Psidium guajava*	Honey bees, Stingless bees, Bumblebees, Solitary bees (*Lasioglossum* spp.)
Jujube	*Zizyphus jujuba*	Honey bees, Solitary bees, flies, beetles, wasps
Litchi	*Litchi chinensis*	Honey bees, flies
Loquat	*Eriobotrya japonica*	Honey bees, Bumblebees
Mandarin orange	*Citrus reticulata*	Honey bees, bumblebees
Mango	*Mangifera indica*	Honey bees, Stingless bees, flies, ants, wasps
Papaya	*Carica papaya*	Honey bees, thrips, large sphinx moths, Moths, Butterflies
Peach, Nectarine	*Prunus persica*	Honey bees, Bumblebees, Solitary bees, flies
Pear	*Pyrus communis*	Honey bees, Bumblebees, Solitary bees, Hover flies (*Eristalis* spp.)
Persimmon	*Diospyros kaki, D. virginiana*	Honey bees, Bumblebees, Solitary bees
Plum	*Prunus domestica, P. spinosa*	Honey bees, Bumblebees, Solitary bees, flies
Pomegranate	*Punica granatum*	Honey bees, Solitary bees, beetles
Raspberry	*Rubus idaeus*	Honey bees, Bumblebees, Solitary bees, Hover flies (*Eristalis* spp.)
Sapodilla	*Manikara zapotilla*	Thrips
Strawberry	*Fragaria spp.*	Honey bees, Stingless bees, Bumblebees, Solitary bees (*Halictus* spp.), Hover flies
Sweet lime	*Citrus limettoides*	Bumble bees, thrips, mites , flies
Watermelon	*Citrullus lanatus*	Honey bees, bumblebees, solitary bees
Oilseeds		
Groundnut	*Arachis hypogea*	Honey bees, other bees
Linseed	*Linum usitatissimum*	Honey bees, Bumblebees, Solitary bees
Mustard	*Brassica alba, Brassica hirta, Brassica nigra*	Honey bees, Solitary bees (*Osmia cornifrons, O. lignaria*)
Niger	*Guizotia abyssinia*	Honey bees , other bees
Oil palm	*Elaeis guineenis*	Honey bees
Rapeseed	*Brassica napus*	Honey bees, Solitary bees
Safflower	*Carthamus tinctorius*	Honey bees, Solitary bees
Sesame	*Sesamum indicum*	Honey bees, Solitary bees, wasps, flies
Soybean	*Glycine max*	Honey bees, bumblebees, Solitary bees
Sunflower	*Helianthus annuus*	Honey bees, bumblebees, Solitary bees

Ornamentals		
Rose	*Rosa spp.*	Honey bees, Bumblebees, Carpenter bees, Solitary bees, Hover flies
Others		
Cactus, Prickly pear	*Opuntia* spp.	Bumblebees, Solitary bees
Plantation Crops		
Beetle nut	*Areca catechu*	Ants , flies , thrips
Cocoa	*Theobroma cacao*	Midges
Coconut	*Cocos nucifera*	Honey bees, Stingless bees
Coffee	*Coffea spp.*	Honey bees, Stingless bees, Solitary bees
Pulses		
Cowpea, Black-eyed pea	*Vigna unguiculata*	Honey bees, Bumblebees, Solitary bees
Lima bean, Kidney bean, Haricot bean, Adzuki bean, Mungo bean, String bean	*Phaseolus* spp.	Honey bees, Solitary bees
Pigeon pea,	*Cajanus cajan*	Honey bees, solitary bees (*Megachile* spp.), Carpenter bees
Vegetables		
Beans	*Dolichos* spp.	Honey bees, Solitary bees
Beet	*Beta vulgaris*	Hover flies, Honey bees, Solitary bees
Bottle gourd	*Lagenaria siceraria*	Honey bees, bugs
Brinjal, Eggplant	*Solanum melongena*	Honey bees, Bumblebees, Solitary bees
Broad bean	*Vicia faba*	Honey bees, Bumblebees, Solitary bees
Broccoli	*Brassica oleracea cultivar*	Honey bees, Solitary bees
Brussels sprouts	*Brassica oleracea Gemmifera group*	Honey bees, Solitary bees
Cabbage	*Brassica oleracea Capitata* group	Honey bees, Solitary bees
Carrot	*Daucus carota*	Flies, Solitary bees
Cauliflower	*Brassica oleracea Botrytis* group	Honey bees, Solitary bees
Celery	*Apium graveolens*	Honey bees, Solitary bees, flies
Chinese cabbage	*Brassica chinensis*	Honey bees, Solitary bees
Cluster bean	*Cyamopsis tetragonoloba*	Honey bees
Cucumber	*Cucumis sativus*	Honey bees, Squash bees, Bumblebees, Leafcutter bee, Solitary bees
Lady's finger	*Abelmoschus esculentus*	Honey bees (*Apis cerana*), Solitary bees (*Halictus* spp.)
Musk melon	*Cucumis melo*	Honey bees, Squash bees, bumblebees, Solitary bees (*Ceratina* spp.)
Onion	*Allium cepa*	Honey bees, Solitary bees
Pumpkin, Gourd	*Cucurbita* spp.	Honey bees, Squash bees, Bumblebees, Solitary bees
Sword bean	*Canavalia* spp.	Solitary bees, Carpenter bees (*Xylocopa confusa*)
Turnip, Canola	*Brassica rapa*	Honey bees, Solitary bees (*Andrena ilerda, Osmia cornifrons, Osmia lignaria, Halictus* spp.), flies

Effect of Bee Pollination on Crop:

1. It increases yield in terms of seed yield and fruit yield in many crops.
2. It improves quality of fruits and seeds.
3. Bee pollination increases oil content of seeds in sunflower.
4. Bee pollination is a must in some self-incompatible crops for seed set *e.g.* sunflower
5. If improper seed set occurs fruit shape is deformed resulting in decreased market value *e.g.* apple
6. Seed sets occur only if bee sits to trip the flowers *e.g.* Lucerne. These plants have tubular flowers with five petals joined at base. They posses one large standard petal, 2 smaller petals on sides and 2 keel petals holding staminal column. When bee sits on keel petal, staminal column strikes against standard petal resulting in shattering of pollen. This is called tripping.

Impact of bee pollination on seed / fruit yield:

Yield increment of different crops with managed pollination over control is presented in Table 4.

Table 4. Yield increment of different crops with managed pollination over control

Crops	Percent increase in yield
Fibre Crops	
Cotton	17-19
Forage Seed Crops	
Lucerne	112
Fruits and Nuts	
Apple	44
Spices and Condiments	
Cardamom	21-37

Oilseed Crops	
Gingely	25
Mustard	17- 43
Rapeseed	30-50
Sunflower	32-48 (6.5% oil content)
Vegetable and Vegetable Seed Crops	
Cabbage	40
Cauliflower	37
Cucurbitaceous Vegetables	30-100
Coriander	187
Lettuce	9
Onion	93
Radish	34

Economic Importance:

The value of bee pollination in human nutrition and food for wildlife is immense and difficult to quantify.

It is commonly said that about one third of human nutrition is due to bee pollination. This includes the majority of fruits, many vegetables or their seed and secondary effects from legumes such as lucerne and barseem fed to livestock.

The worldwide economic value of the pollination service provided by insect pollinators, bees mainly was (Euro) 153 billion in 2005 for the main crops that feed the world. This figure amounted to 9.5% of the total value of the world agricultural food production.

Qualities Which Makes Honey Bees Good Pollinators:

The honey bees have the following qualities which makes them good pollinators:

1. Body covered with hairs and has structural adaptations for carrying nectar and pollen.
2. Bees do not injure the plants.
3. Adult and larvae feed on nectar and pollen which is available in plenty
4. Considered as superior pollinators, since store pollen and nectar for future use.
5. No diapause is observed and needs pollen throughout the year.
6. Body size and proboscis length is very much suitable for many crops
7. Pollinate wide variety of crops.
8. Forage in extreme weather conditions also.

Scope of Bee Keeping For Pollination in India:

Total area of bee dependant crops in India is around 50 million hectare. One hundred and fifty million colonies are needed to meet this, at the rate of 3 colonies per hectare. In India at present, there are only 1.2 million colonies exist. Hence there is a wide scope for expansion of bee keeping for pollination in India.

Decline In The Insect Pollinators Population

The term pollinator decline refers to the reduction in abundance of pollinators in many ecosystems during the past few years. This decline has become a major environmental issue today.

In fact pollinators are products of millions of years of evolution which are eroding at fast rate from the globe. The ecological consequence of contemporary agriculture can be viewed from various angles analyzing each component of agriculture- deforestation for expanding agriculture, soil, irrigation, fertilizer, pesticide, and agronomic practices with their influence on the environment of plants and thereby pollinators.

Factors that Cause Decline of Pollinators:

Factors that cause the loss of pollinators include –

1. Declining biodiversity
2. **Pesticide pollution**
3. **Habitat loss**
4. **Loss of nectar corridors**
5. **Hive destruction**
6. Honey hunting
7. **Light pollution**
8. **Air pollution**
9. **Rapid transfer of parasites and diseases of pollinator species around the world**
10. Threat by invasive honey bees
11. Global warming and climate change
12. Level of knowledge/ awareness

1. Declining biodiversity:

Decline in the biodiversity results in the decline in pollinators and *vis-a-vis*. About 75% of the genetic biodiversity of agricultural crops are lost since the beginning of the 20th century from the earth and it is estimated that 25% of the world's species present in the mid 1980 will be lost by 2015.

Rice, one of the most important cereal crops in South East Asia, only 10 varieties cover third-fourth of rice area, whereas over 30,000 grown before in the same areas in India.

The apicultural problems are severe in the developing countries.

The cost of conserving biodiversity is far less than the penalty of allowing its degradation.

Global extinction rate of species are accelerating at an alarming rate.

It has been estimated that 0.2-0.3% of all species are lost every year. Range of 5-10% of the tropical forest species may become extinct within the next 30 years. It is estimated that 60,000 species will be eliminated in the foreseeable future and 50,000 species which includes insect pollinators also, will be at risk of extinction in the next half of the century.

2. Pesticide pollution :

Pesticides have adverse effects on the bees. Contact insecticides, kill the organisms when it comes in direct contact while systemic insecticides, contaminate nectar and pollen, and kill the bees in the hive.

Dusts and wettable powders are more hazardous to bees than emulsifiable concentrates and granules.

Commercial farmers have no sufficient understanding of pesticide handling, safe application and pollution to the environment. Both the misuse and excessive use of pesticides disturb the natural ecosystem and produce serious environmental problems adding costs in four ways to the people:

i) Health related expenses,

ii) Environmental pollution,

iii) Yield loss due to non-target pesticide application resulting in pesticide induced pest resurgence and destruction of natural enemies, pesticide resistance and

iv) Financial burden both to poor farmers and the country as a whole

Pesticide problem on pollinators is severe in the developed country like USA (loss of about 320 US$ million per year) and is equally important for other countries as well.

It is a sort of crime to apply most insecticides on crops during bloom or to allow the pesticide to drift to blooming weeds that bees are visiting. Bumble bees are in great danger in cotton-growing areas, since they are exposed to repeated application of pesticides during blooming periods while the bees are foraging. Yet such applications are frequently done, with little enforcement of the bee protection directions.

Further, pesticide misuse has reduced the number of beekeepers in the business. Moreover, it affects the native wild bees even more, because they have no caretaker to move them to safe places or protect them.

Widespread aerial applications for mosquitoes do not leave any safe area where wild insect pollinators can reproduce and increase their population.

Actual damage to bee populations is a function of the degree of toxicity of the compound, in combination with the place where it has been applied. A highly potent insecticide applied only to the soil, for instance, would be expected to kill mainly soil-dwelling arthropods.

Bee kill rate per hive:

The kill rate of bees in a single bee hive can be classified as below:

Table 5. Kill rate of bees due to pesticides

Mortality level	Kill rate of bees / day / hive
Normal	< 100
Low	200-400
Moderate	500-900
High	> 1000

Classification of pesticide toxicity:

Insecticide toxicity is generally measured using LD50 – the dose of a toxicant that will kill 50% of the test organism to which it is administered. Toxicity thresholds are generally set as mentioned below:

Table 6. Pesticides toxicity levels on honey bees

Toxicity level	LD50 (µg /bee)
Highly toxic	Less than 2
Moderately toxic	2 to 10.99
Slightly toxic	11 to 100
Practically non-toxic	More than 100 to adult bees

Constraints:

- LD50 is an incomplete measure of toxicity to honeybees and other social insects because it is a measure of individual toxicity, not colony toxicity.
- It does not account for the ways in which bee behavior can mitigate or exacerbate the effects of the pesticide on the colony.
- For example, a moderate to low toxicity pesticide (by LD50 measurement) which is used in dust form and is collected and concentrated along with pollen can be highly lethal to the colony.
- On the contrary, a pesticide which is so toxic that the exposed bees die in the field can be less dangerous to the colony than a less toxic pesticide which allows the exposed bees to return to the hive and contaminate their fellows.

- Likewise, a highly toxic pesticide is "safe" for bees if it is applied at a location without blooming *i.e.* having no flowers which would attract the bees.
- Furthermore, LD50 studies are conducted against adult bees and do not measure the effects on larvae, *etc.*

Degree of pesticides toxicity:

A large number of pesticides have been tested against honey bees and on the basis of their toxicity they have been classified as follows:

It is clear that pesticide spray has been one of the various factors for decline in the population of the pollinators. Therefore, it is essential to survey and collect insect species in various crop plants during their flowering periods, identify and conserve them, and explore their potentiality as crop pollinators.

3. Habitat loss:

Natural forests that play a vital role in maintaining ecological balance, providing energy, animal fodder and timber and recharging water tables, are being degraded day by day causing habitat loss of other life system and ultimately threatening biodiversity and associated pollinators. A constant rise in the population, higher rate of deforestation, and over-exploitation of resources with expansion of farm lands for agriculture and rearing livestock, cause a continuous depletion of the forest resources . To meet the need, the agriculture is expanding and pollinators' habitat is being lost so rapidly that sustainable agriculture is in jeopardy

When fallow / uncultivable land is being included in some farm areas, it removes the habitat and homes of wild bees.

Use of large tractor mounted implements may make the farms and roadsides look neat and clean, but they remove bee habitat at the same time.

Old native crops, which were very good for pollinators have been disappearing.

Urban and suburban development taking place over former areas of pollinator habitat and forests are replaced by monoculture which causes serious loss of pollinators.

4. Loss of nectar corridors:

Migratory pollinators *viz.* monarch butterflies and some humming birds require a continuous supply of nectar sources to gain their energy requirements for the migration. In some areas agriculture or urban / suburban development has disrupted and broken up these traditional corridors, and the pollinators have to

Table 7: Degree of pesticides toxicity on honey bees

Toxic Insecticides		
Highly	**Moderately**	**Relatively Non- toxic**
Severe bee losses can be expected if the following materials are used when honey bees are present at treatment time or within a day thereafter.	These can be used in the vicinity of honey bees if the dosage, timing, and method of application are correct. However, they should not be applied directly on honey bees in the field or at the hives	This group of materials can be used with a minimum of injury
Acephate	Demeton (Systox)	2,4-d
Carbaryl	Disulfoton (Disyston)	Aldicarb
Carbofuran (Furadan)	Endosulfan	*Bacillus thuringensis* (Dipel)
Chlorpyriphos	Phorate	Coumaphos
Cypermethrin		Dicofol
Demeton		Dicofol (Kelthane)
Diazinon		Ethion
Dichlorvos		Methoxychlor
Dimethoate		Petroleum oils
Fenvalerate		Pirimicarb
Fenitrothion		Pyrethrum
Fensulfothion (Dasanit)		Rotenone
Fenthion		Trichlorfon
Imidacloprid		
Lindane		
Malathion		
Methamidophos		
Methiocarb		
Methomyl		
Methoxychlor		
Methyl parathion		
Mevinphos (Phosdrin)		
Monocrotophos		
Oxydemeton methyl		
Parathion		
Permethrin		
Phorate		
Phosphamidon		

find alternative routes or discontinue migration.

5. Hive destruction:

Bees are often viewed negatively by homeowners/ property owners. It is generally observed that homeowners / property owners will search for options for the removal of the bees or wasps from their premises rather than protecting them.

Beekeepers find more difficulty in exploring safe locations for bee hives, as more people are inclined to threat the local beekeeper if they are stung.

6. Honey hunting:

As a result of habitat destruction and honey hunting by local honey hunters, the wild honeybees have been declining.

7. Light pollution:

Increasing use of external artificial lights, interfere with the navigational ability of many moth species. As moths are important pollinators of night blooming flowers and their disorientation may reduce or eliminate the plants ability to reproduce, thus leading to long term ecological effects.

8. Air pollution:

Air pollution from automobiles , factories and power plants has been inhibiting the ability of pollinators such as bees and butterflies to find the fragrances of flowers. Pollutants such as ozone, hydroxyl, and nitrate radicals bond quickly with volatile scent molecules of flowers, which consequently travel shorter distances intact which are assessed feebly by the insect pollinators. Hence, the pollinators are forced to travel longer distances to find flowers providing them nectar, and thus the nearby flowers receive inadequate pollination to reproduce and diversify.

9. Pests and diseases of pollinator species- their rapid transfer around the world:

Increased international commerce has moved diseases , insect pests and mites to new areas of the world, causing much loss of bees particularly in the areas where they do not have much resistance to these pests and diseases.

10. Threat by invasive honey bees:

Many native pollinators decline in population when faced with competition from invasive honey bees.

11. Global warming and climate change:

Global warming is caused by something known as the green house effect, brought about by the ability of the atmosphere to be selective in its response to different types of radiation. Carbon dioxide (56%), Methane (14%), Chloro-flouro carbons (23%) and Nitrous oxide (7%) are main green house gases of which, Carbon dioxide accounts more than 50% for global warming.

It is estimated that the atmospheric temperature would increase by 1.5 to 5.5ºC by the year 2030, causing loss of 10-15% arable productive costal land due to melting of polar ice caps and raise sea level and Carbon dioxide concentration would increase from 290 ppm (100 years ago) to 350 ppm today and likely to go up to 440-500 ppm by 2100.

Scientists have warned that a long-term two degree Celsius or more increase in the average global temperature could threaten reduced food yield in Asia. Global warming alters precarious habitats or eliminates food supplies. It has been estimated that 15% to 37% world's species would eventually become extinct as a result of climate change expected by 2050.

The vulture population of India has crashed down by 95% in the last decade. These birds keep down insect populations, spread seeds, and pollinate flowering plants and scavenge on carrions. More intense and erratic rainfall events are expected to be a feature of climatic change.

12. Level of knowledge/ awareness:

Majority of farmers are not aware of biodiversity conservation and natural pollinators or how to manage pollination of crops.

Conservation of Insect Pollinators / Bees for Pollination:

With the decline of both wild and domestic pollinator populations, pollination management is becoming increasingly important and the conservation of pollinators has become part of biodiversity conservation efforts.

a. Role of Beekeepers:

The decline of pollinators is compensated to some extent by beekeepers, by becoming migratory. Migration may be for traditional honey crops, but increasingly is for contract pollination to supply the needs for growers of crops that require it.

b.Conservation and restoration efforts:

Efforts should be made to sustain pollinator diversity in agro- and natural eco-systems by some environmental groups rather than monoculture, are the ways to help pollinators.

c. National policy on pollinators:

It is clear that insects including honeybees are unquestionably the main pollinating agents for many crop plants. Planners, government authorities and also the agriculturists should not ignore their services.

The management of insect pollinators population is as follows:

1. Place hives very near the field source to save bees energy.
2. Migrate colonies near field at 10 percent flowering.
3. Place colonies at the rate of 3 per hectare for Italian bees and 5 per hectare for Indian honey bee.
4. The colonies should have 5 to 6 frame strength of bees, with sealed brood and young mated queen.
5. Allow sufficient space for pollen and honey storage.
6. Honey bees are susceptible to many pesticides, which results in reduction in the yield of cross pollinated crops.
   a. Need based use of pesticides.
   b. Inform the bee keepers in advance about the spray programme.
   c. Use of less hazardous and selective insecticides.
   d. Spray in the evening when the bee activity subsides.
   e. Certain insecticides in granular and EC formulations are preferred compared to dusts.
   f. Reduce drift effect of toxic chemicals.

Imagine the famine that would befall us if only one insect, the bees, out of the 10 million species, is wiped out.

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Soil Solarization- A Novel Technique for Managing Weeds and Soil Borne Diseases

V.P. SINGH

Principal Scientist
Ditectorate of Weed Science Research
Jabalpur -482004 (M.P.)

1. Introduction

Innovative approaches to control the pests including weeds are in great demand around the world, particularly those which are cost effective and less harmful to environment. The search for such new control methods which are effective and economic and have minimal undesirable side effect is a continuous process. In recent years, there has been increasing concern regarding the hazards of chemicals to the environment, the farmers and the consumers. Therefore, interest in non-chemical approaches which aim to reduce pesticide usage is growing. Manual weeding, though effective and commonly used in India is expensive and time consuming and also is not feasible in all situations. Use of herbicides for controlling weeds is very effective and economical but due to associated residue hazard, evolution of resistant biotypes and polluting the ecosystem have necessitated development of alternate non-hazardous means of weed management. In this light harvesting of solar energy through soil solarization for controlling soil-borne pests including weeds, pathogens and nematodes will be the key preposition to reduce the dependency on chemicals.

Use of polyethylene mulches is not new to agriculture but has been historically used as a post-planting treatment. Black polyethylene sheets are widely used to obtain good weed control amongst other things. However solarization is different in the sense that clear polyethylene films are used as pre-planting treatment. Soil solarization as a pre-planting soil treatment to control soil borne pathogens and weeds, was first described in 1976 by Katan and co-workers in Israel. This involves mulching of the soil with clear plastic films so as to trap the solar heat in the surface soil. The resultant temperature increase would be lethal to soil pathogens, nematodes, weeds etc. This technique has been termed as solar sterilization, solar heating of the soil, or solar pasteurization, plastic or polyethylene mulching or tarping since 1976, but soil solarization is widely accepted and concise. The term 'soil solarization' denotes solar heating of the moistened soil by mulching (tarping or covering) with appropriate mulch. The common mulch for this purpose is transparent polyethylene and in some cases polyvinyl chloride. This approach of killing weed seeds and propagules seems to have greater potential in tropical and sub-tropical regions where air temperature goes up to 45 C during summer months.

2. Principles of soil solarization

Soil solarization is a hydrothermal process, which brings about thermal and other physical, chemical and biological changes in the moist soil during, and even after mulching (Stapleton and DeVay, 1986)

Global radiation composed of short-wave solar radiation and long-wave atmospheric

Table 1: Effect of plastic type on soil temperature during solarization and weed control (Horowitz *et al.*, 1983)

Type of plastic	Maximum soil temperature (°C) at depth		Weed emergence (No./m^2) after plastic removal			
			Pigweed		Common purslane	
	5 cm	15 cm	1 month	11 months	1 month	11 months
Control	30.4	28.2	92^a	70^a	24^a	12^a
Black polyethylene	39.7	31.4	8^b	1^b	29^a	2^b
Transparent P.V.C*	47.4	35.9	0^b	0^b	12^b	2^b
Transparent thin (0.03 mm) polyethylene	49.5	36.1	1^b	0^b	8^b	3^b
Transparent thick (0.10 mm) polyethylene	47.7	35.0	1^b	1^b	6^b	2^b

*P.V.C. = Polyvinyl chloride (0.09 mm)
Figures in the same column followed by the same letter do not differ at 5% level of significance

radiation, is the primary source of energy for heating soils. While the transparent polyethylene is permeable to short wave solar radiation received from the sun, the long wave terrestrial radiation is held back, which results in trapping of the heat in the soil. Polyethylene also reduces heat convection and evaporation of water from the soil. Water evaporating from the soil surface will condense on the mulch and drip back to the soil surface. As a result of the formation of water droplets on the inner side of the mulch will trap the long-wave radiation and thus eliminate radiating cooling of the soil surface. In order to reduce heat losses through sensible and latent heat fluxes, the plastic mulch has to be kept intact (Mahrer *et al*., 1984).

Solarization heats the soil through repeated daily cycles. At lower soil depths maximum temperature decrease, are reached later in the day and maintained for longer period of time

The following recommendations have been made to bring about effective solar heating of soil, providing climatic conditions are adequate (Katan, 1981).

i) Transparent not black polyethylene should be used since it transmits most of the solar radiation that heats the soil.

ii) Soil mulching should be carried out during the period of high temperatures and intense solar radiation.

iii) Adequate soil moisture during solarization is necessary to increase the thermal sensitivity, improve heat conduction in the soil, and enable biological activities.

iv) The thinnest polyethylene tarp possible (25-50 µm) is recommended, since it is both cheaper and comparatively more effective in heating due to better radiation transmittance than the thicker one.

v) Extend the solarization period usually from four weeks to six or eight weeks enables control at deeper layer.

3. Factors influencing effectiveness of soil solarization

3.1 Soil preparation Good land preparation is essential to provide a smooth even surface, so that the polyethylene film is laid close to the soil with a minimum of airspace to reduce the insulating effect of an air layer

3.2 Soil characteristics Dark soils absorb more radiation than light soils. Small differences in soil characteristics or moisture content can translate into large differences in soil heat transfer characteristics (Smith, 1964).

3.3 Soil moisture Adequate soil moisture before tarping/mulching is necessary to increase the thermal sensitivity, improve heat conduction in the soil, and enable biological activities. Saturated soil is optimal by a single irrigation before tarping (Grinstein *et al*., 1979).

3.4 Polyethylene film types and characteristics

Transparent polyethylene films are more efficient in trapping solar radiation (Horowitz *et al*., 1983, Bhaskar *et al*., 1998, Mudalagiriappa *et al*., 1999)) and residual weed control than black films (Table 1). Besides clear transparent polyethylene costs less and has high strength and allows maximum transmittances of radiation. Thinner films, 19-25 µm are more effective for solar heating than thicker films (50-100 µm) and are proportionately less expensive (Stapleton and Devay, 1986). Patel *et al.* (1989) also observed that transparent polyethylene was more effective than black polyethylene in reducing weed density and dry weight in tobacco.

3.5 Beds – width and direction

Mahrer and Katan (1981) recorded a 2 to 4 C lower temperature at the edge of the mulch than the Centre, at the same soil depth. Horowitz *et al.* (1983) observed that there was no weed emergence from a 20 to 140 cm band width, the temperatures at the 5 cm depth were comparable; temperatures were generally 1 to 2 C higher at the 15 cm depth with the wider

Table 2. Effect of period of solarization on population and dry weight of weeds and seed yield of soybean, NRCWS (Singh *et al*., 2000)

Period of solarization	Weed density/m^2		Weed dry weight (g/m^2)		Seed yield (kg/ha)
	30 DAS	60 DAS	30 DAS	60 DAS	
Control	96.9^a	122.9^a	43.9^a	69.6^a	831^a
Solarization for 3 weeks	0.0^b	43.6^b	0.0^b	46.1^b	1391^b
Solarization for 4 weeks	0.0^b	40.1^b	0.0^b	32.2^b	1403^b
Solarization for 5 weeks	0.0^b	38.8^b	0.0^b	32.1^b	1473^b
Summer ploughing	83.6^a	79.4^c	20.8^c	76.4^a	910^a

Figures in the same column followed by the same letter do not differ at 5% level of significance. DAS = Days after sowing band and irrigation during the solarization period.

Beds running in a north-south direction are preferable to an east-west direction to avoid a lower temperature on one side of the bed.

3.6 Timing and duration of soil solarization

The technique is most effective when it is practiced in warmest summer months, with adequate duration of 4-6 weeks under many situations. In India April- May in south and May-June in northern parts experienced intense radiation and are best suited for solarization (Yaduraju, 1993). As solarization effect is restricted to surface soil only (0-10 cm), pest control at greater depths may be achieved with extended period of PE mulching. Egley (1983) found that only one week of solarization treatment significantly reduced the number of viable seeds of *Sida spinosa, Xanthium pensylvanicum, Abutilon theofrasti* and *Anoda cristata*. When the duration increased to 2 weeks, additional species were controlled. Solarization for a period of 10 weeks effectively controlled perennial weeds (Rubin and Benjamin, 1983). The effect was very clear on common purselane and appreciable on the field bindweed. Singh *et al.*, (2000) observed that solarization for a period of 3-4 weeks during summer (May to June) was enough to control most of the annual weeds in soybean (Table 2).

3.7 Size of mulch

Numerical calculation with two-dimensional model (Mahrer and Katan, 1981) reported that soil heating at the edge of the mulch is lower than in its centre. Therefore, narrow mulch is less efficient in heating the soil than a wide one.

3.8 Soil mulching with aged (used) covers

In many situations, used mulching material is available to the farmer at no extra cost. On the basis of field experience it was reported that higher temperature prevail under the old polyethylene sheet than a new one. Avissar *et al*., 1986 found that the photometric properties of the transparent polyethylene sheet change significantly during its ageing process. Fine water droplets condense on the inner side of a new film laid on wet surface, while on an aged film a water film with soil deposits is formed resulting more transmission of global radiation and less atmospheric radiation than the new one for better soil heating.

4. Causes of seed death

The probable mechanisms involved in the weed control process using soil heating (Rubin and Benjamin, 1984) are:

1. Direct thermal killing of germinating or even dormant seeds;
2. Thermal breaking of seed dormancy followed by thermal killing;
3. Thermally induced changes in CO_2/O_2, ethylene and other volatiles which are involved in seed dormancy release followed by thermal killing;
4. Direct effect of high temperature interacting with toxic volatiles released from decomposing organic matter or seed metabolism;
5. Indirect effects via microbial attack of seeds weakened by sub-lethal temperature.

5. Effect of Soil Solarization

5.1 On soil temperature

Maximum temperatures in upper soil layers under ideal conditions are achieved within 3-4 days after solarization begins (Mahrer, 1979). The upper 15-30 cm of soil show diurnal temperature changes influenced by day and night air temperatures. Typical mean maximum soil temperatures in solarization plots are 8 to 12 C higher than in corresponding non-solarized plots (Yaduraju, 1993 and Singh *et al*., 2000). In Dharwad, while the increase with 100 µm TPE film was 9.7 C, it was 13.8 C with 50 µm TPE film and 1.2 C was with black film (Emani, 1991).

5.2 On weed emergence

Due to elevated temperature in soil following solarization treatment it results in reduction in the population of soil borne pathogens, nematodes and weeds. The response to solarization in weeds varies with weed species. Soil solarization was most effective at controlling broad-leaved weeds than sedges and grasses (Reddy *et al*. 1998). Several studies over many years have revealed that many rainy and winter season annuals are susceptible to soil solarization. The dominant weeds *viz. Trianthema monogyna*, *Dactyloctenium aegyptium*, *Acrachne racemose*, *Digera arvensis Echinochloa colona*; *Eleusine indica,*and *Commelina* spp. in rainy season and *Avena ludoviciana*, *Phalaris minor*, *Chenopodium album*; *Rumex dentatus*, *Fumaria indica*, etc. of winter season were highly sensitive to solarization treatment. (Table 3). However, *Cyperus rotundus*, *Melilotus indica* and *Convolvulus arvensis* were tolerant; though the seed-borne sedges were highly susceptible. The survival of *Cyperus rotundus* tubers in the soil has been attributed to heat resistance of the tubers (Kumar *et al.*, 1993). As solarization effect diminishes with soil depth, weeds, which are capable of putting up growth from deeper layers, survive the treatment. Solarization for a mere 10 days gave complete control of *Phalaris minor* and *Avena ludoviciana,* the most dominant grass weeds in winter in India, there was an increase in the population of *M. indica* even at 40 day solarization. The heat tolerance of *M. indica* has been attributed to its thick seed coat (Yaduraju, 1993).

Table 3. Effect of Soil solarization on some major weeds

Weed species	Population/m^2	
	Non solarized	Solarized
Acrachne racemosa	943	161
Avena ludoviciana	9	0
Chenopodium album	30	0
Cichorium intybus	7	2
Commelina benghalensis	14	0
Commelina communis	9	2
Convolvulus arvensis	3	3
Cyperus rotundus	52	40
Dactyloctenium aegyptium	139	21
Digera arvensis	125	3
Echinochloa colona	21	2
Medicago hispida	3	2
Melilotus indica	88	89
Phalaris minor	41	0
Phyllanthus niruri	17	7
Trianthema portulacastrum	173	3

Soil solarization was also found to be highly effective against parasitic weeds like broom rape (*Orobanche* spp.) for which other control methods failed. Soil solarization controlled *Orobanche* by 90 % in Israel (Jacobsohn *et al*., 1980), 72-100% in Sudan (Braun *et al*., 1988) in the faba bean and tomato field. In cabbage, solarization for 2-6 weeks alone killed *Orobanche* seeds at soil surface, but had no significant effect on seeds below the surface. Solarization with chicken manure, however, killed *Orobanche* seeds at all depths. (Haidar and Sidahmed, 2000)

The overall effect is best in crops, which form quick canopy cover. Otherwise, slow growth of crop plants may give way for weed seeds, which have escaped solarization treatment. Although the density of weeds is substantially reduced due to solarization, their increased biomass may seriously interfere with crop growth and yield. Under such circumstances, a low-energy input manual weeding or chemical would prove highly beneficial and cost-effective (Yaduraju, 1993).

5.3 On weed seed bank

The reserves of dormant weeds in agricultural soils provide a source of seeds for persistent weed problems that often require repeated control measures. A reduction in the number of dormant weed seeds in the soil should also correspondingly reduce weed persistence and weed control requirements. Hence, soil solarization would be desirable as a means of reducing the dormant weed seed reserves in the soil. However, solarization was not found to eliminate dormant weed seeds from the germination zone. The treatments killed non-dormant seeds and greatly reduced the number of weed seedlings (Table 4) that otherwise would have emerged (Egley,1983).

Although weed seeds in the surface 5 cm soil are killed to a great extent soil solarization has rather a poor effect on weed seeds at deeper layers. Solarization for 6 weeks killed seeds of *Commelina communis* in the top layer up to 11 cm but that of *Cyperus* sp. and *Echinochloa crusgalli* only upto 3 to 4 cm and for 3 weeks *Eleusine indica* and *Amaranthus* up to 5

Table 4. Effects of soil solarization on weed seedling emergence (Egley, 1983)

Weed species	Weeds emerged (no./m^2)				
	Not covered	Period covered (weeks)			
		1	2	3	4
Grasses	841^a	306^b	41^c	15^c	9^c
Pigweed (*Amaranthus* species)	300^a	65^b	13^b	0^b	0^b
Morning glory (*Ipomoea* spp.)	76^a	54^{ab}	17^b	0^b	2^b
Horse purslane (*Trianthema portulacastrum* L.)	74^a	22^a	26^a	4^a	0^a
Purple nutsedge (*Cyperus rotundus* L.)	24^a	43^a	43^a	9^a	22^a
Total[b]	1385^a	495^{bc}	140^c	28^c	33^c

[a] Within each weed class, means followed by the same letter do not differ at the 5% level according to Duncan's multiple range test. [b] Total includes weeds in addition to those identified in the table.

cm (Standifer *et al*., 1984). Solarization reduced annual blue grass (*Poa annua*) seed survival from 89 to 100 % in the upper 5 cm of soil, but did not reduce survival below 5 cm (Peachey *et al*., 2001).

5.4 On crop growth and yield

As soil solarization has tremendous effect on soil-borne pathogens, nematodes and weeds, the treatment enables the crop to grow and yield better as compared to non-solarized field (Table 5). The magnitude of increase depends upon the type of pest problem and the degree of control. Control of weeds alone due to solarization increased the yield of onion by 100-125 (Katan *et al*., 1980), groundnut by 52% (Grinstein *et al*., 1979), sesamum by 72% (Stapleton and Garza-Lopez, 1988) and 77-78% in soybean (Kumar *et al*., 1993; Singh *et al*., 2000). Solarization is very effective in controlling parasitic weed *Orobanche*, and yield of 78 t/ha of carrot was reported from solarized plot while the non-solarized plot did not yield at all. Similarly, there was a 20% increase in yield of bean due to *Orobanche* control by solarization (Jacobsohn, *et al*., 1980). Many studies on solarization effect demonstrated the increased growth and yield of crop plants even in places where there is no infestation of either soil-borne pathogens, nematodes or weeds. This could be attributed to several chemical and biological changes in soil caused by solar radiation when covered by clear plastic films especially when the soil has a high moisture content (Yaduraju and Kamra, 1997). With adequate control of weeds and nematodes through chemical or mechanical methods, solarization still enhanced the yield of soybean (Yaduraju, 1993).

Table 5. Effect of soil solarization on crop productivity

Treatments	Crop productivity (2 years mean data) Yield (kg ha $^{-1}$)		Total income (Rs/ha)
	Soybean	Wheat	
Control	753	2274	25,488
Hand weeding	1470	3741	38,350
Herbicides	1287	2965	37.381
Soil solarization	1952	3738	51,583

5.5 On chemical changes in soil

Soils mulched with transparent plastic films have frequently been reported to contain higher levels of soluble mineral nutrients. Significant increases in ammonium-nitrogen, nitrate-nitrogen, Ca^{+2}, Mg^{+2} and electrical conductivity were consistently found. Phosphorus, K^+ and Cl^- increased in some soils. Other micro-nutrients Fe^{+2}, $Mn^{+1'}$, $Zn^{+2}$and Cu^{+2} were not increased (Stepleton and Devay, 1986). At ICRISAT,Hyderabad Chauhan *et al*.,1988 demonstrated that solarization did not significantly affect pH, EC or available P levels. Soil NO_3-N concentration only to a depth of 30 cm was increased, specially where soil was irrigated before solarization **(Table 6).** Soil NH_4-N was not affected by solarization at any depth. While, at New Delhi, there was an increase in nitrate-N and ammonical-N but organic carbon content was not altered (Yaduraju, 1993).

However, in many studies in different soils types and nutrient sources, it has been observed that the increases in levels of soil nutrients are transient and do not persist long. Therefore, the increased growth response (IGR) following soil solarization is likely to result from reductions of major factors limiting plant growth such as fungal or bacterial pathogens, nematodes, soil borne insects or weeds rather than increased mineral nutrient availability (Yaduraju and Kamra, 1997).

5.6 On biological changes in soil

In comparison to most other methods of soil disinfestation, the effects of solarization are selective on micro-organisms but it is sufficient to mention that the shift in the micro-biota of the soil following solarization is in favour of antagonists. These organisms are usually saprophytes rather than pathogens which may subsequently inactivate surviving phytopathogenic fungi, bacteria, nematodes and weeds seeds that are damaged or weakened by solarization. *Verticillium* and *Fusarium* wilts of several crops have been successfully controlled by solarization**.** These effects may persist for several seasons. Schreiner *et al*. (2001) observed that solarization did not reduce the infectivity of AM fungi immediately after the solarization. But infectivity was greatly reduced 8 months after solarization. Solarization apparently reduced AM fungi in soil indirectly by reducing weed populations that maintained ineffective propagules. Several investigations have been made on the effect of solarization on native as well as inoculated *Rhizobium*. The native population of *Rhizobium* or nodulation in pigeonpea and chickpea was decreased with solarization followed after irrigation (Chauhan *et al*., 1988). However, in unirrigated condition, soil solarization did not alter *rhizobium* population and nodulation. Population of *Rhizobium*, sufficient to cause heavy nodulation of roots survived solarization in Israel (Katan, 1981). Better response **(Table 7)** of mungbean, cowpea, soybean and groundnut to inoculation of *Rhizobium* was observed in New Delhi (Yaduraju,1993)

Effect of solarization on total parasitic nematode was significant and drastic. The

Table 6. Effect of soil solarization on nitrate and ammonium nitrogen content in soil (mg Kg^{-1}) of different depth of a vertisol

Treatments	Soil depth (cm)					
	0-15		15-30		30-45	
	Pigeon pea	Chickpea	Pigeon pea	Chickpea	Pigeon pea	Chickpea
	Nitrate nitrogen (NO_3-N)					
Non-solarized	5.3	3.2	4.6	3.7	4.5	4.4
Solarized	13.5	9.3	8.2	8.6	5.0	4.6
	Ammonium nitrogen (NH_4-N)					
Non-solarized	4.2	3.4	4.3	6.0	5.5	6.3
Solarized	4.2	4.0	4.6	5.0	5.5	5.2

population of all parasitic nematodes of chickpea including *Heterodera retusus*, *Pratylenchus* spp, *Rotylenchulus reniformis*, *Tylenchorhynchus* spp., and *Heterodera* larvae, was markedly affected by solarization. Solarization also significantly reduced ant and earthworm numbers but had no effect on millipede population (Ricci *et al*., 1999).

The thermal inactivation of soil-borne pests alteration of soil micro-biota to favour antagonists of plant pathogens and pests, release of soluble mineral nutrients from soil all appear to be components in IGR seen in crop plants. With the combination of such a broad scope of favourable components (Stapleton and Devay, 1986), it is likely that most crops would benefit from soil solarization.

Table 7. Effect of solarization and *Rhizobium* inoculation on seed yield (kg/ha) of somelegumes (Yaduraju, 1993)

Crops	Solarized		Non-Solarized	
	Inoculation -	Inoculation +	Inoculation -	Inoculation +
Soybean	1833	2683	717	1383
Groundnut	1489	1756	844	1112
Mungbean	1191	1315	547	556

6. Applicability and potential of soil solarization

Soil solarization is a unique method of pest control. It is (i) non-hazardous, (ii) user-friendly, (iii) environmentally- benign, (iv) not dependent on fossil fuel, (v) effective on a wide variety of pests including soil borne fungi, bacteria, nematodes and weeds, (vi) often effective for more than one season or a year, and (vii) stimulatory to crops.

The solarization technique is simple and easy to be adopted by farmers. However, its immediate application appears to be more promising in nursery areas and in high value crops, such as in vegetables, floriculture, etc. In addition, pre-plant solarization film may be left in place, after plant emergence, as post-plant mulch. Soil solarization has been shown to enhance degradation of pesticide residues in soil, hence could be employed for decontamination of polluted soil. Till date, there are no contradictions on use and efficacy of solarization in any crop, except economic considerations. In estimating its economic value, not only the possible replacement for herbicide and other pesticide treatments but also as an eventual solution for situations in which no other safe and efficient method is available, should be considered.

7. Limitations

Despite of many advantages, solarization is not being adopted on large scale, possibly because of some of the following limitations:

- Solarization is in fact indirectly dependent on fossil fuel, since they are used in the production of the plastics.
- Disposal of plastic film is the greatest problem. The answer to this problem could be use of biodegradable plastic films.
- Removal and reuse of the film is not feasible in large-scale operations that utilize machines to lay plastic films.
- Lack of persistence of nematode control and poor control of some weeds mean that supplemental control methods are often needed, particularly in crops that occupy a field for a long duration.
- In some climates cloudiness and rainfall during the hottest part of the year can limit effectiveness.
- Difficult to retain the films intact during period of heavy winds.

It can only be used in regions where the climate is suitable and the land is free of crops for about a more than a month. The major constraint is the high cost of the treatment; currently the cost of PE films is very high in India. Thinner films, which are incidentally more efficient, would be more economical. As the period of use is limited to 4 to-6 weeks, very often the same material could be used once again, thus reducing the cost by one half. Control of different types of pests, in successive crops grown in succession, savings in nutrient application and increased growth and yield of crops, all will have to be taken into consideration while computing the economics of soil solarization treatment.

8. Conclusion

Solarization is an effective non-hazardous technique for pest control including broad spectrum weeds, but its use is restricted to the region where the climate (intense solar radiation and clear sky) is suitable and the land is free of crops for about a more than a month at the time of mulching. Majority of the area experiencing more than 40 C mean daily temperature from April to June, most importantly crop free period is suitable for solarization. Besides pest control, the polyethylene mulching also alters the soil chemical and biological properties. These changes usually bring about enhancement in crop growth and yield. Moreover, soil solarization also reduces the necessity for chemical applications to soil and the requirement of fertiliser. Its effect on some deadly soil-borne diseases and on perennial and parasitic weeds is a big advantage. This technique could be profitably practised in nursery beds and high value crops. The cost of the treatment can be considerably reduced by 50 % through its reuse to solarize the other area of the field in the same summer.

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Herbicide Tolerant Crops – Emerging Tool in Weed Management

V.S.G.R. Naidu[1] and A.R.G. Ranganath[2]

[1]Senior Scientist
[2]Director (DWSR)
Directorate of Weed Science Research
Jabalpur – 482004 (M.P.)

Despite the significant achievements in food grain production since independence, Indian agriculture continues to face serious challenges from ever increasing population. Our population has crossed 1.2 billion and is expected to be 1.5 billion by 2025 and may cross 2 billion by the end of this century. India would need about 300 million tones of food grains by 2020 i.e., an increase of about 5 million tones per year in the next 20 years. Weeds are a component of our crop production system. They continually interfere with crop production by competing with crop plants for nutrients, soil moisture and solar radiation. In addition, weeds can harbour insects and disease pests. Noxious weeds and weed seeds can greatly undermine crop quality. The cultivation of dwarf high yielding crop varieties responsive to fertilizers and irrigation and the new intensive cropping systems have aggravated the problem of weeds.

Weed management in the field crops is challenging due to;

i. Complexity of weed flora
ii. Inefficient traditional methods
iii. Complexity of application of different herbicides for various weeds in varying crops.
iv. Laborious, untimely and drudgery causing.
v. Adverse environmental and soil conditions.
vi. Smaller land holdings.
vii. Lack of technical knowledge.

Weed control through manual/ mechanical though very effective, has certain limitations such as unavailability of labour during peak period, high labour cost, unfavourable environment particularly in rainy season etc. The reduced availability of labours for agricultural operations is mainly due to modernization, industrialization, decrease in land holdings, migration from rural to urban areas, etc. Biological weed control is considered environmentally benign and less expensive. However, this method is slow, often less effective and can't be used in all situations. The efficacy of bio-control agents under field conditions is highly dependent on environmental conditions. Under such conditions, use of herbicides is advantageous and economical.

The development of safe, effective and relatively inexpensive herbicides coupled with advances in application technology during the past have provided many successful weed management options in crop production. Herbicides being selective, dependable and effective against target weeds gained popularity in the recent years especially under intensive agriculture. In India use of herbicides for weed management is meager (17%) as compared to developed nations (47%). This is mainly due to low purchasing and risk bearing capacity as well as perception of dry land farmers about weed management. Herbicides offer a better alternative to mechanical weeding. The discovery and use of herbicides have revolutionized the agriculture in many developed countries. Despite the several advantages, many concerns like, food safety; ground water and atmospheric contamination, increased weed resistance to herbicides, destruction to beneficial organisms and concern about endangered species, etc., have also been reported with the indiscriminate use of herbicides. Moreover, many herbicides are required to manage complex weed flora in different crops.

Imparting herbicide resistance to normally herbicide susceptible crops to produce herbicide Tolerant Crops has been the most extensively exploited area of plant biotechnology. To date, herbicides have been tailored to be used with particular crops, rather than the crops being bred to tolerate the herbicide. Herbicides that control a broad spectrum of weed species often have limited use, because they also injure crops (Glyphosate, Glufosinate). The most desirable herbicides for weed control and crop safety often have other less desirable environmental characteristics (e.g. non-target toxicity, environmental persistence and economic viability). Further more, engineering crops for resistance to existing nonselective herbicides may be one of the viable options for agrochemical industries relative to the huge costs associated with the discovery, development and commercialization of new herbicides.

Techniques for production of Herbicide Tolerant Crops

Herbicide resistance in crops can be achieved by -

- Altering the target site, so that the herbicide no longer binds,
- Over expressing a target enzyme, so that the effect of the herbicide is overcome, or detoxifying the herbicide, so that it is no longer lethal to the plant.

Trends in adoption of Herbicide Tolerant Crops

The first use of herbicide resistant crop was in 1994 with the introduction of IMI (Imidazolinone resistant) corn hybrids and STS (Sulfonylurea tolerant) soybean varieties. Genes tolerant to certain herbicides or responsible for altered herbicide modes of action have been incorporated in to corn, cotton, canola and soybean and are now commercially available. These include glyphosate (Roundup Ready) resistant soybean and corn, Glufosinate (Liberty Link) resistant corn and soybean, Bromoxinyl (BXN) resistant cotton, Imidazolinone (Clearfield) resistant canola and Sethoxydim (Post) resistant corn. During the last 15 years (1996 to 2010), global adoption rate for transgenic crops has been unprecedented and reflect grower satisfaction with the products that offer significant benefits ranging from more convenient and flexible crop management, higher productivity or net returns/hectare, and a safer environment through decreased use of conventional pesticides, which collectively contribute to a more sustainable agriculture. The global area of transgenic crops has increased by 87-fold, from 1.7 million hectares in 1996 to 148.0 million hectares in 2010. Of which, 60% (89.3 m. ha) were tolerant to specific herbicide, 17.7 % (26.3 m. ha) were resistant to insect damage and 21.8 % (32.3 m. ha) were both herbicide tolerant and insect resistant (Clive James, 2010). Out of the total area under GM crops during 2010, USA, planted 47% of the total area (66.8m ha) followed by Brazil (25.4 m. ha), Argentina (22.9 m. ha), India (9.4 m ha), and Canada (8.8 m. ha). Herbicide tolerant soybean (73.3 m ha) was the most dominant transgenic crop grown commercially 2010 followed by corn (7.0 m. ha), canola (7.0 m. ha) and cotton (3.5 m. ha).

Benefits of Herbicide Tolerant Crops

- Increased flexibility to manage problem weeds.
- Multiple uses of herbicides will be prevented.
- Less use of prophylactic soil applied herbicides.
- Reduced total herbicide usage.
- Use of more environmentally benign herbicides.
- Greater adoption of conservation tillage.
- More practical use of economic thresholds in treatment decisions.
- Lack of herbicide residue problems.
- An increased margin of safety with which herbicides can be used and subsequent reductions in crop loss due to herbicide injury.
- Reduced risk of crop damage from residual herbicides used in previous rotational crops.

Concerns

- Potential for increased use of herbicides.
- Abandonment of alternative weed control practices other than herbicides.
- Herbicide Tolerant Crops may become weed problems or resistance may be transferred (through gene flow) to other species.
- Accelerated development of resistant weed populations from use of higher rates of herbicides (Clupper *et al*, 2006).
- Misuse of herbicides, leading to ground water contamination or other environmental problems.
- General apprehension about the release of genetically engineered organisms in to the environment.

Potential risks from widespread use of Herbicide Tolerant Crops

Direct effects

- Changes in the genetic diversity of crops.
- Increased HT volunteer crop problems
- Invasion of the Herbicide Tolerant Crops beyond the farm boundary

***Escape of transgenes from** Herbicide Tolerant Crops*

- Introgression to weedy relatives and amplification effects of existing weeds.
- Modification of crop progenitors in center of origin and diversity.

Indirect effect *(associated with application of the herbicide)*

- Non-selective herbicides wipe out all vegetation except the Herbicide Tolerant Crops.
- Impact on diversity of flora and fauna.

- Development of herbicide resistance in weeds.
- Shift in weed flora.
- Spray drift reaching non-HR crops grown nearby.

Problem of volunteer crops

It is believed that long term use of Herbicide Tolerant Crops, particularly in continuous monoculture, may create crop volunteers (Linda Hall and Keith Topinka, 2000) that are difficult to control. This has been a major concern in European countries, where volunteers of conventionally bred crops are already causing significant management problems. Volunteers will be a particular concern with crops like rice, soybean, and mustard that establish readily from seeds dispersed during harvest. Careful consideration will therefore be needed before multiple herbicide resistance genes are stacked in the same cultivar.

Development of "Super weeds"

It is understood that crops and related wild or weedy plants can and will exchange genes through pollen transfer, if provided with the opportunity, and have been doing so ever since there have been crops and weeds. The identification of spontaneous hybrid forms in a number of crop-weed complexes is well established, including between Johnson grass (*Sorghum halepense*) and sorghum and between wild and cultivated sunflower. In India, wild relative of soybean and corn does not exist, as this country is not the center of origin of these crops. Therefore introducing HT-soybean and corn in India are risk free. However, introducing HT-rice and mustard may be risk-prone as large number of wild relatives like wild rice in rice and wild mustard and many species of *Brassica* exists in our country. Hybridization between cultivated rice and red rice is common and has the potential to increase the adaptability of red rice populations.

Endangering biodiversity

It is feared that large scale use of Herbicide Tolerant Crops along with use of non-selective herbicides greatly imparts biodiversity. This may be true in case of the countries like USA, where single crop is grown on a larger area and use of non-selective herbicide would kill all other vegetation except the crop. However, practically, despite use of Herbicide Tolerant Crops on a large scale for over 10 years no detrimental effect to biodiversity has been noticed in the USA. However, in India, there is a great diversity and variability in land holding and crop choice; therefore, it is unlikely that biodiversity would be affected significantly. On the contrary the scientists from Broom's Bran Research Station (UK) showed that strategic use of GM crops has in fact enriched the biodiversity. Use of Herbicide Tolerant Crops facilitates the adoption of conservation tillage where in soil microbes, earthworms, beneficial insects and bird populations are maintained.

Social implications

Safety of GM foods to human beings and animals has been a debated issue. A large amount of data is available today which provide a clean chit to GM food. The arguments against GM food have been largely unscientific and on 'assumed' risks rather than 'real' risks. In India the Herbicide Tolerant Crops are not yet been introduced commercially. A section of the people claim that Herbicide Tolerant Crops are not suited or relevant to India. They fear that Herbicide Tolerant Crops replace labour and deny rural women the livelihood as most of the weeding is done by them. This argument is difficult to understand. In the same vein are we talking about banning use of herbicides and agricultural machinery as they also displace labour. In the urban scenario, does this mean we need to ban use of computers in offices and modern gadgets in the kitchen and the washing machine as they do deprive thousands of men and women their livelihood. They forget the fact that manual weeding is laborious, time consuming and drudgery. Herbicide provides timely, effective and economical weed control. It provides opportunity to divert labour to take up more productive agricultural enterprises. In WTO regime, it is necessary to reduce the cost of production to compete in the International market.

Conclusions

- The overwhelming adoption of Herbicide Tolerant Crops is primarily due to easy, efficient and often economical control of weeds.
- The movement of Herbicide Tolerance trait to weed population is a critical issue. Large scale adoption of GM crops should be done with great care in regions where genetically compatible wild relatives and weeds exist.
- Long term impact of Herbicide Tolerant Crops on biodiversity and environment is not yet completely ascertained.
- Contamination of non-GM food with GM food in a significant economic and political issue.
- Scientific assessment of relative risks and benefits is essential.
- There is a need for a policy decision on Herbicide Tolerant Crops in India.
- Unscientific and rhetoric arguments against Herbicide Tolerant Crops be controlled.

- Much of the opposition is based on the fear of replacement of labour, which is totally unrelated.
- Follow the belief that every problem has a solution.

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Management of Resources for Rice Production

G.P. Tembe

Associate Professor

Department of Soil Science & Agricultural Chemistry
JN Krishi Vishwa Vidhyalaya, Jabalpur – 482004 (M.P.)

Large variations in average yield of wheat and other rabi crops after rice at farmers fields and yields obtained in National Demonstrations and in experimental plots in rice – wheat based cropping system suggest a considerable scope of increasing production of rice, wheat and other rabi crops. The average yield of rainfed crops in rice based cropping system in the State is poor, about 0.4 ha^{-1}. In a recent review Patnaik et al. (1991) from 69 per cent of rice land of Eastern States of India.

Soil Physical Constraints Identified in Rice – Based Cropping System

- Water excess during heavy rains
- Water deficit at critical stages of rice growth
- Soil texture and shallow depth of soil profile
- Regeneration of structure of puddles soil
- Cloddy nature of seedbed after rice
- Difficulty in seedbed preparation (tillage) for rabi crops
- Poor seed-soil contact resulting in poor germination of rabi crops
- Unavailability of suitable management practices for rice-based cropping system

To alleviate these soil related constraints in rice-based cropping system in vertisols and associated soils of Kymore plateau and Satpura hills ICAR has initiated a series of long term field experiments in 1985 – 86 on the use of organic amendments, tillage practices, methods of rice cultivation and nutrient management in these soils.

Details of experiments:

In these experiments main plot was amendment or tillage or systems of rice cultivation and nutrient levels in sub or sub plots. The amendment viz., farm yard manure (FYM), rice husk (RH), saw dust (SD) were applied @ 10 t ha^{-1} before 15 days of planting of paddy and were mixed thoroughly. In another set of experiment, 3 tillage treatments viz., zero tillage or no tillage, cultivator + disc harrow and deep ploughing by mould board plough were created both in kharif and rabi seasons. In these tillage treatments, three methods of rice cultivation viz., direct seeded paddy, lehi system of rice cultivation (farmers practice) and transplanted paddy were used in different seasons. The sub-sub plots received three levels of phosphorus standardized at 0 to 90 kg P_2O_5 ha^{-1} and nitrogen at 0 to 120 kg ha^{-1}. The physico-chemical properties of these soils are presented in.

Table 1. Effect of organic amendment on soil physical properties at various growth stages of paddy (Av. Of 1990 – 91 to 1992 – 93)

Depth (m)	Amendment (@ 5 t ha^{-1})							
	Control		F.Y.M.		Rice husk		Saw dust	
	T_1	T_2	T_1	T_2	T_1	T_2	T_1	T_2
Bulk density (Mg m^{-3})								
0-0.15	1.12	1.29	1.05	1.20	1.13	1.24	1.04	1.23
0.15-0.30	1.25	1.43	1.28	1.36	1.27	1.27	1.23	1.23
0.30-0.45	1.38	1.46	1.35	1.40	1.37	1.49	1.28	1.44
Penetration force (kg cm^{-2})								
0-0.15	1.65	3.60	1.27	2.10	2.17	2.11	1.45	2.99
0.15-0.30	2.74	4.95	2.38	4.07	3.09	4.16	2.26	4.82
0.30-0.45	4.09	5.23	3.42	5.56	3.98	5.58	3.15	6.24
Basic infiltration rate (mm hr^{-1})								
Surface	-	2.53	-	3.50	-	3.33	-	3.00
Hydraulic conductivity (mm hr^{-1})								
0-0.15	-	2.70	-	6.5	-	5.90	-	4.2

(T_1 and T_2 – refer to observations taken at the time of transplanting and harvesting of paddy, respectively)

Table 2. Effect of organic amendment on soil physical properties (Av. of 1987 – 88 to 1992 – 93) at various growth stages of paddy

Physical property	Soil depth (m)	Amendment (@ 5 t ha^{-1})			
		FYM	Rick husk	Saw dust	No amendment
Bulk density (Mg m^{-3})	0-0.15	1.15($\pm$ .04)	1.16($\pm$ .07)	1.18($\pm$ .04)	1.20($\pm$ .08)
	0.15-0.30	1.24($\pm$ .05)	1.28($\pm$ .06)	1.27($\pm$ .03)	1.30($\pm$ .05)
	0.30-0.45	1.39($\pm$ .04)	1.43($\pm$ .08)	1.41($\pm$ .05)	1.44($\pm$ .05)
Penetration force (kg cm^{-2})	0-0.5	1.81($\pm$ .39)	2.31($\pm$ .93)	2.88($\pm$ .81)	3.05($\pm$ 1.19)
	0-0.10	3.37($\pm$ .39)	3.77($\pm$ .69)	3.91($\pm$ .52)	4.59($\pm$ .46)
	0-0.15	5.83($\pm$ .81)	5.73($\pm$ 1.38)	5.93($\pm$ .81)	6.53($\pm$ 1.01)
Hydraulic cond. (mm hr^{-1})	Surface	6.58($\pm$ .16)	6.08($\pm$ .50)	4.66($\pm$ .84)	2.68($\pm$ .12)
	0-0.10				
Basic infiltration rate (mm hr^{-1})	-				

Values given in parenthesis are the standard deviations from the mean values.

Table 3. Effect of organic amendments on grain yield (kg ha^{-1}) of rainfed paddy in vertisols

Year	Amendments				Average yield	CD 5%
	FYM	Rick husk	Saw dust	Control		
1985	3126	2808	2304	2514	2638	622.9
1986	4690	4330	4150	4220	4347	NS
1987	2219	1833	1970	1716	1934	144.0
1988	2247	2114	2087	1057	1875	430.0
1989	1735	1666	1443	1238	1520	252.0
1990	3397	3244	3067	2951	3165	441.0
1991	2546	2316	1936	1826	2156	124.4
1992	3389	3152	2935	2529	3001	513.4
1993	5598	5220	4372	3843	4758	579.0
Average	3216	2664	2696	2433	2821	-
% increase over control	32.2	17.94	10.80	-	-	-

Soil Physical properties

These data revealed that highest bulk density and penetration force values were recorded in control and saw dust plots and lowest in FYM and rice husk treated plots. The decrease in bulk density and penetration force in FYM and rice husk treated plots may be due to more aggregation of soil particles. Similar results were reported by Jayawardhane and Blackwell (1986) in rice soils of Srilanka.

Higher infiltration rate and hydraulic conductivity were recorded in FYM followed by lowest in contol plots. This might be due to greater ability of FYM to increase the macropore spaces n the soil than that in other amendments. Similar results were reported by Resend (1987) in paddy soils.

Effect of amendments on yield of paddy

Grain yield data of paddy presented in revealed that the yield was maximum in FYM treated plots and lowest in control plots in all the years.

Effect of amendments on germination of rabi crops

Counted healthy seeds of wheat, chickpea and linseed were planted in randomly selected two rows of each plot. Daily germination counts were recorded and summary of germination data of different crops is presented. Highest germination of all the crops was recorded in FYM treated from 1990 onward, different tillage treatments viz., watering (5 ha mm) and seedline compaction in seeded rows were tested for studying germination of chickpea, wheat and linseed in rice based cropping system. Germination data presented in revealed that chickpea and linseed.

Table 4. Effect of organic amendments applied in upland paddy on germination (%) of rabi crops in vertisol (Av. 1990 – 91 to 1992 – 93)

Treatment	Wheat	Chickpea	Linseed
F.Y.M.	73.79	85.22	69.20
Rice husk	70.09	83.15	61.13
Saw dust	65.40	77.10	58.00
No amendment	57.96	64.02	51.00

Table 5. Per cent moisture content (mm^{-3}) at sowing of rabi crops under different amendment treatments applied during kharif season

Depth (m)	F.Y.M.	Rice husk	Saw dust	Control
0 – 0.05	31.93	31.17	28.78	28.25
0.05 – 0.10	34.2	34.31	32.25	30.48
0.10 – 0.20	34.55	34.18	33.64	32.87

Table 6. Effect of different treatments on germination (%) of rainfed rabi crops grown under rice-based cropping system (Av. Of 1990 – 91 and 1992 – 93)

Treatment (in seeded rows)	Wheat	Chickpea	Linseed
Watering	73.69	82.82	65.26
Compaction	68.39	77.37	59.99
Control	60.71	71.76	53.41

Table 7. Per cent moisture content (mm^{-3}) after creation of treatment at sowing of crops under rice based cropping system

Depth (m)	Watering	Compaction	Control
0 – 0.05	36.04	34.27	26.78
0.05 – 0.10	35.50	34.95	31.98
0.10 – 0.20	34.96	34.63	33.84

Effect of amendments on grain yield of wheat

Grain yield data of rainfed wheat presented revealed that average wheat yield was not so high but still etter that the farmers fields. Significantly higher yield of wheat was recorded in FYM and rice husk treated plots.

During the year 1990 – 91 to 1993 – 94, the effect of organic amendments on the performance of chickpea and linseed was evaluated. Addition of FYM to paddy crop significantly increased the grain yield of chickpea and linseed. In some of the years, the effect of other amendments was also significant. Among crops, chickpea responded more to amendments than linseed. Highest yield of chickpea in 1993 – 94 was due to better climatic conditions.

Water use and water use efficiency data of rabi crops presented in revealed that under rainfed conditions FYM plots had higher water use values as compared to saw dust and control plots. Among all the amendment treated plots, all three crops had more or less same water use values. Linseed had slightly lower water use values as compared to wheat and chickpea.

The results of long term experiment on use of organic amendments conducted under raifed upland paddy conditions in vertisols have clearly shown that incorporation of FYM and rice husk (@ 5 t ha^{-1}) before 15 days of transplanting of paddy was beneficial for the maintenance of organic carbon level in these soils.

Table 8. Effect of organic amendments on grain yield (kg ha^{-1}) of rainfed wheat in upland rice wheat cropping system

Year	Amendments				Average yield	CD 5%
	FYM	Rick husk	Saw dust	Control		
1985 – 86	1856	1666	1626	1505	1664	225
1986 – 87	1247	1151	1005	831	1058	NS
1987 – 88	2152	2041	1902	1756	1963	235
1988 – 89	1548	1410	1211	1103	1318	205
1989 – 90	1317	1146	945	730	1045	76
1990 – 91	1285	1210	1076	899	1117	47
1991 – 92	2546	2316	1936	1826	2156	124
1992 – 93	2579	2363	2246	2192	2345	154
1993 – 94	1901	1823	1676	1304	1676	133
Average	1826	1681	1514	1355	1594	–
% increase over control	34.76	24.0	11.73	–	–	–

Table 9. Effect of organic amendment on the grain yield (kg ha^{-1}) of rainfed chickpea and linseed in rice based cropping system

Amendment	Chickpea					Linseed			
	90–91	91–92	92–93	94–95	Av.	90–91	91–92	92–93	Av.
F.Y.M.	1616	1361	1370	1733	1520 (62.6)	947	698	531	725 (29.50)
Rice husk	1504	1134	1320	1651	1402 (46.2)	923	573	508	668 (19.71)
Saw dust	1247	975	1225	1560	1252 (33.4)	824	543	488	681 (10.80)
Control	1113	515	1067	1056	937	760	456	459	558
Av.	1370	996	1245	1500	1277	864	567	509	646
CD 5%	29	173	154	192.0	–	28	103	NS	–

Values given in parentheses are the % increase in yield over control

Table 10. Effect of rabi tillage treatments on the grain yield of rainfed wheat grown under upland rice based cropping system

Treatment in seeded rows	Grain yield of wheat (Kg/ha^{-1})						
	88–89	89–90	90–91	91–92	92–93	94–95	Av.
Watering	1033	1152	1239	1054	2598	2107	1530 (27.18)
Compaction	910	1038	1158	1036	2312	1852	1384 (15.04)
Control	752	951	956	875	2125	1561	1203
Av.	898	1047	1117	988	2345	1840	1372
CD 5%	80.14	75.66	49.22	124.56	339.47	100.00	–

Table 11. Effect of rabi tillage treatments on the grain yield (kg ha^{-1}) of rainfed chickpea and linseed in upland rice based cropping system

Treatment in seeded rows	Chickpea					Linseed			
	90–91	91–92	92–93	94–95	Av.	90–91	91–92	92–93	Av.
Watering	1509	1153	1355	1717	1433	967	653	552	724
Compaction	1447	1058	1313	1628	1361	861	575	481	639
Control	1222	776	1068	1345	1103	768	474	457	566
Av.	1393	955	1245	1563	1299	865	570	496	643
CD 5%	55.5	111.4	129.4	107.5	–	45.9	64.29	54.15	–

Table 12. Effect of kharif season applied amendments on water use (WUE) (cm) and water use efficiency (WUE) (kgha^{-1} cm^{-1}) of rainfed wheat, chickpea and linseed in rice based cropping system (Average of three years)

Amendment	*Wheat		*Chickpea		*Linseed	
	WU	WUE	WU	WUE	WU	WUE
F.Y.M.	26.64	65.89	26.55	56.06	24.58	30.43
Rice husk	25.09	63.47	25.54	52.32	22.88	29.14
Saw dust	24.22	59.92	24.61	47.83	21.75	30.20
Control	23.53	56.83	22.78	40.55	20.63	26.63

*Based on soil moisture changes in 1.80 m soil profile

Table 13. Effect of long term applied amendments on chemical properties of the soil (sunken beds)

Treatment	pH	EC (dsm^{-1})	OC (%)	Av. N. (kg ha^{-1})	Av. P_2O_5 (kg ha^{-1})	Av. K_2O (kg ha^{-1})
F.Y.M.	6.82	0.32	1.01	238.3	25.49	503.2
Rice husk	6.82	0.33	0.83	219.5	24.60	498.7
Saw dust	6.75	0.33	0.77	181.9	14.34	485.8
Control	6.83	0.32	0.53	128.6	11.34	455.3
Uncultivated sunken bed	6.87	0.31	0.84	166.77	11.04	381
Flat	6.93	0.35	0.56	181.89	18.02	442

Table 14. Effect of organic amendment in combination with USG on soil physical properties at flowering stage of paddy (Av. 87 – 88 & 88 – 89)

Properties	Depth (m)	Control	FYM+USG	pH +USG	SD+USG	PS+USG
Bulk density (Mg m^{-3})	0-0.15	1.34	1.23	1.24	1.27	1.28
	0.15-0.30	1.45	1.35	1.35	1.38	1.41
Penetration force (kg cm^{-2})	0-0.05	3.50	2.26	2.30	2.56	3.48
	0-0.10	5.60	5.60	3.66	4.96	5.00
	0-0.15	6.63	6.63	6.34	6.24	5.93
Hydraulic conductivity (mm hr^{-1})	0-0.10	2.25	3.01	2.83	1.91	2.58
BIR(mm hr^{-1})	-	2.34	2.53	2.56	2.59	2.47
Capillary porosity (%)	0-0.10	10.40	44.37	44.76	-	45.92
Non capillary porosity (%)	0-0.10	2.43	1.94	1.52	-	2.16
Saturation(%)	0-0.10	42.83	48.32	46.28	-	48.09

USG = Urea super granule, pH = Paddy husk, SD = Saw dust, PS = paddy straw

Table 15. Effect of methods of rice cultivation on physical properties at flowering stage of paddy in (Av. of 1990 – 88 to 1992 – 93)

Physical property	Soil depth (m)	Methods of rice cultivation		
		Direct sown	Lehi system	Transplanted
Bulk density (Mg m^{-3})	0-0.15	1.23(± .02)	1.28(± .06)	1.29(± .03)
	0.15-0.30	1.30(± .03)	1.32(± .03)	1.33(± .05)
Penetration force (kg cm^{-2})	0-0.5	5.07(± 1.48)	5.18(± .45)	6.28(± .88)
	0-0.10	6.52(± .78)	7.21(± 1.40)	8.11(± 1.97)
	0-0.15	7.21(± 1.81)	8.91(± 2.09)	9.37 (± 2.06)
Hydraulic cond. (mm hr^{-1})	0-0.10	3.0(± .05)	2.4(± 0.7)	2.1(± 0.6)
Basic infiltration rate (mm hr^{-1})	-	2.8(± 0.2)	2.7(± 0.2)	2.0(± 0.50)

Values given in parenthesis are the standard deviations from the mean values.

Table 16. Effect of methods of rice cultivation on physical properties at flowering stage of wheat in rice based cropping system (Av. of 1990 – 88 to 1992 – 93)

Physical property	Soil depth (m)	Methods of rice cultivation		
		Direct sown paddy	Lehi system paddy	Transplanted (Puddled)
Bulk density (Mg m^{-3})	0-0.15	1.25	1.27	1.32
	0.10-0.20	1.33	1.35	1.38
Penetration force (kg cm^{-2})	0-0.5	4.5	8.1	9.1
	0-0.10	6.4	10.6	9.1
	0-0.15	7.6	10.9	9.0
Hydraulic cond. (mm hr^{-1})	0-0.10	3.70	3.20	3.0
Basic infiltration rate (mm hr^{-1})	-	3.2	2.8	2.9

Table 17. Effect of rabi tillage on soil physical properties at flowering stage of wheat in rice based cropping system

Physical property	Soil depth (m)	No tillage	Shallow tillage	Deep tillage
Bulk density (Mg m^{-3})	0-0.15	1.32	1.27	1.24
	0.10-0.20	1.38	1.37	1.31
Penetration force (kg cm^{-2})	0-0.5	7.5	7.16	7.16
	0-0.10	8.6	8.93	8.53
	0-0.15	8.3	9.73	9.60
Hydraulic cond. (mm hr^{-1})	0-0.10	2.70	3.40	3.8
Basic infiltration rate (mm hr^{-1})	-	2.70	3.0	3.2

Table 18. Effect of tillage on germination (%) of wheat under rice wheat cropping sequence (1993 – 94)

Treatment	Methods of Rice Cultivation			Average
	Direct sown Paddy	Lehi system	Transplanted Paddy	
No tillage	72.1	63.2	49.6	61.6
cultivator + disc Harrow	55.8	53.8	41.0	50.2
MB plough + disc harrow	47.8	41.0	40.2	43.0
Rotavator	89.6	82.4	71.0	80.0
Average	66.3	60.35	50.5	-
CD 5 %	Tillage 7.21	Method of rice cultivation 2.06		Interaction 4.12

Table 19. Effect of organic amendments and forms of urea on grain yield of crops in rice-wheat cropping system

Treatment	Paddy (Kg ha^{-1})				Wheat (Kg ha^{-1})			
	87-88	88-89	89-90	Av.	87-88	88-89	89-90	Av.
PU	3686	3848	1650	3061	3349	3561	2574	3161
FYM+PU	3836	4909	2704	3816	3856	4450	3310	3872
PH+PU	3790	4079	2512	3460	4164	4112	3164	3813
PS+PU	3811	3818	2272	3300	4309	3762	2865	3645
SD+PU	-	3950	2394	3172	-	3935	2834	3385
USG	3985	3928	1772	3228	3753	3521	2713	3362
FYM+USG	3845	5085	3512	4146	3824	4597	3561	3992
PH+USG	3525	4241	3165	3644	4109	4290	3166	3855
PS+USG	3877	4171	2680	3576	4577	3816	2917	3770
SD+USG	-	4025	2888	3456	-	4025	2845	3435
Control	1607	2214	1307	1709	3259	1966	1980	2402
Average	3551	4025	2441	3338	3911	3830	2903	3548
CD 5 %	625.67	489	113.90	-	335.0	108.61	412	-

Table 20. Effect of organic amendments and forms of urea on grain yield of crops in Chickpea-Linseed crops in rice based cropping system

Treatment	Chickpea (Kg ha^{-1})				Linseed (Kg ha^{-1})			
	87-88	88-89	89-90	Av.	87-88	88-89	89-90	Av.
PU	473	798	756	676	1248	1923	2507	1892
FYM+PU	372	1312	1250	978	1210	2568	2314	2030
PH+PU	562	1123	1068	918	167	2314	2200	1062
PS+PU	497	1014	810	774	1523	2260	2000	1928
SD+PU	383	810	949	714	1256	2046	2046	1782
USG	427	835	798	687	1363	2141	1923	1809
FYM+USG	586	756	1312	885	1307	1850	2568	1908
PH+USG	494	1250	1123	955	1493	2507	2314	2104
PS+USG	470	1068	835	791	1442	2314	2141	1965
SD+USG	413	949	1014	792	1324	2200	2260	1928
Control	323	375	375	357	1024	1012	1012	1016
Average	454	935	935	775	1351	2103	2117	1856
CD 5 %	66.5	36.1	135	-	293	644	430	-

Table 21. Effect of methods of rice cultivation on grain yield of paddy and wheat in vertisols of Jabalpur

Methods of rice-cultivation	Paddy (kg ha^{-1})				Wheat (kg ha^{-1})			
	1991	1992	1993	Av.	91-92	92-93	93-94	Av.
Direct seeded	4209	3502	4688	4133	3712	3523	4476	3883
Lehi	3464	2667	5548	3893	3448	3434	4277	3719
Transplanted	4913	2715	5560	4396	3796	3368	4137	3767
Average	4195	2961	5265	4140	3653	3443	4276	3789
CR 5%	417	353	562	-	292	115	161	-

Table 22. Effect of Kharif and rabi tillage treatments on grain yield of crops in rice – wheat cropping system

Tillage	Paddy (kg ha^{-1})				Wheat (kg ha^{-1})			
	1991	1992	1993	Av.	91-92	92-93	93-94	Av.
No tillage	4311	3042	5219	4190	3873	3245	4431	3950
Cultivator + disc Harrow	4182	2922	5413	4172	3807	3137	4302	3749
MB plough + disc harrow	4092	2919	5165	4058	3275	3646	4096	3672
Average	4195	2961	5265	4140	3651	3441	4276	3789
CD 5 %	NS	NS	NS	-	251	418	194	-

Table 23. Effect of rabi tillage on water use (WU) and water use efficiency (WUE) of wheat grown under different systems of rice cultivation

Treatment	1991 – 92			1992 – 93			1993 – 94		
	Yield (kg ha^{-1})	WU (cm)	WUE (kg ha^{-1} cm^{-1})	Yield (kg ha^{-1})	WU (cm)	WUE (kg ha^{-1} cm^{-1})	Yield (kg ha^{-1})	WU (cm)	WUE (kg ha^{-1} cm^{-1})
Direct seeded paddy									
No tillage	3948	42.16	91.12	3963	40.61	97.58	4566	31.51	145
Shallow tillage	3856	41.71	92.44	3341	41.76	80.00	4438	30.82	143
Deep tillage	3437	41.61	82.52	3895	42.44	91.77	42.45	33.21	127
Average	3747	41.84	88.69	3733	41.60	89.78	4416	31.85	138.3
Transplanted paddy									
No tillage	4115	41.49	99.18	3692	41.61	88.72	4249	27.57	138
Shallow tillage	3998	40.86	97.84	3164	42.80	73.92	4209	32.4	129
Deep tillage	3274	42.10	77.77	3770	43.72	87.43	3945	35.22	112
Average	3795	41.48	91.59	3542	42.51	83.35	4133	31.73	126.3

Table 24. Effect of phosphorus levels on the grain yield of paddy and wheat in vertisols of Jabalpur

P levels (P_2O_5 kg ha^{-1})	Paddy (kg ha^{-1})				Wheat (kg ha^{-1})			
	91-92	92-93	93-94	Av.	91-92	92-93	93-94	Av.
0	3948	2867	4787	3867	3338	3281	4037	3552
40	4272	3001	5276	4183	3639	3432	4397	3822
80	4366	3015	5731	4370	3980	3617	4601	4066
CD 5%	189.0	NS	185.7	-	297.0	278.59	127.6	-

Direct Seeded Rice –Approach for resource conservation

Girish Jha

Professor and Head
Department of Agronomy
JN Krishi Vishwa Vidhyalaya, Jabalpur – 482004 (M.P.)

Transplanted rice has deleterious effects on the soil environment for the succeeding wheat and other upland crops. Direct seeded rice which removes puddling and drudgery of transplanting the young rice seedlings provides an option to resolve the adaphic conflict and enhance the sustainability of rice-wheat cropping system (Giri *et al. 1993*). Puddling requires lots of scarce water at a time when there is little water in the reservoirs, destroys soil structure and adversely affects soil productivity. DSR overcomes the problem of seasonality in labour requirement for rice nursery raising and transplanting operations. Non-development of ground water in kharif, late onset of monsoon and drudgery of operations often delays rice transplanting which leads to late vacation of fields, forcing farmers to plant wheat after the optimum sowing time. DSR facilitates timely establishment of rice and succeeding winter crops (Gopal et al 2010 and Gill 2008). Unlike puddle fields, DSR fields do not crack and thus help save irrigation water. Surface retained residue serve as physical barrier to emergence of weeds, moderate the soil temperature in summers and winters, conserve soil moisture, add organic matter and nutrients to the soil on decomposition.

Direct Seeded Rice

Rice can be directly seeded either through dry or wet (pregerminated) seeding. Dry seeding of rice can be done by drilling the seed into a fine seedbed at a depth of 2-3 centimeters. Wet seeding requires leveled fields to be harrowed and then flooded (puddling). The field is left for 12-24 hours after puddling, then germinated seeds (48-72 hours) are sown using a drum seeder. Seed can be broadcast for either dry or wet seeding, but manual weeding is more difficult. Indeed, weed management is a critical factor in direct seeding. Timely application of herbicides (timing is dependent on the method of seeding) and one or two hand weeding provide effective control.

Land preparation

- Plow the fields during summer to control emerging weeds
- Leveling the fields well facilitates uniform irrigation and better germination

Machinery Requirement

- Minimum-till drill/Power tiller drill
- Zero-till drill
- Bed drilling

Seed depth and soil moisture

- Optimum depth of seed:2-3 cm. The seed should be covered by soil for proper germination and to avoid bird damage.
- In lowlands and finer textured soils, planking may not be necessary after seeding.
- Soil moisture content at seeding should be sufficient for proper germination
- Surface mulch: helps retain soil moisture longer to improve emergence and reduce weed menace

Seed rate and cultivars for DSR

- Seed rate:80 to100 kg/ha, in general
- Seed rate reduced about 40-60 kg /ha
- Fine grain and Basmati cultivars require much less seed
- Early to medium short duration cultivars having early vigor

Seeding time

- Drill the dry seed of normal rice at the start of monsoon i.e. when farmers put seed into nursery bed
- May 3rd week to June 2nd week (Jesth 1st week to Jesth 3rd week)

Weed management

The Critical period of weed -crop competition in dry seeded rice

Country	Critical period of competition (days)	Source
India	10-20 21-42 30 15-45 45 55-60 (monsoon) 70 (summer)	Sharma *et al.* (1977) Upadhyay and Choudhary (1979) Kolhe and Mittra (1981), Bhan *et al.* (1980) Sahai *et al.* (1983) Naidu and Bhan (1980) Tosh (1975); Mukhopadhyay *et al.* (1971) Mohammed Ali and Sankaran (1980)

Competition for nitrogen between rice and weeds was most severe during the first half of the rice growing season. From un-weeded control plots, the NPK uptake by transplanted rice was reported to be in the range of 24.0-28.5, 4.1-6.6 and 48.4-61.4 kg / ha, respectively, while removal by weeds ,was in the range of 9.5-14.6,2.8-3.6 and 12.1-25.1 kg/ha, respectively. In wet-seeded rice system, weeds generally grow with rice crop thus deplete considerable amount of applied costly fertilizer nutrients and result in poor crop growth and lower grain yield. In non-weeded control plots, the nutrient removal by weeds was more than that of transplanted rice, which was estimated to be in the range of 34.0-48.7, 5.4 -6.3 and 36.6 – 42.8 kg NPK, respectively.

Chemical weed control

Pre-germinated weeds can be knocked down with glyphosate/grammoxone (at 0.5% two days before seeding) or by 1-2 very shallow ploughings (stale seed bed method)

Second flush of weeds can be removed manually

Direct seeded under puddled condition			
		Lit / kg / ha	
Butachlor+Safener	50 EC	1.50	3-5 DAS
Pretitachlor+Safener	50 EC	0.60	0-3 DAS
Anilophos+Ethoxysulfuran	21+1 SC	0.375+ 0.015	5-7 DAS
Direct sown rice under upland conditions			
Pendimethalin	30 EC	1.50	3-5 DAS
Bispyribac Sodium Salt		0.20	

Benefits of Direct Seeded Rice :

- Avoids repeated puddling, preventing soil degradation and plow-pan formation
- Facilitates timely establishment of rice and succeeding crops as crop matures 10-15 days earlier (Gangwar *et al* . 2008)
- Saves water by 35-40%, reduces production cost by Rs 3000/ha, and increases yields by 10%
- Saves energy: labor, fuel, and seed
- Solves labor scarcity problem and reduces drudgery of labors

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Climate Change and Soil

Jagdish Prasad

Principal Scientist
NBSS & LUP Amaravati Road, Nagpur (MH)

In agriculture domain, crop productivity is influenced by atmospheric, drought and edaphic stresses in addition to bioitic ones significantly which pose scientists a big challenge in time to care. In the world only 9% of the area is conducive for crop production, while 91% is under stress. This include 24% under mineral stress and 14% is under freezing stress and 11% waterlogged. This has more relevance in India scenario as 67% of the area is rainfed and crops invariably experience stresses of different magnitude.

In the context of edaphic stress, soil may be viewed both as sink and source as aggravated by stresses and accordingly management strategies to be followed. There are many edaphic stresses which directly/indirectly affect the productivity of systems including crop, livestocks, microbes, fishes and tackling the very complex problem, a group of dedicated scientist from different discipline are pre-requisite.

Agricultural sustainability depends largely on the maintenance or enhancement of soil health/soil quality. So managing soil resources is of paramount importance in view of changing climate. Although it is multifaceted problem soil is facing due to climate change, it is very difficult to deliberate each and every possible effect. Despite the growing recognition of the soil as a possible victim of climate change & the consequent alternation in soil processes as the regulating factors of crop response in future, nothing substantial has been done by us. Scientists have worked on pedogenic $CaCO_3$ and non- pedogenic $CaCO_3$ and its influence on soil and or sequestration of organic carbon as index of climate change. The formation of pedongenic calcium carbonate gets induced by drier climate and hence soluble $CaCO_3$ gets depleted from system and hence there is concomitant increase in sodicity. The climate change and in particular aridity do not allow the organic carbon to remain in soil for longer period. Further decrease in organic carbon may affect the rhizospheric ecology as majority of microbes are heterotrophs. The increase in pH/sodicity may also change the microbial population and more particularly of actinomycetes. Visualising the enormous impact of aridity will affect crop productions to a larger effect.

Now is the high time that research should support the proactive transformation and tool to guide the decision about agricultural investment and development.

Effect of Pesticide on Soil Health and Microbial Activity

B. Sachidanand

Principal Scientist
Department of soil Science & Agricultural Chemistry
JN Krishi Vishwa Vidhyalaya, Jabalpur 0- 482004 (M.P.)

The use of pesticides have increased considerably under good agricultural practices to combat pests and diseases. This has resulted in reaching these chemicals in to the soil profile, thereby persisting for a longer period causing deteimental effect on the soil microorganisms. Pesticides, whether natural or synthetic do have toxicological significance posing risk in various components of environments. A pest may be any organism, insect diseases rodent nematode fungal disease, weed, herb, bacteria etc., which is injurious to health of man or to man's economic efforts.

Pesticides directly effect the soil microorganisms in terms of influencing the plant growth by-

1. Altering the soil microorganisms which helps in mineralization and making nutrients in available form such as *Azotobacter, Rhizobium*, phosphorus solublizing microorganisms cellulolytic microorganism which determine soil fertility, as the soil microflora make valuable contribution in making the soil healthy and fertile.
2. Affects mycorrhizal symbiosis in plants change number of nodules.
3. Changes soil in several microorganisms in quantitative aspects of, disturbing microbiological equilibrium and soil health.
4. Variation in nitrogen balance in soil affecting growth and activity of nitrifying bacteria, Nitrosomonas and Nitrobacter and
5. Interference with ammonificaiton in soil.

Thus the soil application of pesticides may interfere in intermittent stage of profuse microbial activity in the soil. Alternatively, pesticide might affect the dormant structure and possibly cause lethal to germination of the spores, which may be susceptible either to chemical or to adverse conditions, organisms may die and are destroyed.

In animals, pesticide resistance appears rapidly in mites, ticks and to some extent in aphids. After 65 years of GAP, DDT still continues to be in practice for public health programme though its use in agriculture is banned.

Classification of pesticides:

Pesticides come under a broad group of chemicals categorizing into chlorinated hydrocarbons, organophosphorus compounds, carbonates, organosulphur compounds, heterocyclic molecules, halogenated nitroaromatic compounds, phenols and inorganic substances. They are being used for plant protection measures since decades in the form of insecticides, herbicides, acaricides, fungicides, rodenticides etc.

Nitrogen transformation and other elements Ex. Phosphorus, Sulphur, Iron and Manganese are in addition to carbon and nitrogen

Microbial activity in soil:

The activities of microorganisms in soil profile are an essential tool for the global cycling of the nitrogen, sulfur, carbon, phosphorus and other elements. It is very important to understand the pathway that how the pesticide enters or are transformed in soil. This mainly depends on the nature and the conditions of the microorganisms living in the soil environment. Therefore, soil can not be considered as a single environment but is a complex of micro-environments which usually interact with each other. The micro environment can be modified by the nature and amount of food substrates for the microbes and a large number of physical and chemical factors, food substrate originating from a wide varieties of organic residues such as dried and dead plants, the soil, animals and corpses and droppings of the above fauna and the microbes themselves.

In natural soils an alteration in any single environmental factor may set off consequential changes having more profound effect on soil metabolism and population balance that might have been anticipated. Slight change in moisture content will effect aeration which, in turn, may alter the oxidation reduction stages of inorganic materials.

Impact of pesticides on microorganism in soil:

Pesticides applied directly or indirectly to soil to control various pests, destroy or affect the agricultural crops, live stock and humans. Large amount of organic and inorganic compounds

Table 1. Effects of selected pesticides on Soil Enzymic activity

Pesticide	Enzyme effect							
	Aspora-genase	Dehydro-genase	Urease	Catalase	Phosph-atase	Protease	Invertase	Proteinase
Benzoic and Phenoxy	?	I	I	S	S	?	S	I
Alkanoic acid								
Carbamates	?	N	I	?	S	I	I	?
Hetero cycle Pesticides	?	I	I	?	S	I	I	I
Nitrophenols	?	ISN	IS	I	?	?	N	
Substituted Ureas	IS	I	I	IS	S	I	I	?
Triazines	S	I	I	IS	S	I	I	?

I = Inhibition; S = Stimulation; ? = Effect unknown; N = No effect
Grossbard (1976) Bonamati et al (1985) and Litchfield and Huben (1973)

Table 2. Effect of some pesticides on soil microbial population

Microbial group	Pesticide effect (IS?N)				
	Chlorinated	Fumigants	Fungicides	Substituted Ureas	Triazines
Chemoheterotrophic bacteria	ISN	I	SN	ISN	N
Chemoautotrophic Bacteria	IN	I	N	?	IN
Actinomycetes	N	I	SN	SN	SN
Rhizobia	I	I	I	I	IN
Photosynthetic Bacteria	I	I	IN	?	I
Saprophytic Fungi	NS	I	I	IN	N
Mycorrhizal Fungi	IN	I	I	I	IN
Algae	I	I	I	I	I

I = Inhibition; S = Stimulation; ? = Effect unknown; N = No effect
Adapted from Babich and Stotzky, 1982, Lal and Saxena, 1982

enter in the soil from the disposal of wastes from industrial, agricultural, domestic and national defence programmes. Pesticides adversely influence the growth and activity of beneficial microorganisms. Microbial activity results in biochemical transformation in soil. Nitrogen transformation is one of the major microbial functions transforming organic nitrogen to inorganic form. The major transformation includes ammonification, nitrification and denitrification.

Soil microorganisms such as mycorrhizal fungi is important for phosphorus nutrition of plant, its transformation is of utmost important for release of phosphrous.

Sulphur cycle in the environment through the activities of microbes that assimilate sulphate mineralize organic sulphur compounds and liberates H_2S or oxides of H_2S to elemental sulphate.

Since a series of bacteria are possible autotrophic nitrifiers such as chemoautotrophic microorganisms, they are more sensitive to the action of pesticides than processes such as ammonificaiton, done by diverse microbial population.

<u>Ammonium oxidation to nitrite</u>

$NH_4^+ + 3/2\ O_2 \rightarrow NO_2 + H_2O + 2\ H^+$ (ΔF = -69 K Cal.)

Organism: *Nitrosomonas europaea, Nitrosospira briensis, Nitrococcus mobilis, Nitrosolobus multiformis, Nitroso Vibrio tenuis*

<u>Nitrite oxidation to nitrate</u>

$NO_2 + ½\ O_2 \rightarrow NO_3$ (ΔF = -18 K Cal.)

Organism: *Nitrobacter winogradskyi, N. agilis.*

Heterotrophic nitrification in soils:

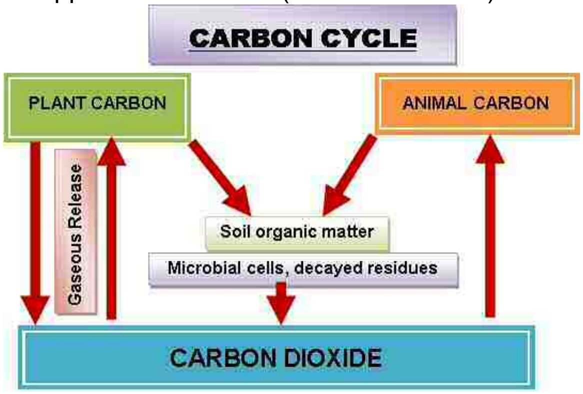
Nitrite is highly toxic to many plants and animal species including humans. Therefore process that inhibits ammonium oxidation could have adverse health effect.

Organic N, $NH_4^+ + ½\ O_2 \rightarrow NO_2, NO_3 + 2\ H^+$

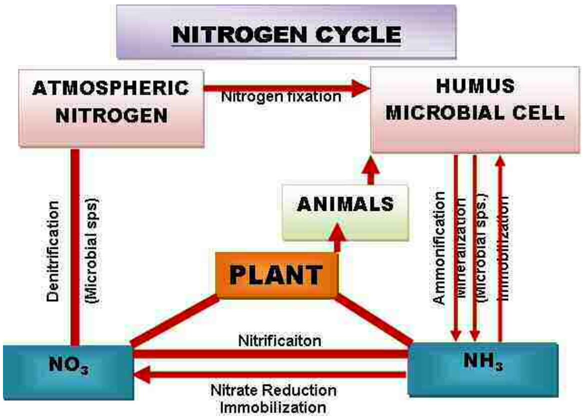
Organisms, Bacteria (eg: *Arthrobacter* sp. *Pseudomonas* sp), *Actinomycetes* (*Streptomyces* sp. *Nocardia* sp) and Fungi (*Aspergillus sp. Penicillium* sp)

It is reported that substituted ureas and atrazince inhibit denitrification in the presence of pesticides resulting in preventing fertilizer loss by denitrification. Several herbicides inhibit denitrification upto 46% such as Diuron, Linuron, Neburon, Chlorbromuron and Atrazine to the extent of 27, 40, 46, 46 and 40 per cent respectively.

Rhizobium sp. are more sensitive to pesticides than free living bacteria Azotobacter sp. Azotobacter chroococcum is affected by aldicarb, disulfoton and fensulfothion, while BGA (Nostoc) can tolerate up to 2000 ppm of propazine where other strains are killed by just of 1 ppm concentration (Gross bard 1976).



Effect of some of the selected pesticide on the enzymic activity has been well studies. It



is known that most of the pesticides are inhibitors of different enzymic activity, little are stimulated and very few have no effect. Similarly, some of the microbial groups are affected by pesticide, with inhibitory stimulatory and no effects.

Pesticide degradation by microorganisms:

Pesticides are degraded by microorganisms in soil. It has been reported that many bacteria and fungi converts DDT to DDD. Example, *Achromobacter, Aerobacter, Agrobactrium, Bacillus, Clostriduim, Corynebacterium, Escherichia, Ervinia, Kurthia Pseudomonas and Streptococcus*. Aldrin gets converted to dieldrin by *Trichoderma, Fusarium, Penicillium* and *Pseudomonas* without any loss of insecticidal properties. Heptachlor is converted to heptachlor epoxide in soil by Fusarium, Rhizopus, Penicillium, Trichoderma, Nocardia, Streptomyces, Bacillus and Micromonospora Converts Lindane to & HCH by clostridium and Escheriachia, disappearing fastly in flooded soil.

The herbicides and fungicides are also degraded by microbes. Simazine and atrazine are degraded by *Aspergillus, Rhizopus, Fusarium, Penicillium* and Trichoderma, Linoson herbicides are degraded specially by *Asperigillus nidulans* etc. Fungicides like Ferbam (Ferric dimethyl dithiocarbomate) and Ziram (Zinc dimethly dithio carbomate) are degraded by yeasts. PCNB (Pentachloronitrobenzene) is degraded by Rhizoctinia solanii and mercurial fungicide are attacked by *Penicilluim, Asperiglius* and Bacillus, species.

Factors influencing Pesticides in soil

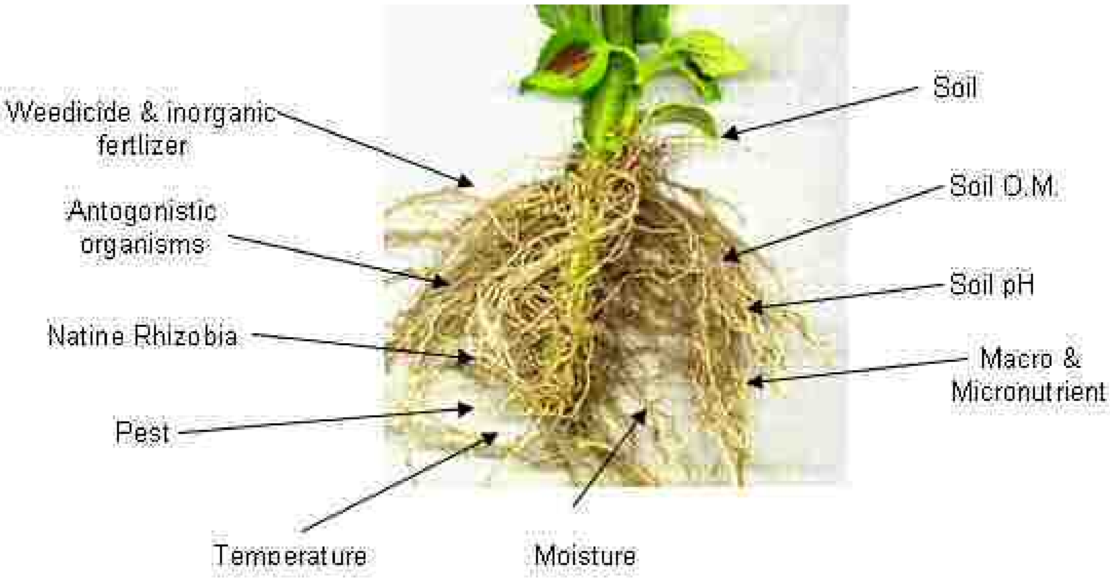
Factors that influences the fate of pesticides in soil are

1. Chemical decomposition
2. Photochemical decomposition
3. Microbial decomposition
4. Volatilization
5. Movement in soil
6. Plant and organism uptake and adsorption

Persistence of pesticide in soil varies probably due to differences in analytical techniques used in monitoring residues. The effective persistence of pesticide in soil varies from few weeks to several years depending on the chemical characteristic of the compound and its reaction in soil. Phosphates being highly toxic don't persist for longer periods of more than 3 months, but chlorinated pesticides persists for more than 4 to 10 years.

S. No.	Pesticides	Persistence
1.	Chlordane	5 Years
2.	DDT	4 Years
3.	BHC	3 Years
4.	Heptachlor	1-3 Years
5.	Diazinon	3 Months
6.	Disulfoton	4 Weeks
7.	Phorate	2 Weeks
8.	Malathion and Parathion	2 Weeks
9.	Deuron	8 Months
10.	Linuron	4 Months
11.	2-4 D	1 Month
12.	Zimazine	12 Months
13.	Atrazine	10 Months

Environmental pollution and human hazards due to use of intensive pesticides and industry wastes are of great concern. Once a pesticide is released in the environment, it is



distributed in soil depending on its physic chemical properties of the soil. The microbial components mainly bacteria, fungi, algae and protozoa are important for degrading plant and animal matter, recycling organic and inorganic nutrients in soil, especially in carbon nitrogen phosphorus and sulfur transformation. The pesticide application should not be at the cost of soil health deterioration. We have to look for Bio pesticides application which can be a substitute, to certain extent, to chemical synthetic pesticides. This approach needs to educate farmers from grass root level on the judiciously use of pesticides in order to prevent environmental pollution and minimizing contamination in food chain.

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Nutrient Diagnosis and Management in Citrus : Recent Developments

A.K.Srivastava

Principal Scientist
National Research Centre for Citrus, Nagpur (MH)
Email : aksrivas2007@gmail com

1. Background Information

Citrus nutrition has been the subject of exclusive investigation world over during the last 50 years or so, effectively. Resultantly, innumerable technologies came into practice in many commercial citrus orchards, needless to elucidate the consequences of these. However, in the light of changing global environment and consequent upon them, the newly emerging nutritional problems made citrus nutrition, a more popular and burning issue with regard to sustaining the quality citrus production

Precise identification of nutrient constraints right at the field, an effective amelioration technology, combating various limitations offered by soil, and accordingly simulating the nutritional requirement through studies on root configuration, characterizing nutrient uptake behaviour, and addressing salinity borne problems besides using organic citrus culture, all constitute important components of an effective citrus nutrition programme.

1.1 Nutrient Uptake : Index of Fertilizer Requirement : Different citrus spices observed a different pattern of nutrient uptake which suggested database uptake pattern of different nutrients could act as an effective indice of working out the fertilizer requirement. Sweet orange is more nutrient exhaustive than mandarin or acid lime in terms of Fe, Mn or Zn removal. Or alternatively, acid lime is more nutrient extracting than sweet orange with reference to N, P and K removal. However, mandarin remove far higher K than sweet orange or acid lime.

1.2 Production Sustainability : Reduced longevity coupled with poor efficiency of commercial 'Nagpur' mandarin orchards collectively render the economics of cultivation non-remunerative more often quite untimely due to unsustainability in production. Quadratic regression of orchards age with fruit yield and tree efficiency revealed an increase in fruit yield from 37.7 to 66.3 kg tree^{-1} and tree efficiency 8.6 to 11.0 % within 6 to 17 years, and beyond that, both parameters declined invariably. Other biometric relations viz., orchard age versus tree volume and tree volume versus fruit yield followed a similar curvilinear quadratic pattern with peak fruit yield coinciding with the orchard age of 17 to 20 years. Such statistical basis can be effectively applied for yield forecasting of citrus orchards on a long term basis.

1.3 Soil Carbon Stock of Citrus Orchards : Unprecedented decline in productivity of these orchards is a common feature, especially when orchards attain an age beyond 15 years. Of the many contributory factors, soil nutrient reserve holds prime importance. Stock of total carbon (Organic + Inorganic – C) in soil predominantly governs the transformation and availability of nutrients which in turn displays its direct and indirect implications on crop performance. In the background of key role of soil total -C sustaining long term productivity, the studies were, therefore, carried out with the objective to stock of both organic and inorganic –C in surface and sub-surface soils besides other nutrients and their relationship with productivity of sweet orange orchards.

The total carbon content on average basis was observed to vary from 8.00 to 28.70 g kg^{-1} in surface and from 8.60 to 31.70 g kg^{-1} in subsurface. A large variation in available nutrients viz., available N from 86.7 to 202.4, P 5.9 to 16.8, K 173.4 to 403.2, Fe 4.3 to 21.7, Mn 4.6 to 16.7, Zn 0.34 to 1.17, B 0.32 to 0.68, and Mo from 0.06 to 0.18 mg kg^{-1} was observed with a fruit yield ranging from 40.3 to 147.1 kg tree^{-1}. Out of these available nutrients, the fruit yield was positively and significantly correlated with available N (r = 0.952, significant $p = 0.01$), Fe (r = 0.448, significant at $p = 0.05$), Mn (r = 0.386, significant at $p = 0.01$), and B (r = 0.582, significant at $p = 0.01$). But, the degree of correlationship of fruit yield was highest with organic carbon content (r = 0.986, significant at $p = 0.01$) and to a lesser degree with inorganic carbon content (r = 0.596, significant at $p = 0.01$). However, total carbon content proved to be the best indicator for orchard productivity (r = 0.992, significant at p = 0.01). These relationships were more significant at 0-15 cm than 15-30 cm orchards. High performing sweet orange orchards (74.8-147.1 kg tree^{-1}) were observed to have 123.3-166.1 available N, 10.7-13.7 available P, 224.0-288.4 available K, 6.4-15.6 available Fe, 14.9-16.7 available Mn, 0.90-1.17 available B, 0.08-0.12 mg kg^{-1} available Mo, 5.5-7.8 g kg^{-1} organic –C and 11.7-22.6 g kg^{-1} inorganic -C.

1.4 Delineation of Citrus Production Zones : GIS Application: Redressal of spatial variability in soil fertility is important to identify the nutrient constraints and productivity zones to rationalize the nutrient use and optimize the factor productivity. Leaf analysis and fruit yield data bank generated through exploration of 7 states across northeast India were analyzed through diagnosis and recommendation integrated system (DRIS) to determine leaf nutrient optima and geographical information system (GIS) to develop spatial variogram of nutrient constraints to delineate major production zones.

It is well recognized that crop behavior and soils are not uniform within a given orchard. Resultantly, growers have generally responded to such variability by taking appropriate actions such as improving drainage, changing fertilization time, source etc. Advances in software aided decision support systems (DSS) like DRIS and GIS, have led to usage of newer interpretation tools having much wider application potential. Precision citrus farming basically depends on correctness of measurement and understanding on variability in available supply of nutrients, which can be summarized in three steps namely: i assessing variation, ii managing variation, and iii evaluation of yield response. The available technologies enable us in understanding the variability and by giving site-specific recommendations, the variability can be addressed precisely to make precision citriculture a viable management strategy. With this background information, efforts were made to identify major promising productivity zones for concentrated development of 'Khasi' mandarin orchards in northeast India.

2. Soil Properties and Orchard Efficiency (OE)

Orchard efficiency (OE) is one of the indice of evaluating the sustainability in production behaviour of citrus orchards. A wide range of soil properties broadly categorised into particle size distribution, water soluble and exchangeable cations, and soil available nutrients were investigated in relation to efficiency of Nagpur mandarin (*Citrus reticulata* Blanco) orchards established on smectite rich 3 soil orders (Entisols, Inceptisols, and Vertisols) representing 18 locations of central India. The soil properties viz., free $CaCO_3$, clay content, water soluble- and exchangeable-Ca^{2+}, available N, P, and Zn contributed significantly towards variation in OE. The threshold limit of these limiting soil properties was further established using multivariate quadratic regression models as: 132.1 g kg^{-1} free $CaCO_3$ (Y = 43.47 + 26.65cos (0.027x – 3.24)), 418.1 g kg^{-1} clay (Y= 60.74 + 51.47cos (0.0098x + 2.91)), 149.9 mg l^{-1} water soluble Ca^{2+} (Y = -138.63 + 6.54x – 0.085x^2 + 0.0004x^3 - 0.00007x^4), 25.9 cmol(p^+) kg^{-1} exchangeable Ca^{2+}(Y = 52.15 exp. ((-(29.87 – $x)^2$)/(2 x 9.22^2)), 114.6 mg kg^{-1} available N(Y = 593.96 + 15.49x + 0.14(x^2 – 0.0003x^3)), 12.8 mg kg^{-1} available P(Y = 46.09/(1+389.29exp.(-0.94x))), and 0.96 mg kg^{-1} available Zn(Y = 56.09 – 34.02 exp. (-3.35 $x^{5.83}$)) in relation to optimum OE of 82.1%. These reference values were very close to those obtained from best fit models, and could be effectively utilised in addressing soil related production constraints for precision-aided citriculture.

3. Development of Nutrient Diagnostics

3.1 Leaf Nutrient Diagnostics : The leaf analysis integrates the effect of many variables like soil and climate, which can be used to a great advantage.

3.1.1 Leaf sampling technique : The accuracy of foliar analysis, depends upon the specificity of sampling with respect to leaf age, position of leaves on the terminal, type of terminal, time of sampling cropping and other growing conditions.

3.1.1.1 *Sampling period or leaf age* : The suitable period of leaf sampling was observed at 6-8 months of leaf age in *Ambia* flush (February bloom) in Typic Haplustert soil type and 5-7 months in *Mrig* flush (July bloom) in Typic Ustochrept and Typic Ustorthent soil type. Leaf sampling age followed across various citrus growing countries further suggest that no particular leaf sampling age is followed. It has to be standardized under a given set of growing conditions.

3.1.1.2 *Leaf position* : An appraisal of nutrient composition of leaves collected at positions of 2nd, 3rd and 4th leaf on a shoot indicated statistically non-significant variation in the concentration of different nutrients viz., N, P, K, Ca, Mg, S, Fe, Mn, Cu and Zn studied in 6 to 8 month old leaves during both the years. These observations indicated that all the leaf positions were equally effective index leaves for finding out the nutrient status of tree. The earlier studies showed that concentration of N, P, K and Ca in 3rd and 4th leaves behind the fruit were nearer to the concentration in leaves from non-fruiting growth.

3.1.1.3 *Leaf sample size* : The statistically non-significant variation in leaf N, P, K, Mg, Fe, Mn, Cu and Zn status was observed in 6 to 8 month old leaves considering the leaf sample size varying from 30-70 leaves covering 2 to 10 % trees. These minimum variations in leaf nutrient composition indicated that leaf sample size as low as 30 leaves covering 2 % trees was equally effective for foliar analysis as much as 70 leaves covering even 10 per cent trees. However, many other studies across the world have recommended appropriate leaf sample size as low as 40 leaves and as high as 100 leaves.

3.1.2 Leaf nutrient norms : The leaf nutrients norms were developed employing two diverse diagnostic methods (Field response studies and modelling through DRIS) using different citrus cultivars. The difference in diagnostic methods apart from the agroclimate and nutrient uptake behaviour of cultivar are the major contributory factors towards variation in reference values being recommended in relation to yield.

3.1.2.1 *'Nagpur' mandarin* : Optimum leaf nutrients standards for 'Nagpur' mandarin was worked out as: 2.24-2.40% N, 0.07-0.110% P, 1.18-1.56% K, 1.32-1.55% Ca, 0.48-0.67% Mg, 110-132 ppm Fe, 29-43 ppm Mn, 8-14 ppm Cu and 19-30 ppm Zn.

3.1.2.2 *'Khasi' mandarin* : Optimum leaf nutrient standards for 'Khasi' mandarin was observed as : 2.23-2.49% N, 0.10-0.11% P, 1.86-2.12% K, 2.12-2.32% Ca, 0.28-0.38% Mg, and 148-180 ppm Fe, 72-85 ppm Mn, 10-19 ppm Cu and 24-39 ppm Zn.

3.1.2.3 *'Kinnow' mandarin* : Optimum leaf nutrient standards for 'Kinnow' mandarin was determined as : 2.28-2.53 % N, 0.10-0.13% P, 1.28-1.63% K, 2.12-3.12% Ca, 0.32-0.53% Mg, ppm Fe, 41.7-76.3 ppm Mn, 6.1-10.3 ppm Cu and 21.3-28.5 Zn.

3.1.2.4 *'Mosambi' sweet orange* : Optimum leaf nutrient standards for 'Mosambi' sweet orange was worked out as : 1.98-2.57% N, 0.091-0.17% P, 1.33-1.72% K, 1.73-2.98% Ca, 0.32-0.69% Mg, 69.5-137.1 132 ppm Fe, 42.2-87.0 ppm Mn, 6.6-15.8 ppm Cu, 11.6-28.7 ppm Zn, 12.8-23.1ppm B and 0.39-1.1 ppm Mo.

3.2 Descriptors for Nutrient Deficiency : Development of visible symptoms is attributed to metabolic disorders which cause changes in micromorphology of plants before these symptoms are identifiable. The way in which symptom develop and manifest on younger or older leaves or fruits gives a reliable indication of the cause of the nutritional disorders. Both deficiency and excess of nutrients can lead to reduced crop yield with inferior fruit quality. The morphological characteristics developed through deficiency symptoms of different nutrients could be effectively used as first hand aid in diagnosis of nutrient constraints :

3.3 Soil Fertility Diagnostics : The soil test method rests on the assumptions that roots would extract nutrients from the soil in a manner comparable to chemical soil extractants, and that there is a simple direct relation between the extractable concentration of nutrients in the soil and uptake by plants. This is based on the concept that an ideal soil is one where the cations are present in ideal proportions. One serious defect of this approach, is that it has to be significantly modified in relation to soil type, in particular as between calcareous and non-calcareous soils. Besides adjusting the recommendations in relation to targetted yield. Otherwise, soil nutrient depletion has grave implications in terms of : i. more acute nutrient deficiencies, ii. two wide spread nutrient deficiencies, iii. fall in fertilizer use efficiencies and in returns from fertilization, iv. weakening the foundation of sustainable high yield and v. very high remedial cost involved in building up the depleted soils.

3.3.1 Indices of soil fertility : Various indices of soil fertility were correlated with fruit yield in order to develop multiple-tier system of soil fertility evaluation. The fruit yield was significantly correlated with available N (r = 0.532, *p = 0.01*), P(r= 0.412, *p=0.01*), K (r = 0.389, *p = 0.05*), Fe (r = 0.508, *p = 0.01*), Mn (r = 0.489, *p = 0.01*), and Zn (r = 0.532, *p = 0.01*). While, bacterial and fungal count as an effective parameters of soil microbial population, were more significantly correlated with fruit yield (r = 0.561 and r = 0.612, *p = 0.01*). With correlation worked to further finer parameters such as soil microbial biomass nutrients (SMBN), viz., C_{mic} (r = 0.582, *p=0.01*), N_{mic}(r = 0.692, *p=0.01*) and P_{mic} (r = 0.698, *p= 0.01*) further improved, suggesting that microbial biomass nutrients are more sensitive indicators than soil microbial population. Similarly soil enzymes viz., urease (r = 0.712, *p=0.01*), alkaline phosphatase (r = 782, *p=0.01*) and dehydrogenase (r = 789, *p =0.05*) were still highly correlated with fruit yield demonstrating their most sensitive nature to input response in soil fertility fluctuations. These parameters are currently being indexed for further refinement.

3.3.2 Nutrient partitioning : Occurrence of nutrient constraint at any phenological growth stage in a highly nutrient responsive crop like citrus could jeopardize the incentive accruing through balanced fertilization. The current state of knowledge on the above subject is very limited. Dynamics of different nutrients across all six growth stages (January-February as stage I, March-April as stage II, May-June as stage III, July-August as stage IV, September-October as stage V and November - December as stage VI) of Nagpur mandarin trees grown on alkaline calcareous Haplustert was studied. Comparison of nutrient dynamics across different growth stages under two diverse performing trees suggested that except stage II, dynamics of different nutrient concentration were significantly different upto stage VI, lending strong support to the fact that nutrient acquisition capacity of sink (i.e. leaves) never attained a complete cessation at any stage of growth. Initially upto stage II, nutrient concentration followed almost a static trend and, thereafter, the expression of sink capacity i.e. partitioning of nutrients became distinctly evident. Interestingly, trees showing high yield performance maintained an optimum nutrient concentration upto stage VI contrary to those with low yield performance. The stages III and IV were identified as most critical stages for nutrient application in order to harness the maximum fertilizer use efficiency through studies on nutrient dynamics. These observations provided the desired proof to recommend the differential nutrient concentration to be maintained at different critical growth stages in order to obtain maximum fertilizer use efficiency vis-à-vis high yield.

3.2.3 Soil fertility norms : Differential soil fertility norms were obtained in relation to commercial citrus cultivars are briefly summarised below :

3.2.3.1 'Nagpur' mandarin : Optimum soil fertility limit was observed as : Alkaline $KMnO_4$-N 118.4-121.2 mg kg^{-1},Olsen- P 9.2-10.3 mg kg^{-1}, NH_4OAc-K 178.4-232.5 mg kg^{-1}, DTPA-Fe 12.4-16.2 mg kg^{-1}, DTPA-Mn 8.6-12.2 mg kg^{-1}, DTPA-Cu 2.1-2.3 mg kg^{-1}, and DTPA-Zn 0.98-1.1 mg kg^{-1} in relation to fruit yield of 39.7-54.1 kg $tree^{-1}$.

3.2.3.2 *'Khasi' mandarin* : Optimum soil fertility limit was observed as : Alkaline $KMnO_4$-N 220.8-240.6 mg kg^{-1}, Bray-P 6.2-7.8 mg kg^{-1}, NH_4OAc-K 252.2-300.8 mg kg^{-1}, DTPA-Fe 82.2-114.6 mg kg^{-1}, DTPA-Mn 21.4-32.8 mg kg^{-1}, DTPA-Cu 0.82-1.62 mg kg^{-1}, and DTPA-Zn 2.18-4.22 mg kg^{-1} for an optimum fruit yield of 25.0-32.0 kg $tree^{-1}$.

3.2.3.3 *'Kinnow' mandarin* : Optimum soil fertility limit was observed as : Alkaline $KMnO_4$-N 118.2-128.4 mg kg^{-1}, Olsen-P 9.4-16.3 kg^{-1}, NH_4OAc- K 158.3-208.2 mg kg^{-1}, DTPA-Fe 3.1-9.3 mg kg^{-1}, DTPA-Mn 4.8-7.3 mg kg^{-1}, DTPA-Cu 0.58-1.25 mg kg^{-1}, and DTPA-Zn 0.64- 0.98 mg kg^{-1} for the fruit yield of 61.8-140.3 kg $tree^{-1}$.

3.2.3.4 *'Mosambi' sweet orange* : Optimum soil fertility limit was observed as : Alkaline $KMnO_4$-N 130.1-142.2 mg kg^{-1}, Olsen-P 9.8-11.4 kg^{-1}, NH_4OAc- K 182.4-210.3 mg kg^{-1}, DTPA-Fe 13.2-18.6 mg kg^{-1}, DTPA-Mn 14.6-22.6 mg kg^{-1}, DTPA-Cu 2.16-2.42 mg kg^{-1}, DTPA-Zn 0.98-1.21 mg kg^{-1}, hot water soluble-B 0.28-0.48 mg kg^{-1}, and $(NH_4)_2$ C_2O_4-Mo 0.08-0.10 mg kg^{-1} for the fruit yield of 79.4-93.9 kg $tree^{-1}$.

4. Changing Strategies of Nutrient Management

In recent years, soil fertility management has witnessed a fresh look in terms of foliar application, residual versus cumulative fertilizer response, substrate dynamics-INM, fertigation, SSNM-VRT and fertilization as per nutrient partitioning.

4.1 Foliar Application of Fe : It must also be cleared when and under which circumstances foliar fertilization is better than common basic soil fertilization, namely e.g. in case of soil deficiencies in nutrients (either due to their total absence or trace elements being bound because of unfavourable soil condition), as this has a negative influence on the plant growth but also in the cases of soil nutrient imbalances (also this having an unfavourable influence, on root absorption or on optimal growth).

The experiment was originally initiated in 12-yr-old orchard deficit in N, P, Fe and Zn 2004-07 comparing soil application versus foliar application of Fe, each at three levels viz., 100, 200, and 300 g $tree^{-1}$ with constant dose of N, P and K. The basal doses of N, P, K and Fen were supplied uniformly to all the treatments. These treatments were tested in a randomised block design with five replications at Nimji village Kalmeshwar. Amongst the comparison of soil application of $FeSO_4$ (SA_{100}, SA_{200} and SA_{300}) versus foliar application of $FeSO_4$(FA_{100}, FA_{200} and FA_{300}), the foliar application of $FeSO_4$ @ 200 g $tree^{-1}$ $year^{-1}$ (T_5) produced the best response over either any of the other foliar applied treatments like T_4, T_6 or soil applied treatments such as T_1, T_2 and T_3 with reference to various parameters viz., flowering intensity, fruit set, tree volume, fruit yield, soil fertility changes, leaf nutrient composition and fruit quality. The treatment T_7 involving combined application of $FeSO_4$ (200 g $tree^{-1}$ $year^{-1}$) and FYM (10 kg $tree^{-1}$ $year^{-1}$) responded much better over treatment T_5 showing the superiority of combined application of $FeSO_4$ and FYM over $FeSO_4$ alone. Water soluble-Fe, exchangeable-Fe and complex-Fe were determined to be the three major soil Fe fractions maintaining Fe-supply to Nagpur mandarin.

4.2 Soil Application of Zn and Modelling Zn-Nutrition : This is one of the most popular methods of fertilization. Infact, soil fertilization is the basic condition for adequate mineral supply to plants since plant's main organ for absorbing nutrient and water is the root. Zinc (Zn) deficiency is the most prevalent nutritional disorder in citrus orchards world. over. The management strategy of Zn deficiency today is still governed by the efficacy of two conventionally used methods of Zn supply to plants via soil or foliar fertilization. A field experiment with 12-yr-old 'Nagpur' mandarin (*Citrus reticulata* Blanco) orchard was, therefore, carried out during 2004–07 comparing soil application versus foliar application of Zn, each at three levels viz., 100, 200, and 300 g tree^{-1} with constant doses of N (600 g tree^{-1}), P (200 g tree^{-1}), K (300 g tree^{-1}), and Fe(60 g tree^{-1}) on Haplustert soil type with reference to response on flowering intensity, fruit set, tree volume, fruit yield, changes in soil fertility/leaf nutrient status, fruit quality, and transformation of native soil Zn fractions. Soil application of Zn at all the three levels, produced significantly higher increase in tree volume over foliar application on equivalent rates viz., T_1 (2.53 m^3) vs. T_4 (2.06 m^3) and T_2(4.30 m^3) vs. T_5 (2.23 m^3). The yield-determining parameters like flowering and fruit set intensity (no. m^{-1} shoot length) were, respectively, much higher with soil applied (135.74 and 21.90) than foliar applied Zn (31.20 and 11.6). These observations set the favorable conditions required for yield response, e.g., all the three treatments involving soil application of Zn, T_1 (32.1 kg tree^{-1}), T_2 (52.6 kg tree^{-1}), and T_3 (51.8 kg tree^{-1}) were correspondingly superior over T_4 (22.5 kg tree^{-1}), T_5 (34.3 kg tree^{-1}), and T_6 (42.1 kg tree^{-1}) as foliar application treatments. All the three major fruit quality parameters (juice, acidity, and TSS) were likewise more influenced by soil application than foliar application of Zn. Improvements in soil Zn fractions (mg kg^{-1}) viz., exchangeable Zn (0.25–0.60), complex-Zn (2.71 to 4.86), organically bound Zn (0.86 to 2.0), and Zn-bound to carbonates and acid soluble minerals (2.56–4.96) were observed in response to Zn fertilization with treatments T_1–T_3. On the other hand, foliar applied Zn treatments (T_4–T_6) produced no such changes in any of the soil Zn fractions.

4.3 Residual Versus Cumulative Fertilizer Response : Earlier multilocation field experiments helped to establish the optimum fertilizer requirements varying 600-800 N – 200-400 P_2O_5 – 100-300 g K_2O tree^{-1} year^{-1} on Ustorthents – Haplusterts. Similarly, the optimum Zn and Fe (200-300 g as $ZnSO_4$ and $FeSO_4$, respectively, tree^{-1} year^{-1}) requirement was worked out through multilocation experiments on Haplusterts. These were treated as recommended doses of fertilizers, and tested for their residual versus cumulative effects in long term experiments laid out on Haplustert. The response of application of 1/6th of RDF for 5 years on canopy volume, fruit yield and quality was significant. Similarly, the response of agewise nutrient dose was also significant including the interaction effect, suggesting that the response of fertilization was gradually getting evident with time lapse. The observations are suggestive of the fact that initially the above nutrient doses imparted reduction in soil fertility over initial fertility, but with fourth year onward, their response on soil fertility changes became significantly evident.

4.4 Organic Manuring Versus Inorganic Fertilization : Long term studies comparing organic versus inorganic fertilization showed that no significant difference with reference to either fruit yield or fruit quality with IF maintaining better available pool of nutrients in soil.

4.5 Fertigation and FUE : Various irrigation and fertilizer levels singly and in combination were evaluated through fertigation in terms of response on the tree growth, fruit yield, quality and leaf nutrient composition of Nagpur mandarin (*Citrus reticulata* Blanco) budded on rough lemon (*Citrus jambhiri* Lush.) on an alkaline calcareous Lithic Ustochrept under hot sub-humid tropical climate of central India. Irrigation at 20 % depletion of available water content and fertilizer treatment of 500 g N - 140 g P_2O_5 - 70 g K_2O tree^{-1} year^{-1} individually were observed to be optimum irrigation and fertilizer requirement, respectively. Implementation of fertigation helped in reducing the fertilizer and water requirement by 33% and 40%, respectively.

4.6 Spatial Variation in Soil Fertility and SSNM : Site specific nutrient management (SSNM) offers the most appropriate option to address the spatial variation in soil fertility using variable rate fertilization (VRF) as per soil test values. The spatial variability in available NPK Fe Mn Cu was measured through exhaustive grid sampling and geocoding. Accordingly, two contrasting soil types viz., Typic Ustorthent and Typic Haplustert showed a significantly different magnitude of response of Nagpur mandarin to fertilization. Best fertilizer treatments in terms of response on canopy growth, fruit yield, fruit quality and leaf nutrient concentration were observed to be 1200 N - 600 P_2O_5 - 600 K_2O - micronutrients (300 g each of $ZnSO_4$ and $MnSO_4$ alongwith 100 g borax tree^{-1}) on Typic Ustorthent soil type. While on Typic Haplustert soil type, 600 g N - 400 g P_2O_5 - 300 g K_2O + micronutrients (300 g each of $ZnSO_4$ and $MnSO_4$ alongwith 100 g borax tree^{-1}) and 400 g $MgSO_4$ tree^{-1} proved most effective. Higher application of K at the rate of 900 g tree^{-1} alongwith 600 g N - 400 g P_2O_5 produced much higher acidity and induced late maturity on Typic Haplustert when compared in combination with 1200 g N - 600 g P_2O_5 (Srivastava *et al*., 2006). Such a differential response of fertilization showed no similarity with recommended fertilizer doses earlier worked out through multilocation trials. Similarly, SSNM studies carried out on sweet orange showed far superior results over fertilizer treatments based on existing recommendations or farm practice. The higher net economic return with SSNM validates its importance in large-scale orchard adoption to minimize the gap between actual and potential productivity. The SSNM treatment in this study provided a comparatively higher net returns than those received from farmer's fertilizer practice or the recommended dose of fertilizers. These results clearly showed that some revision of the current fertilizer recommendation system is required if full productivity potential on a given soil type is to be realized. SSNM could be further fitted precisely into precision Citriculture combining multiple fertilizer application through fertigation with canopy sensors so that both irrigation and fertilizers are jointly given according to canopy size of trees within an orchard.

4.7 Microbial Consortium and INM : Exploiting microbial synergisms is one of the popular methods of substrate dynamics and associated changes in nutrient environment of rhizosphere. A large number of microbes were isolated from rhizosphere of citrus orchards established on acid soils of northeast India, neutral alkaline soils of central India and northwest India. The microbial diversity existing within top 0-20 cm rhizosphere soil was characterized and isolated the promising microbes. These microbes comprised of N-fixers (*Azotobacter chroococcum* and *Azospirillum brasilens*), P-solubilizers fungi (*Trichoderma harzianum* and *T. viride*) and P-solubilizing bacteria viz., *Pseudomonas fluorescens, P. striata, Bacillus subtilis, B. mycoides, B. polymyxa, B. stearothermophilus, B. cereus, B. coagulans, B. licheniformis, B. circulans, B. pumilus,* and *B sphaericus*. The efficient microbes isolated through soil (*B. polymyxa* 12 x 10^3 cfu g^{-1}, *P. fluorescens* 5 x 10^3 cfu g^{-1}, *T. harzianum* 12 x 10^3 cfu g^{-1}, *A. chroococcum* 16 x 10^3 cfu g^{-1}, and *B. mycoides* 3 x 10^3 cfu g^{-1}) were brought in broth in order to achieve much high population as a substantial value addition (*B. polymyxa* 33 x 10^7 cfu ml^{-1}, *P. fluorescens* 14 x 10^7 cfu $ml^{-1,}$ *T. harzianum* 32 x 10^7 cfu ml^{-1}, *A. chroococcum* 10 x 10^6 cfu ml^{-1} and *B. mycoides* 7 x 10^5 cfu ml^{-1}) known as microbial consortium and, then evaluated for 3 weeks for population changes at weekly interval in a complete consortium mode.

The efficacy of microbial consortium was tested through 40 days long incubation study using organic manure as FYM (OM) and inorganic fertilizers (NPK as IF) in different combinations viz., T_1 = 100% OM + MC, T_2 = 10% OM + 90% IF + MC, T_3 = 25% OM + 75% IF + MC, T_4 = 50% OM + 50% IF + MC, T_5 = 75% OM + 25% IF + MC and T_6 100% IF + MC. The highest bacterial population was observed with T_1 (52 x 10^4 cfu g^{-1}), followed by T_5 (38 x 10^4 cfu g^{-1}), T_3(26 x 10^4 cfu g^{-1}), T_4(21 x 10^4 cfu g^{-1}), T_2 (7 x 10^4 cfu g^{-1}) and T_6 (6 x 10^3 cfu g^{-1}) in decreasing order. Different INM-based treatments involving MC so developed displayed distinctive advantage over IF in the first pre-bearing 5 years of field evaluation in terms of soil microbial biomass nutrients (C_{mic}, N_{mic} and P_{mic}) and carbon loading of soil besides bringing significant changes in soil fertility. These results suggested two cardinal points viz., i. the developed microbial consortium holds a good promise in possible INM format and ii. exclusive combination with inorganic fertilizers produced depleting effect of population buildup. The microbial consortium thus developed is currently being assessed through long term field study on development of suitable INM module.

5. Perspectives

Out of different diagnostic methods in practice, only leaf analysis complimented by soil analysis, has made some headway. The researches on DRIS with citrus as test crop have shown some distinct advantages over conventional leaf analysis-based interpretation tools in order to make diagnosis possible at any stage of crop development. In this regard, ideally we need to develop the polypeptide- based warning system using biochemical markers to facilitate round-the-year nutritional care of crop through a better use of precision oriented informatics keeping in mind the orchard efficiency as an ultimate index of productivity. This could be further refined through crop logging for various nutrients. Geo-referenced soil sampling has proved to be an effective tool in defining soil variability within an orchard. Once the critical soil properties are identified, the procedural steps can be evolved to address the inconsistency in fertilization response could be conveniently worked out.

The conditions under which citrus trees are most likely to respond to corrective nutrient treatments are still not fully understood. The role of different nutrients in flowering, fruit set, fruit quality (external and internal) and juice shelf life; models defining the critical periods of nutrient supply to assure sustained response and its uptake for helping the management decision under different citrus-based cropping systems; and devising means for improved nutrient uptake efficiency need to be attempted to unravel many of the complexities involved with nutrition. However, using newly emerging techniques of nutrient management like open field hydroponics with restricted root zone and sensor-based SSNM, concerted efforts would be required to develop yield monitors in the light of adequacy level of plant nutrition vis-à-vis development of precision-based citrus production system.

6. Technologies Developed

i. Leaf analysis based fertilizer scheduling for Nagpur mandarin, 'Mosambi' sweet orange and Acid lime

ii. Leaf nutrient diagnostics for optimum productivity of various commercial citrus cultivars which are currently being utilised for advisory purpose to the citrus growers on country wide basis

iii. Soil suitability diagnostic criteria for different cultivars viz. Nagpur mandarin 'Mosambi' sweet orange, Khasi mandarin, Pummelo, lemon.

iv. Fertigation technique and irrigation scheduling using microirrigation system

v. Site specific nutrient management strategy for precision citriculture

vi. Microbial consortium and substrate dynamics.

7. Thrust Area : Way Forward

Despite many cutting edge technologies addressing a variety of core issues of nutrient management, many more issues are yet to be attempted which are highlighted as:

i. Role of improved plant nutrition on changes on anti-oxidant versus drought tolerance

- Field identification of different nutrient deficiencies and their profiling for different antioxidants
- Evaluation of changes in anti-oxidants in response to different nutrients in a progressive nutrient field experiment.
- Establishment of relation between antioxidant system with indices of drought tolerance.

ii. Expansion of DRIS indices and their validation to different citrus varieties and development of soil fertility diagnostics as per soil type

- Survey and establishment of database for soil analysis, leaf analysis and fruit yield from across different belts
- Modelling for nutrient diagnostics vis-à-vis climate change
- Validation of nutrient diagnostics.

iii. Development of citrus specific INM module and carbon sequestration vis-à-vis microbial turnover of nutrients and substrate dynamics versus nutrient transformation

- Survey of cultivar specific citrus orchards and intensive collection of soil samples from rhizosphere zone
- Isolation and characterization of microbial diversity within cultivar specific rhizosphere.
- Identification of promising microbes through incubation studies and development of microbial consortium
- Evaluation of microbial consortium in INM module and recommendation for appropriate INM module depending upon region specific varieties.

iv. Development of SSNM into Senor-based DSS (Decision Support System) for variable rate fertilization and improved fertilizer use efficiency

- Development of spatial soil fertility variogram (by developing GPS and GIS database) as decision support tool for precision fertilizer recommendation.
- Development of SSNM strategy and evaluation through long term field experiments
- Development of logical relationship between canopy volume (using canopy sensors) and fertilizer requirement
- Identification and evaluation of variable rate fertilization for possible improvements in fertilizer use efficiency through field experimentation.

v. Development of protocol for organic cultivation of citrus

- Identification of components of organic citrus and nutrient profiling of available organic fertilizer sources of manures.
- Field evaluation of organic practices involving nutrition, insect pests and disease/management alongwith influence on post-harvest handling and processing.

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Production of Enriched Bio-Organics

N.G. Mitra[1] and B.S. Dwivedi[2]

[1]Principal Scientist
Department of Soil Science & Agricultural Chemistry
[2]Scientist
Department of Agronomy
JN Krishi Vishwa Vidhyalaya, Jabalpur – 482004 (M.P.)

1. Introduction

With reference to the current scenario, the country to feed the huge population has earned a remarkably record to produce 212 mt (million tonnes) foodgrains during 2001-02. Thereafter, despite increase in total production, there was proportionate decrease in the production. For the year 2010, the country needs 246 mt, and for the year 2020 needs 294 mt. The details of production (mt) of major food crops are

Food items	Production (2001-02)	Demand	
		Current (2010-11)	Future (2020-21)
Rice	93.1	138.6	143.7
Wheat	71.8	85.8	162.8
Total cereals	198.8	224.4	265.8
Pulses	13.2	21.4	27.8
Total food grains	212.0	245.8	293.6

With the current Foodgrains production standing at about 215 million tones (mt), India needs to produce an additional around 10 mt of Foodgrains annually, in order to feed the increasing rate of population growth by 1.578%. It is estimated that during 2010-11 about 246 mt (million tonnes) of Foodgrains is needed annually and to produce this about 25 ± 2 mt of plant nutrients (N + P_2O_5 + K_2O) as mineral fertilizer is required.

Because of continued cultivation over centuries and intensification of agriculture in recent years, there has been progressive and substantial depletion of the soil reserves. Of late, secondary and micronutrient deficiencies are also emerging as the crop response to these nutrients is increasing. Therefore, there is a need to add plant nutrients to the soil through mineral fertilizers, organic manures, biofertilizers, etc.

Therefore, the nation utters a clarion calls to ‘Go back to Basics’ with emphasis on organic farming for sustainable production. When entire dependence on chemical fertilizers for future agricultural growth would means imbalance nutrition to crops and loss in soil health, possibilities of water contamination and unsustainable burden on the fiscal system. Therefore, supplement the crops with balanced nutrition in sustainable manner, Integrated Plant Nutrient Management (IPNM) should be followed for sustainable agriculture with food security incorporating the use of organic matter, biofertilizers and bio-stimulants of organic nature are advised. However, individual application of organic matter and biofertilizers has some unavoidable hurdles and limitations in response and afford to application.

2. Responses and limitations in individual use of organic matter and biofertilizers

Organic matter alone

At present, on an average about 2 tonnes / ha of organic manure is being used annually which is below the general recommendation of 10-20 tonnes / ha. Alternative use of cattle dung as fuel is the major constraint in increasing availability of organic manures in India that causes a high cost involvement in transportation and application. Despite low and inconsistent nutrient content in OM, its nutrient content vary from one type to other.

Biofertilizers alone

Application of biofertilzers may increase crop yield by 10-20% with addition of nutrients 10-30 kg N or P / ha to the soil.

However, performance of biofertilizers is highly unpredictable due to their biological nature and susceptibility to biotic and abiotic stresses. There is a need to develop more effective, competitive and stress tolerant strains to increase nutrient supply form biofertilizers.

Hence, it is the high time to knock the door of our sense towards application of a new organic product as ‘Enriched Bio-organics’ that can simultaneously and promptly supplement nutrients in sustainable and eco-friendly manner.

3. What it contains ?

Rich Organics (enriched bio-organics) contains well-matured organic matter and growth promoting substances of biological origin. It contains major, minor and trace elements available in a form that facilitates its entry into the plant system in totality like chelated nutrients. It has free living nitrogen fixing and phosphate solubilizing microorganisms to benefit plants. It contains bio-stimulants that boost up plant vigour / vegetative growth, flowering, fruiting and yield of crop as targeted by the producer.

Note: The aim of any good organic manure is to supply fully bio-converted organic matter in a form that can support microbial and plant life.

4. Present Scenario of Enriched Bio-organics production

At present, there is neither a production unit established in the State nor any amount of Enriched Bio-organics is produced. However, different Companies in collaboration with State Sericulture Research and Development Institutes in India are manufacturing various crop specific manures, particularly in Karnataka, Maharastra and Tamil Nadu. The results are very encouraging. They launched it in various names viz., Rich Organics (Horticulture special), Rich Organics (Paddy Special), Rich Organics (Sugar Cane Special), etc.

Therefore, ample scope of widespread response, adoption and profitability out of commercial production of the Enriched Biorganics can be assured.

5. Technical Concept in production of Enriched Bio-organics

The topic has main target of *agro-waste management and its biodegradation for production of Enriched Bio-organics*.

Agricultural residue can also be put to use in different ways, development of enriched compost, vermicompost and certain enzymes that can be used commercially. Hydrolytic industrial enzymes e.g. microorganisms can also produce Cellulase, hemicellulase, xylanase, protease etc. for commercial purposes by using agro waste as Carbon source. Likewise, biodegradation of agro waste through hydrolytic enzyme produced by microorganism is possible in controlled conditions for value addition of agro waste. One of the options is protein enrichment of agro waste for animal feed production by solid-state fermentation. Microbial consortia could be effectively utilized for biodegradation of agricultural wasted for sustainable growth and crop production.

Procedure for rapid decomposition of organic wastes

S.No	Ingredient	Composition
1.	Rock phosphate	10%
2.	FYM	15%
3.	Ash	10%
4.	Decomposer liquid* (bio-inoculant mixture, each 10^7 cfu/ml)	1 ltr / t
	i. *Bacillus*	
	ii. *Torula*	
	iii. *Pleurotus*	
	iv. *Trichoderma*	
	v. *Aspergillus / Penicillium*	
	vi. *Azospirillum* / PSM	
5.	Moisture	40%

* Microbial composition may vary to achieve better biodegradation as per requirement.

6. Enrichment of compost

A. Microbial addition

The advantage of an engineering background, with a rapid and large scale waste processing, and a fair understanding of organic chemistry have made it possible to obtain completely mature and good quality compost without appreciable loss of nutrients (98% locking) within a short time of 1 month or so. The new product can easily be made 100% homogenized compost, or it can be granulated with a look as a synthetic agricultural product.

The basic idea to incorporate compatible beneficial microorganisms involves in EM culture. EM is a culture of microorganisms found in and gathered from nature. **EM is not a product of genetic engineering but exist in any healthy natural environment.** Therefore, EM can improve the chemical, physical and biological aspects as well as microbial aspect.

Chemical aspect: nutrients, pH, BC, etc.

Physical aspect : water permeability, water retainability, etc.

Biological aspect: up to a billion microorganisms per gram that include millions of yeast and actinomycetes, thousands of photosynthetic bacteria, etc.

EM is dominated by beneficial fermenting microorganisms like lactic acid bacteria and actinomycetes. This is why EM can prevent the spread of the putrefying and pathogenic germs and is used in making compost and prepare soil.

i. Microorganisms in EM (development of microbial consortia)

i. *Photosynthetic bacteria:* The main microorganisms in EM. Mostly anaerobic and can multiply every 2 - 3 hours. The best temperature: 50 - 60°C. Photosynthetic bacteria can produce sugar and amino acids from the root secretion, organic material and attacks harmful gasses like hydrogen sulfide (H_2S), methane (CH_4), ammonium (NH_3), etc. The conventional photosynthetic bacteria *are* *Rhodopseudomonas palustris* (purple phototropic bacteria) and *Rhodobacter sphaeroides*.

ii. *Lactic acid bacteria*: Lactic acid bacteria can multiply every 20 minutes. The best temperature is about 20°C. Lactic acid bacteria can decompose protein, starch, etc. into soluble matter rapidly with the help of yeast, then produces lactic acid and other various anti-oxidants. Lactic acid bacteria can help eliminate harmful microorganisms like *Fusarium* sp., which causes disease problems in continuous cropping. The good example of this kind of microorganisms is *Bacterium lacticum* or *Bacterium lactis, Lactobacillus plantarum, L. casei,* and *Streptococcus Lactis*, etc.

iii. *Yeasts*: Yeasts can multiply every 15-20 minutes. The best temperature: 25°C. Yeasts can produce bio-active matter like Vitamin B, C, and E, enzymes, hormones, etc. that vitalize the plants and promotes their growth and development. *Saccharomyces cerevisiae; Candida utilis* (usually known as *Torula, Pichia Jadinii* or yeast plant) are some common of this group that performs alcohol fermentation.

Composition of cellulosic biomass is as below which can be converted through glucose or glucose / xylose finally to lactic acid by *Saccharomyces* yeasts.

a. Cellulose 45%
b. Hemicellulose 25%
c. Lignine 25%
d. Other 5%

iv. *Actinomycetes:* Gram-positive actinomycetes produce anti-microbial substances. They can multiply every 30-60 minutes. The best temperature ranges from 14°C to 25°C. Actinomycetes live synergistically (in symbiosis) with photosynthetic bacteria, enhancing their ability to eliminate harmful microorganisms. Harmful anaerobic microorganisms to the extent of 80% are fungi. Fungi need chitin for their cell wall. Actinomycetes compete with the harmful fungi for chitin, suppressing their growth in the process. Actinomycetes usually breed after the organic materials

S. No	Bio-stimulant	Purpose	Application mode / rate
1	Sea weed extract (Kelp) *Sargassum*, *Ascophyllum nodosum*, and *Laminaria*	Natural hormones, minerals and trace elements	Foliar Soil
2	Amino acids	L-amino acids (17)	Foliar
3	Indole acetic acid (IAA) $C_{10}H_9NO_2$	Stimulates growth of main stem (apical dominance)	Foliar 100-500 ppm
4	Indole butyric acid (IBA)	Promotes the formation of roots in plants and to generate new roots in the cloning of plants through cuttings	Soaking of cuttings Herbaceous 1000 ppm Softwood 2000-3000 ppm Semi hardwood 2000-4000 ppm Hardwood 3000-6000 ppm
5	Naphthalene acetic acid (NAA) $C_{12}H_{10}O_2$	Increases the number, length and dry weight of root hairs, small roots and large roots	Soaking of cuttings 50-100 ppm
6	6-Benzyl aminopurine	It is a cytokinin; increases the thickness of stems, increase the leaf surface and the number of side branches	Foliar 300 to 400 ppm
7	Brassinolide ($C_{28}H_{48}O_6$)	Naturally occurring plant steroid; strengthens a plant's immunity to stresses; improves root growth, better seed germination, plant photosynthesis, resistance to cold and water shortage	Foliar 0.0001-0.30 ppm
8	Gibberellic Acid ($C_{19}H_{22}O_6$)	Naturally occurring plant hormone	Foliar 35-650 ppm
9	Triacontanol $CH_3(CH_2)_{29}OH$	It is a growth promoter: it raises plant yield by improving photosynthesis and cell division	Foliar 25-100 ppm

Other bio-stimulants

Molasses, Worm leachate, Mycomax, Chitosan, Fulvic acid, Fish emulsion, etc.

have already decomposed. Too much actinomycetes in the soil can result in too much disintegration of the organic matter, hardening the soil.

Some important actinobacteria are *Mycobacterium*, *Corynebacterium*, *Nocardia*, *Rhodococcus* and a few species of *Streptomyces albus* and *S. griseus*

v. *Fermenting fungi*: The fungi such as *Aspergillus oryzae* and *Penicillium* sp. produce alcohol, ester and anti-microbial substances. This prevents the development of harmful insects and helps control the bad smell. They are mostly aerobic. The common examples of this group are *Aspergillus oryzae* and *Mucor hiemalis*.

B. Value Addition (organic nutrients)

Plants need sugar and bio-active matter like hormones to absorb soluble organic nutrients like amino acids. Some microorganisms can produce bio-active matter as well as amino acids, but putrefying microorganisms don not produce bio-active matter. Plants need proteins, which they produce from amino acids, nitrogen and sugar. Amino acids are produced from nitrogen and sugar. Sugar is produced by photosynthesis of the plants. The plants can also produce amino acids, but this takes up more energy and sugar. The plants don not need so much energy if they can absorb amino-acids produced by the micro-organisms in the soil. Other bio-active stimulants are phytochemicals, vitamins, plant enzymes and hormones. (*Note*: Too much nitrogen without sugar can cause the burning of the roots).

Some of the bio-active matters can also be extraneously supplied as commercially available products in the name of phyto-hormones (Bio-stimulants) as below

7. Evaluation of Enriched Bio-organics from mature compost

The modern microbiology has several sophisticated methods to conspicuously identify the strains with genotypic attributes. Gel-electrophoresis for PCR-amplified small-subunit rRNA genes (SSU rDNA) sequencing technique is most suitable and convenient method to identify an organism taxonomically with their nucleotide ratio. Gene-marking is another method useful for chromosome mapping and genetic identification of the organisms. Therefore, correct evaluation of selected microorganisms is possible through tests on taxonomic, biochemical and genetic behaviour.

Enriched bio-organics or Rich Organics is a unique bioorganic soil enricher made from biodegradable organic substances, mainly of plant origin, through controlled and accelerated microbial composting process with additional plant nutrient value(s) of organic in nature. Rich Organics is a dark brownish, free flowing powder having earthy smell and free from viable weed seeds and pathogens.

Note: The aim of any good organic manure is to supply fully bio-converted organic matter in a form that can support microbial and plant life.

Physico-chemical and biological characteristics and composition of enriched bioorganics

I. Physico-chemical characteristics	
pH	7.0 to 8.2
C : N	10 - 15:1
Moisture	20 - 25%
Bulk density	0.64 g / cc
Organic carbon %	16 ± 2
Nitrogen %	1.5 to 1.8
Phosphorus %	
Total	2.5 to 3.2
Available	1.25
Potash	1.05
Calcium	2.00 ± 1.00
Magnesium	0.70
Sulphate	0.50
Iron	6000 ppm
Manganese	705 ppm
Zinc	740 ppm
Copper	375 ppm
Cobalt, molybdenum, boron	Traces
II. Biological composition (cfu/ml)	
Total bacteria	10^{10}
Actinomycetes	10^{4}
Fungi	10^{6}
Azotobacter	10^{6}
Root nodule bacteria	10^{8}
Phosphate solubilizers	10^{6}
Nitrobacter	10^{2}

In case enriched bio-organics is produced carefully, it is proved that it must contain higher nutrient value as compared to simple decomposed FYM or even chemical fertilizers targeted to one or a few specific nutrients.

Comparison of nutrient values of enriched bio-organics (from city compost) with other products

Nutrient	Enriched bio-organics	FYM	Chemical fertilizer
Direct Nitrogen	11 kg	5 kg	Through the fertilizer like urea as per application
Indirect Nitrogen (Fixation by Microbes)	20 kg	Some qty.	Nil
Phosphorous	12 kg	4 kg	Super phosphate as per application
Indirect conversion of fixed phosphorous into available form.	7 kg	--	--
Potassium	10 kg	5 kg	Through muriate of potash as per application
Trace elements	Almost all necessary micro-nutrients	Several trace elements	Hardly any, except Sulphur
Total	60 kg	14 kg	50 kg

(The nutrient values may vary depending on nutrient content of the raw material used)

- Organic fertilizer - rich organics contribution worked out at 1000 kg / acre dosage.
- Phosphorous conversion into available from is dependent on the amount of fixed phosphorous in soils.
- Organic fertilizer - rich organics and FYM will also contribute through growth promoting substances.
- Direct Manurial value of Organic fertilizer - rich organics is about 400% better than normal cow-dung.
- Organic fertilizer - rich organics is almost a complete balanced plant food.

8. Practical / Scientific utility of Enriched Bio-organics

1. Improves soil structure and better tilth.
2. Better soil aeration and water percolation, reducing soil erosion.
3. Increases water and nutrient holding capacity.
4. Provides reserve plant nutrients.
5. Helps in supply of growth promoting substances.
6. Contributes to better taste and flavor of produce.
7. Provides PSM, root nodule bacteria, nitrobacter, etc.
8. Prevents nutrient loss and improves fertilizer usage efficiency.
9. Minimizes the toxic effect of chemical fertilizers, while complementing the use of chemical fertilizers.
10. Serves as major food source for microbial population thus keeping the soil alive.
11. It is weed free and pathogen free.
12. Prevents micro-nutrient deficiencies in plants.
13. Better root and tiller growth, maintain plant health, vigour and green colour.
14. Increases crop yield by 20-40%, with the increase of grain yield 10-30%
15. It is unique natural organic manure.
16. The rate of application is very less $1/10^{th}$ as that recommended for ordinary organic matter / compost.

Soil Fertility Dynamics under Different Land Uses

A. K. Singh and Mandhata Singh

Department of Agricultural Chemistry and Soil Science
School of Agricultural Sciences and Rural Development, Nagaland University,
Medziphema-797106 (Nagaland)

Agriculture in north eastern hilly region is mainly of primitive type and this area is far behind in development. There are various land use systems prevailing in the region, which are very common in sloppy and valley lands. Some LUS are

(A) Shifting cultivation
(B) Bun method of cultivation
(C) Alder based system
(D) Terrace rice cultivation or *Panikheti*
(E) Zabo system
(F) Apatani plateau system
(G) Cultivation on slopes with contour bunds
(H) Bari system (Homestead gardening)
(I) Bamboo drip irrigation

Shifting cultivation

The north-eastern hilly region of India is facing heavy soil erosion and loss of soil fertility. Deforestation caused acute environmental degradation and ecological imbalance. Shifting cultivation or Slash & Burn agriculture, locally known as *Jhum* cultivation, is the main form of agriculture in this region. Agriculture under this system is practiced in steep slopes after removing the forest vegetation and thus is susceptible to excessive soil erosion. With changing requirements of high population pressure on land, *jhum* cultivation becomes very devastating in nature causing drastic decline in crop yield, loss of forest cover, soil fertility, biodiversity and environmental degradation.

Soil Physico-chemical behaviour under shifting cultivation

In general, shifting cultivation practices deteriorate the soil fertility due to huge soil loss of about 2-200 t ha^{-1} yr^{-1} (Singh and Singh, 1978). A minimum period of 10 to 15 years is very much essential to maintain the soil fertility for sustainable crop production (Singh *et al.,* 2003). In north-east India, the average annual loss of top soil, organic carbon, P_2O_5 and K_2O due to shifting cultivation were to the extent of 40900, 702.9, 0.15 and 7.5 kg ha^{-1}, respectively (ICAR, 1983). Carbon and nitrogen in the soil is the most limiting factors for plant growth after a forest is cut and then burned. Fallow period under shifting cultivation is not enough for consideration of the restoration capacity of soil. The proper ratio of cropping and fallow should be considered for sustainable *jhum* cultivation. It is found that the bulk density, more soil erosion and disintegration of soil particles as a result of very narrow ratio of cropping and fallow period. Continuous adoption of narrow ratio of cropping and fallow reduced the inherent capacity of soil resulting poor build up and deterioration in soil health. Therefore, balanced ratio of cropping and fallow periods are required for maintaining the soil more fertile and retain nutrients in adequate amount for sustainable production.

Bun method of cultivation

Cultivation of tuber crops and vegetables on series of beds formed on slopes is widely practiced in this region. The system locally known as 'BUN' method of cultivation, involves putting of dried vegetation mainly Khasi pine *(Pinus kesiya)* along with existing weeds like *Sataria gluaca, Imperata cylindrical, Lantana camara* in the form of raised beds along with slope, covering the same with soil collected from surrounding, burning of the covered vegetation and planting of tuber crops. When sufficient dried vegetation is not available, the beds are made of soil only. Though good crop yield is obtained, the system leads to huge soil loss.

Nutrient status after burning under Bun system

Burning of grasses during Bun cultivation caused an increase in pH and exchangeable bases whereas organic carbon and exchangeable A1 content reduced. Increase in pH was the result of an increase in bases (Ca, Mg and K) after burning of biomass and subsequent enrichment of these bases (Venkatesh *et al.,* 2001). Organic carbon content in soils drastically reduced as a result of burning by rapid loss of organic matter due to oxidation of un-humified materials. Nye and Greenland (1964) also reported rapid loss of organic matter in the first year of shifting cultivation cycle in Tripura soils. Available N, P, K and S in the soil were also increased due to burning during the first year. Available Fe, Zn and Cu decreased by 16.4, 35.4 and 15.2 %, respectively. This might be due to increase in soil pH after burning and possibly increased adsorption of late two cations by A1, Fe and Mn oxides. The increase in Mn content to more than fourfold on burning may be attributed by conversion of Mn_2O_3 to MnO. The bun system also helps in maintaining aerobic condition in root zone area. Probably this is the reason that the systems are very popular during rainy season and mostly vegetables, potato, ginger and turmeric are cultivated by this method of cultivation.

Alder based system

The alder-based *jhum* system is unique and highly productive form of shifting cultivation. Alder (*Alnus nepalensis*) is a non-leguminous large deciduous tree. It is a pioneer plant which grows in degraded lands or low fertile soil. The alder tree has root nodules, which improve soil fertility by fixing atmospheric nitrogen into the soil. Nitrogen fixation in *A nepalensis* takes place through a symbiotic relationship between plant with nitrogen-fixing actinomycetes of genus *Frankia.* The deep root system gives some stability to slopes that tend to slip and erode. Considerable quantities of nutrients are recycled through the litter of *Alnus* sp. Leaf and twig litter of *Alnus* may produce 3-6 t/ha litter annually, containing N 3.4 - 3.7 g, P 0.08 - 0.10 g, K 0.6 - 0.7 g and Ca 0.2 g per 100 g dry matter. The wood is used in various domestic needs such as fuelwood, charcoal burning and construction. Alder has been genuinely utilized by the people of the region as an integral component in different agro-forestry systems. For instance, *alder based farming system* (agri-silviculture and horti-silviculture) in Nagaland and *alder- large cardamom system* (horti-silviculture) in Sikkim is of utmost importance in uniqueness and value.

Terrace rice cultivation or *Panikheti*

It has been developed and practised by Angami and Chakhesang tribes of Nagaland for cultivation of rice. In this system, water from the source is conveyed through local channels from the top most to the lower terraces. Water is channelized in a *zig-zag* fashion so as to break the speed of movement and to maintain desired water level in all the terraces. Almost similar system of terrace rice cultivation (*Dhan kheti*) is prevalent in Sikkim too.

Zabo system

It is an indigenous system practised in the Phek district of Nagaland, which is a combination of forest, agriculture, livestock and fisheries with well developed soil and water conservation base. The system envisages rain water utilization, soil health maintenance through organic recycling and incorporation of livestock as the subsidiary source of income.

Apatani plateau system

It is a unique system of paddy cultivation prevalent in the Subansiri district of Arunachal Pradesh extending to a stretch of 26 sq. km. The Apatani tribe of the state practises wet rice cultivation following principles based on excellent knowledge of soil and water conservation. Besides other measures, paddy-cum-fish culture and growing millets on terrace risers for their stabilization and overall yield augmentation are some of the unique features of the system. Continuation of the system for centuries without marked reduction in yield itself shows its worth. Rather, this system has played a critical role in making the Apatani plateau, the rice bowl of Arunachal Pradesh.

Cultivation on slopes with contour bunds

Contour bunds as soil conservation measure are widely used on slopes for growing crops where farmers have tried to develop settled agriculture. Though the main idea of this particular measure is to convert the slopes into level benches in due course of time but the purpose is hardly served. Heavy soil losses are reported in this system due to lack of maintenance.

Bari system (Homestead gardening)

It is also common in different parts of Assam, Meghalaya and Tripura where households try to integrate diversified components into a system. Farmers try to accommodate different crops, multipurpose tree species, livestock including fisheries with water harvesting and residue recycling measures as per their preference, requirement and suitability. The homestead gardening in itself is a system of component integration near and around houses like agriculture, horticulture including fruits and vegetables, livestock in the form of cattle, goats, pigs, tree species for fuel, fodder and timber with water harvesting for domestic use and fishery-cum- duckery production.

Bamboo drip irrigation

It is an efficient system of water use for agricultural production. The system has been developed and used for centuries by the farmers of Jaintia hills in Meghalaya. In this system, water is conveyed from the source through split bamboos to the intended crop fields. Using their wisdom, farmers have also selected crops of low water requirement to be irrigated efficiently by this system.

INM and sustainability

The goals of the sustainable agriculture is to develop farming systems that are productive and profitable, conserve the natural resource base, protect the environment, and enhance health and safety in the long run. The need of time is sustainability of agriculture at enhancing rate of productivity. The enhanced rate of productivity requires that soil quality be at least sustained at its present level or if possible be enhanced. Land degradation is often related to decline in soil quality. It is caused by misuse of human beings resulted in decline in soil productivity through adverse changes in soil organic matter and nutrient status. The total area under degraded land in the country is about 114.01 M ha. The extent of area under water and wind erosion is 23.62 and 8.89 M ha, respectively.

The loss of soil nutrients can be greatly reduced through effective soil and water conservation measures and appropriate crop rotations. The enhancement of crop uptake through the right package of practices for growing crop also reduces the possibility of loss of nutrients by various mechanisms. The nutrient supplementation through chemical fertilizer must be balanced through i. Available nutrient status, ii. Nutrients need of the crop and removal from the soil, iii. Nutrient loss through erosion, volatilization, leaching, fixation, etc. iv. Accretion of nutrients from air, irrigation water, through crop residue, organic manures and v. amount of N added through biological N fixation. Some of the alternative measures are as follows

Integrated farming system

The alternative systems (Integrated farming systems) to shifting cultivation were developed in ICAR Research Complex in 1983. After almost 17 years, the soil pH decreased in most of the farming systems except in agriculture, agri-horti-silvi-pastoral systems, maximum decrease being in forestry and shifting cultivation. The organic carbon enrichment under shifting cultivation might be due to continuous growth of broom grass (pasture). Maximum accumulation of exchangeable Ca^{2+} was noted under agriculture system. Exchangable Mg^{2+} showed a decreasing trend in all the systems except in agriculture, agri-horti-silvi-pastoral and livestock based farming systems. Highest accumulation of exchangeable K in agri-horti-silvi-pastoral system may be attributed by the nature of species and variation in the quantity of fertilizer inputs. There was substantial build up of available N in soils under all the systems. The rise in available P in agriculture, livestock based system could be due to heavy and continuous dressing of cow dung litter for long period. The overall fertility build up followed the trend as agriculture > agri-horti-silvi-pastoral > livestock based farming system (Majumdar *et al.,* 2002). However, Das *et al.* (1997) recommended that livestock based or horticulture farming systems could be the alternative to shifting cultivation on sloppy land under mid to low altitude condition in Meghalaya. According to them, horticulture system ameliorated acid Alfisols by reducing the A1-toxicity followed by livestock based farming system, while organic matter build up was highest by the livestock based system (1.63%) followed by agro-forestry system (1.6%).

Modified agriculture system

The different agro-forestry systems (AFS) were *Arboretum* (mixed multipurpose tree species) + annual agricultural crops; Khasi mandarin *(Citrus reticulate* Blanco.) + annual agricultural crops; Assam lemon *(Citrus lemon* L.) + annual agricultural crops; Silvi-horti-pastoral [alder *(Alnus nepalensis*) + pineapple *(Ananus squennsa* L.) + fodder grasses] and multistoried AFS [alder + tea *(Camellia sinensis*) + black pepper + annual agricultural crops]. The tree species in *Arboretum* system included *Alnus nepalensis, Parkia roxburghii, Prunus cerasoides, Cryptomeria japonica, Symingtonia populnea* and *Pinus kesiya.* The fodder species in the Silvi-horti-pastoral system were stylo *(Stylosanthes guyanensis*), guinea *(Panicum maxicum*), setaria *(Setaria sphacelata*) and local grass *(Imperata cylindrical*). Annual agricultural crops grown in different systems were turmeric *(Curcuma longa* L.), colocasia [*Colocasia esculenta* (L.)], paddy *(Oryza sativa* L.), ginger *(Zingiber officinale*), maize *(Zea mays*), soybean (*Glycine max*), groundnut *(Arachis hypogaea*) *etc.* Natural forest is mainly dominated by *Pinus kesiya* along with *Schima wallichii, Lagerstroemia speciosa* and *Bambusa pallida*.

Soil physic-chemical behaviour under agro-forestry system

Different agro-forestry systems were developed here to find out the alternative systems of shifting cultivation. A general increase in bulk density values was observed with soil depth in all the agro-forestry systems, ranging from 0.94 to 1.19 Mgm^{-3}. The decrease in bulk density in natural forest, multistoried AFS and silvi-horti-pastoral systems can be related to the effect of relatively high organic carbon content (1.23 to 2.70%) due to heavy litter fall and their subsequent decomposition in the soil profile. The lower values of soil aggregates under Khasi mandarin and Assam lemon could be ascribed as more disintegration of soil structure due to different agricultural operations in comparison to natural forest, multistoried AFS and silvi-horti-pastoral systems, maintaining intensive vegetative cover throughout the year higher capacity to retain soil moisture. The low erosion ratio values in silvi-horti-pastoral and multistoried AFS (3.07 and 3.06, respectively) showed that these systems were most suitable for soil and water conservation in hilly ecosystem. This could be ascribed as the effect of heavy litter fall, which might have increased the cohesiveness in the soil system after decomposition. Available water content in different systems varied marginally throughout the soil profile. Multistoried AFS (25.30%) and silvi-horti-pastoral (24.23%) systems had the slightly lower values of available water in relation to natural forest (26.94%). Significant variation in available water capacity may be attributed to the differences in quantity, nature of colloidal materials present, pH and pore size distribution among the various systems.

Crop-wise plant nutrient prescription

Crop wise plant nutrient prescription (CPNP) is recommended dose of nutrients, which are applied in crop through fertilizers and organic sources. Earlier the recommended doses of nutrients are limited to application of N, P and K. Now CPNP also considered application of secondary and micronutrient. Essential elements are absorbed by the plants for their growth and development. These elements are supplied by soil in varying quantities either from its reserves or through application of organic or inorganic sources. The idea of CPNP is to meet nutrient requirement and to maintain soil fertility for sustainable production. The Objective of CPNP is i. to supply nutrients deficient in soil as per the crop requirement ii. to ensure timely availability of nutrients as per requirement of area and iii. to be based on the economic capacity of a farmer for investment.

Soil fertility dynamics under different land uses

Nutrient diagnostics in pineapple

The nutrient diagnostics for pineapple is developed and reported **First time from India by Sema *et al*. (2010)**. DRIS (Diagnosis and recommendation integrated system) norms were computed from the data on leaf mineral composition, soil available nutrients, and corresponding mean fruit yield. DRIS norms derived primarily from leaves sampled suggested optimum leaf macronutrient concentrations (%) as: 1.21-1.85 N, 0.49 – 0.60 P, 1.19 – 1.62 K, 0.27 – 0.35 Ca, and 0.43 – 0.56 Mg. While optimum level of micronutrients (ppm) was determined as: 78.4 -102.5 Fe, 41.5 – 58.3 Mn, 7.4 – 10.2 Cu and 12.2 – 15.8 Zn in relation to fruit yield of 1051-1350 g fruit^{-1}. Likewise, DRIS indices for fruit fertility developed from soil samples collected at 0-20 cm depth corresponding to similar level of fruit yield, the optimum limit of soil available nutrients (mg kg^{-1}) was observed as: 145.4-167.1 mg kg^{-1} N, 9.2-12.9 mg kg^{-1} P, 206.9 -234.2 mg kg^{-1} K, 3.83 – 5.65 meq 100^{-1} g Ca, 3.43 - 5.13 meq100^{-1} g Mg, 100.7 – 138.2 mg kg^{-1} Fe, 1.53 – 2.66 mg kg^{-1} Mn, 0.23 – 0.33 mg kg^{-1} Cu and 0.69 – 0.93 mgkg^{-1} Zn. DRIS indices developed on the basis of leaf and soil analysis revealed deficiency of N, P, Ca, Mg, Cu, Zn and Mn.

Coconut-based patchouli performance under inorganic versus organic fertilization

Coconut-based farming system is the tradition of tropical and subtropical regions. But, using patchouli [*Pogostemon cablin* (Blanco)] as an intercrop under coconut is of comparatively recent adoption and no information is absolutely available on possibility of improving of quality of patchouli through better nutrient supply. Field experiment was, therefore, carried out using different sources of organic manures and inorganic fertilizers within the interspaces of coconut plantation. Application of vermicompost 5 t/ha alone produced maximum biomass of leaves (11.24 t ha^{-1}) followed by pig manure 10 t ha^{-1} (10.82 t ha^{-1}), and FYM 20 t ha^{-1} (9.54 t ha^{-1}), all being significantly superior over control (7.54 t ha^{-1}). Among the various levels of nitrogen, maximum leaves biomass was observed with 100 kg N ha^{-1} (12.63 t ha^{-1}) followed by 80 kg N ha^{-1} (11.64 t ha^{-1}a), and 60 kg N ha^{-1} (8.96 t ha^{-1}) with highest yield (19.97 t ha^{-1}) registered through the combination of vermicompost 5 t ha^{-1}+100 kg N ha^{-1}, which in turn maintained higher bacterial population (48 x 10^5 versus 15 x 10^4 c.f.u/g soil) for better nutrient acquisition through improvements in supply level of soil available nutrients. These responses consequently improved the oil concentration in leaves (3.65% with vermicompost 5 t ha^{-1}+100 kg N ha^{-1} versus 2.40% with control) and alcohol (47.12% with vermicompost 5 t ha^{-1}+100 kg N ha^{-1} versus 44.52% in control) as quality indices which offers a database support to raise the quality of patchouli leaves besides improving coconut yield (40-55 nuts palm^{-1}) under coconut-patchouli farming system (Kikon *et al*., 2010)

INM for quality production of ginger on acid Alfisols

Integrated nutrient management (INM) is considered as the most viable method of raising crop production through sustained mitigation of constraints. Different treatments involving sole application of inorganic nitrogen (0, 25, 50, and 75 kg N ha^{-1}), biofertilizer inoculants (control, inoculation with *Azotobacter, Azospirillum* and *Phosphotika*), and their combination were evaluated for the performance of ginger on sandy loam acid Alfisol. Combined application of chemical N fertilizer N_2 (50 kg N ha^{-1}) and *Azospirillium* B_2 (20 g 10 kg^{-1} seed bit) produced much higher rhizome and cured yield (22.8 and 4.3 tons ha^{-1}) than with either N_2 (20.3 and 4.0 tons ha^{-1}) or B_2 (20.4 and 3.8 tons ha^{-1}). Nutrient uptake (kg ha^{-1}) followed the similar pattern, being higher with N_2B_2 (37.39 N - 4.33 P – 69.31 K) than N_2 (31.26 N - 3.80 P - 54.49 K) or B_2 (31.21 N – 3.67 P – 54.43 K) alone. Similarly, volatile oil which was 0.48% with B_2 and 0.49% with N_2 improved to 0.58% with N_2B_2. The oleoresin content of 4.38% with N_2B_2 was much higher than either N_2 (4.26%) or B_2 (4.27%)

alone. These observations suggested that the optimum quality production of ginger can be obtained with application of 20 kg N ha^{-1}+ *Azospirillium* (20 g 10 kg^{-1} seed bit) treatment (Talimongba *et al.,* 2008)

Nutrient prescription for sustainable production of crops in North East India

Crop	Nutrient prescription recommendation		References
	Organic source	**Inorganic source**	
Patchouli	Vermicompost 5 t ha^{-1}	100 kg N ha^{-1}	Kikon *et al.*, 2010
Ginger	*Azospirillium* 20 g 10 kg^{-1} seed bit	50 kg N ha^{-1}	Talimongba *et al.*, 2008
	Pig manure 5 t/ha	N:P:K::50:30:30 kg ha^{-1}	Yanthan *et al.*, 2010
Onion	Vermicompost 2.5 tha^{-1}	50 kg N ha^{-1}	Ethel *et al.*, 2010
Capsicum	Poultry manure 5 t ha^{-1}	N:P:K::60:30:30 kg ha^{-1}	Deepika *et al.*, 2010
Radish	FYM 10 t ha^{-1}+ *Azotobacter* and *Phosphotica* 500 g kg seed^{-1}	N:P:K::40:30:30 kg ha^{-1}	Sentiyangla *et al.*, 2010
Mungbean	Seed treatment with *Rhizobium*	N:P:K::20:40:30 kg ha^{-1} along with S and Co.	Singh and Singh, 2010
Soybean	Seed treatment with *Rhizobium*	N:P:K:S::20:90:40:30 kg ha^{-1}	Singh *et al.*, 2010

Fertilizing for Sustainable Onion Production Systems

Studies evaluated straight versus combined applications of manures, fertilisers, and microbial biofertilisers with reference to onion bulb yield and soil nutrient balances. Given the good supply of quality manures, observations favored the combined application of inorganic fertilisers and manures over sole application of either nutrient source. Application of 50 to 75% of the fertiliser recommendation plus any microbial inoculants treatment failed to achieve a viable alternative (Ethel *et al*., 2010).

General recommendation

The recommendation for cultivation of any crop should be made after careful study of factors like soil texture, use of organic matter, use of irrigation water, crop variety, crop management practices and cropping system etc. To maintain and improve soil fertility it is necessary to amend present recommended dose of nutrients - nitrogen by increasing 20-25%, phosphorus - either it could be maintained or increased by 10-25% and potassium - presently its application is limited in certain crops, therefore its application may be based on 25-50% of removal. Similar criteria could also be considered for application of sulphur and zinc and other micronutrients. To make it effective, supply chain of nutrients from production to consuming point should be ensured along with adequate support of credit, warehousing, transport, promotional activity etc.

Effect of simulated erosion on soil fertility

Simulated erosion caused a reduction in soil pH, organic carbon content, water holding capacity and available N, P and K levels in soil. The bulk density and clay content of the soil however, increased. Application of 15, 30 and 45 kg N/ha caused a significant increase in available N content in soil. Available phosphorus also increased significantly on application of 30 and 45 kg N/ha. The increase in available K on addition of N was not significant. Simulated erosion rates of 5, 10 and 15 cm caused a significant reduction in plant height, number of pods, plant dry matter and grain yield. Increase in simulated erosion rates resulted in progressive decline in grain yield. The grain yield decreased by 18.2, 47.7 and 68.2% on removal of 5, 10 and 15 cm surface soil, respectively. Addition of 30 and 45 kg N/ha could compensate only 2.2 and 4.3% towards yield loss due to simulated erosion, respectively. Erosion significantly decreased N, P and K uptake by plant. Addition of N fertilizers on contrary caused an increase in N, P and K uptake (Chauhan *et al*, 2007).

Conclusion

As sustainability of the land resource base has become great concern in recent years, regenerative agricultural technologies for the sustainable development of hilly areas in respect of soil, water and nutrient management must integrate socio-economic issues and bio-physical processes. So, the priorities for hilly agriculture for sustained productivity and soil health should combine the following points:

1. Integrated farming system approach for soil fertility management based on land use systems on watershed basis.
2. Restoration of highly degraded land suffering from soil erosion and chemical degradation by agro-forestry, horticulture and pasture plantation crops.
3. Soil conservation and agricultural production no longer should be regarded as separate activities. It must be an integral part of agriculture development and should start with improved farming systems.

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Vermicompost and Vermiwash: Biotic Indicators of Soil Health for Sustainable Agriculture

A. K. Upadhyay

Scientist
Department of Soil Science & Agricultural Chemistry
JN Krishi Vishwa Vidhyalaya, Jabalpur – 482 004 (M.P.)
Email: upadhyayamit8@gmail.com

In view of the high cost of inorganic fertilizers and wide gap between addition and removal of plant nutrients by the crop, the recycling of organic wastes has become the necessity in agricultural systems. Intensification of agriculture has adversely impacted on the biodiversity, whereas, the increased use of agrochemicals and declined use of organic manures under intensive cultivation has not only contaminated the ground and surface water but has also disturbed the harmony existing among the soil, plant and microbial population. There has been a growing public concern about adverse impacts of chemical fertilizers and pesticides on the environment and on the safety and quality of food is not properly used. Organic manures are bulky material added in large quantities mainly to improve soil fertility, to maintain humus status and to provide favorable conditions for soil microorganisms. This helps in replenishment of nutrients eliminated by crops or otherwise protect the plant nutrients to be lost through leaching and soil erosion. Thus, organic manures supply practically all the elements required by the crop. It provide all macro and micronutrients, improve the soil structure and provide food for soil microorganisms and soil nutrients are released slowly over time (Worthington, 2001) and can enhance the restoration and productivity of soil (Hornick and Parr, 1987; Parr and Hornick, 1992[a]).

Vermicompost

Vermicompost (also called worm compost, vermicast, worm castings, worm humus or worm manure) is the end-product of the breakdown of organic matter by some species of earthworm, feeding on biological degradable waste material and plant residues. Vermicompost is literally the best nutrient-rich, organic fertilizer and soil conditioner. The process of producing vermicompost is called vermicomposting. It is rich in microbial life which help in breaking down of organic form of substances already present in the soil into plant available forms and eco-friendly, non-toxic, consumes zero fossil energy and is a recycled biological product unlike other compost, worm castings also contain worm mucus which protect plant nutrients from washing away and holds moisture efficiently. These inputs maintain soil fertility by improving physical, chemical and biological soil properties as well as sustain soil organic carbon and humic substances and can be used to promote the development of beneficial organisms in the soil. It improve soil structure, water holding capacity, seed germination, drainage, base exchange capacity, checks soil erosion and also helps in the uptake of humic substances or its decomposition products influencing the overall growth and metabolism of plants, also improves the hormonal and biochemical activities of humus substances (Mathur and Gaur, 1977, Nardi *et al.*, 2004 and Prasad *et al.*, 1972. These inputs sustain soil organic carbon and humic substances. Humic matter affects membrane permeability, protein carriers of ion, activation of respiration and Kreb's cycle in plant. They also influence the photosynthesis, formation of ATP, amino acids, carbohydrates, protein and nucleic acid synthesis and selective effects on enzyme activities (Vaughan and Malcolm, 1985).

Vermicomposting is a promising method of transforming organic wastes into usable substrates. In this process, the digestive tracts of certain earthworm species (e.g. *Eisenia foetida*) are used to stabilize organic wastes. The final product is an odorless, clean, peat-like substance, which has good structure, moisture holding capacity, organic material containing relatively adequate quantities of N, P, K and several micronutrients essential for plant growth. The end product of vermicompost is rich in essential macro and micronutrients along with microorganisms in a very simple form. Adding vermicompost not only improves the soil structure and fertility but also leads to improvement in overall plant growth and thus increases their yield.

Nutrient rich in vermicompost

The production of vermicompost from any biodegradable organic waste i.e. agricultural waste, city garbage, industrial waste and sewage waste by using earthworms and its utilization in agriculture is one of the most economic ways in keeping the soils alive and healthy for sustainable production/productivity. It is rich in plant nutrients and provides vital macro-elements such as N, P_2O_5, K_2O, Ca, Mg and micro-elements such as Zn, Fe, Mn and Cu.

Apart from this, it contains vitamins, enzymes and plant growth promoting substances such as auxins, cytokinins, gibberellins, etc. It also harbours beneficial microflora. It contains organic carbon (9.15-17.99 %), nitrogen (1.5-2.5 %), phosphorus (0.9-1.7 %), potassium (1.5-2.4 %), calcium (0.5-1.0 %), magnesium (0.2-0.3 %), sulphur (0.4-0.5 %), copper (2.30-2.95 ppm), iron (2-9.3 ppm) and zinc (5.7-11.5 ppm) depending on the nature of substrates used for vermicomposting. Mahendra Pal (2002) reportd that the vermicompost contains 0.74 $\pm$ 0.14, 0.97 $\pm$ 0.11 and 0.45 $\pm$ 0.15 % nitrogen, phosphorus and potassium, respectively.

Benefits of vermicompost

- Enhances soil productivity
- Produces crops with a better taste, luster and lasting quality, without toxic residues: crops can therefore fetch a higher price in the market
- Promotes faster growth of plants, increases crop yield
- Reduces soil erosion
- Increases water-holding capacity of soil
- Induces resistance to pest and disease attack
- Easy to produce and low in cost
- Reduces salinization and acidification

Bedding

Bedding is any material that provides the worms with a relatively stable habitat. This habitat must have the following characteristics:

- Good bulking potential. If the material is too dense to begin with, or packs too tightly, then the flow of air is reduced or eliminated. Worms require oxygen to live, just as we do. Different materials affect the overall porosity of the bedding through a variety of factors, including the range of particle size and shape, the texture, and the strength and rigidity of its structure.
- High absorbency. Worms breathe through their skins and therefore must have a moist environment in which to live. If a worm's skin dries out, it dies. The bedding must be able to absorb and retain water fairly well if the worms are to thrive.
- Low protein and/or nitrogen content (high Carbon: Nitrogen ratio). Although the worms do consume their bedding as it breaks down, it is very important that this be a slow process. High protein/nitrogen levels can result in rapid degradation.

Techniques for preparation of vermicompost

(1) Pit method: A bed of size of 10 x 1 x 0.3 m is most suitable. The beds should be treated with chloropyriphos @ 2 ml/litre of water to prevent ant and termite problem. After 15 days, fill the beds in layers with organic residues as explained:

- **First layer:** Decomposable plant material (bottom of bed).
- **Second layer:** Cow dung/ farm manure/ biogas sludge.
- **Third layer:** Spread earthworms (1000-2000 in number).
- **Fourth layer:** Cow dung/ farm manure/ biogas sludge.
- **Fifth layer:** Dry crop residue/ green succulent leafy material, plus cow dung.
- **Sixth layer:** Thick layer of mulch with cereal straw (top of bed).

Each layer, except the third, should be 3-4 inch thick, so that the bed material is raised above the ground level. Sufficient dry and green wastes should be used. The mulch at the top prevents loss of moisture and acts as a barrier to predators like birds. The beds should be in shade.

(2) Heap method: In this method, composting is done on the ground without the pits. Organic material is piled up on the ground, as in the pit method, the only difference is that the heap gets a dome shape. The suitable size for a heap is 10 x 1 x 0.6 m.

(3) Wooden box or brick column: Rectangular wooden or brick structures (3x1x1 m) are erected above the ground level and the organic material is dumped inside serially as in earlier methods.

These beds have to be watered regularly to maintain a moisture level of 60-80 per cent till the harvest of vermicompost.

Vermicomposting requirements

Compost worms need five basic things:

1. An hospitable living environment, usually called "bedding".
2. A food source.
3. Adequate moisture (greater than 50% water content by weight).
4. Adequate aeration.
5. Protection from temperature extremes.

Multiplication of earthworms

Earthworms are bisexual, but cross-fertilisation is the mode of reproduction. Adult worms after 15-21 days of copulation lay cocoons which look like coriander seeds. The eggs present inside the cocoon hatch into neonates in about 15-21 days. Neonates take 35-60 days to attain adulthood, which is characterised by a swollen band near the enterior part of the body. *Eudrilus eugeniae*, *Eisenia foetida* and other species used for vermicomposting, completes its lifecycle in about 65-80 days. It lays 400 plus cocoons in about 60 days.

Vermicomposting can be tested from a small collection of pellets on the top of the beds around 45-60 days after start. This is indicative of good multiplication of worms in the beds. In about 60 days, the material is degraded completely and vermicompost is ready for harvesting. The rate of degradation depends on the loading of worms. More the worms, faster the degradation. The heap method, however, has proved to be more effective than the pit system.

Rainy and winter season favors faster multiplication of worms than summer. With manipulation of soil temperature during summer by providing shade and regular watering, the rate can be enhanced.

Harvesting of vermicompost

After 60-70 days, the beds are ready for harvest. Seven days prior to harvesting, watering of the beds has to be stopped so that the earthworms in the top layers move down for want of moisture.

The beds should be disturbed and the material collected in pyramidal heaps for about 24 hours. The semidried compost from the top of the bed can be collected and sieved to remove any inert material. The concentrated vermiculture (earthworms) that remains at the bottom can be used again for vermicomposting. The compost can be dried in shade (12 hours), bagged and stored. About 3 tonn of vermicompost can be harvested in two months from 10 beds of 10 x 1 x 0.6 m each.

Natural enemies

The important natural enemies of vermiculture are ants, termites, flatworm, centipedes, rats, pigs, birds, etc. Preventive measures include treating of the site with insecticide chloropyriphos 20 E C @ 2 ml/ litre or mixing of neem cakes @ 30 g/ kg food while filling the beds.

Precautions

- Use only plant materials (Such as vegetable peelings, leaves or grass).
- Remove glass, metal and plastic materials from the organic materials.
- Protect against birds by covering the rings with wire or plastic mesh.
- Sprinkle water regularly and maintain moisture level.
- Prepare compost in the shade to protect it from sun and rain**.**

Uses of vermicompost

- Vermicompost is ready in 2 to 2.5 months. When it's ready, it's black, light weight and has no bad smell.
- It can be used for all crops (agricultural, horticultural, ornamental and vegetable) at any stage of the crop development.

Application method and time of vermicompost

- Agricultural crops: apply vermicompost by broadcasting when the seedlings are 12-15 cm in height.
- Flowers, vegetables and fruit trees: apply vermicompost around the base of the plant, at any stage of development, and cover with soil.

Quantity of vermicompost

- General Agricultural use: 3-4 tonnes ha^{-1}
- Fruit tree: 5-10 kg per tree
- Vegetables: 3-4 tonnes ha^{-1}
- Flowers : 500-750 kg ha^{-1}

Vermiwash

Vermiwash is liquid plant growth regulator, which contains high amount of enzymes, vitamins and hormones like auxins, gibberellins etc. along with macro and micronutrients used as foliar spray.

Methods of preparation

- Take one big bucket and one mug.
- Set up one stop cork on the lower most part of the bucket.
- Put a layer of broken bricks, pieces of stones having thickness of 10-15 cm in the bucket.
- Over this layer put another layer of sand having thickness of 10-15 cm.
- Then put a layer of partially decomposed cow dung having 30-45 cm thickness over it.
- Then put another layer of soil having 2-3 cm thicknesses.
- Now open the stop cork of the bucket and when the materials taken in the bucket.

- Then put 100-200 nos. of earthworms in the bucket.
- After that, a layer of paddy straw having 6 cm thickness is given.
- Now open the stop cork of the bucket and spray water regularly for a period of 7-8 days.
- After 10 days the liquid vermiwash will be produced in the bucket.
- Hang one pot with a bottom hole over the bucket in such a way so that water falls drop by drop.
- Every day 4-5 litres of water is to be poured in the hanging pot.
- Keep another pot under stop cork to collect the vermin wash. Every day 3-4 litres vermin wash can be collected.

Application of vermiwash

- Mix 1 litres of vermiwash with 7-10 litres of water and spray the solution in the leaf (upper and lower side) in the evening.
- Mix 1 litre of vermiwash with 1 litre of cow urine and then add 10 litres of water to the vermin urine solution and mixed thoroughly and keep it over night before spraying 50-60 litre of such solution and to be sprayed in hectare of land to control various crop diseases.

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Physiological Basis of Water Logging

Sathrupa Rao

Professor & Head
Department of Plant Physiology
JN Krishi Vishwa Vidhyalaya, Jabalpur – 482004 (M.P.)

Introduction

Higher plants require access to free water, excess water in the root environment may be injurious or even lethal because it blocks the transfer of oxygen and other gases between the soil and the atmosphere. Crop plants require a free exchange of atmospheric gases for photosynthesis and respiration. Plants can be easily suffocated if gas exchange is impeded. The most common impediment to gas diffusion is water that saturates the root environment in poorly drained soils or accumulates above soil capacity. During submergence, plants are exposed to a reduction in oxygen supply because of the slow diffusion rate of oxygen. Turbid flood-water can become anaerobic, especially during the night (Setter et al. 1987) and plants react to an absence of oxygen by switching from an oxidative to a solely substrate-level phosphorylation of ADP to ATP; the latter reactions predominantly involve glycolysis and fermentation Soil water logging has long been identified as a major abiotic stress and the constraints it imposes on roots have marked effects on plant growth and development and the survival of numerous plant species not only in natural ecosystems but also in agricultural and horticultural systems (Dat *et al*. 2006).

Definition of Waterlogging

- Waterlogging is a soil condition where excess water in the root zone inhibits gas exchange with the atmosphere. This may be caused due to excess irrigation, flooding, or rain
- Flooding is a condition in which free standing water is present above the soil surface. Waterlogging usually coincides with flooding, while it is observed that many water logged areas are not flooded.

What is Water logging Tolerance

- When a plant species or tissues which grows or survives in waterlogged soils is said to be waterlogging tolerant

Primary Symptoms of Waterlogging

- Lower leaves turn bright yellow and later die
- Upper leaves turn pale yellow due to nitrogen shortage

Hypoxia

The reduction of oxygen below optimal levels is termed as hypoxia and is a most common stress and occurs during short- term flooding when the roots are submerged under water but the shoot remains in the atmosphere. Hypoxia also occurs in roots near the surface of longer-term flood water.

Anoxia

The complete lack of oxygen, termed anoxia, occurs in soils that experience long-term flooding, in plants completely submerged by water, in deep roots. Long-term flooding shifts the microbial flora in the soil in favor of anaerobic micro-organisms. The soil tends to accumulate more reduced, and phytotoxic forms of mineral ions such as nitrite (from nitrate) and ferrous (from ferric) ions (Ponnamperuma 1972) and few plants are adapted to growth in these soil.

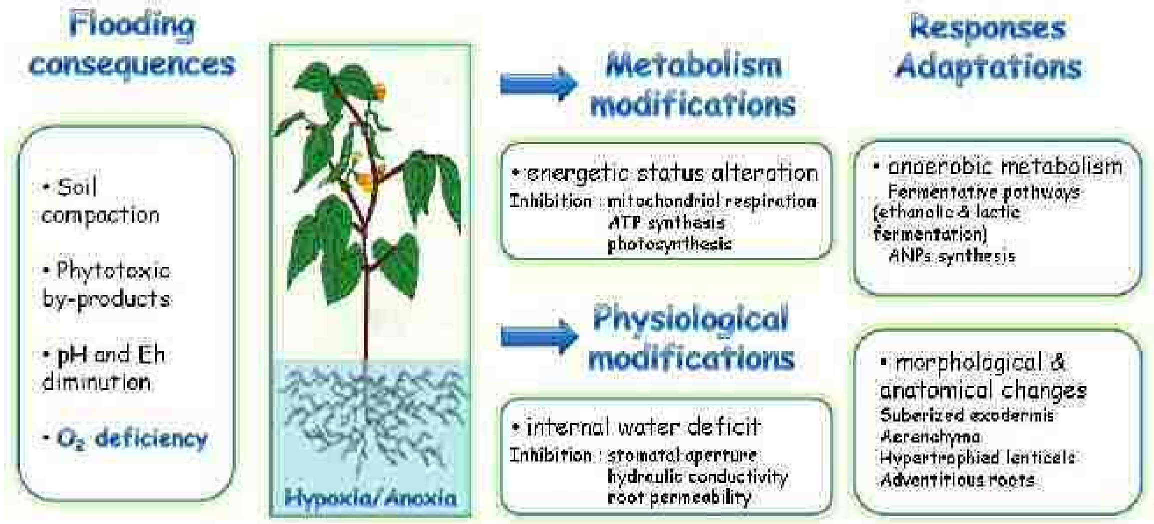
Plant adaptations to hypoxia/anoxia

- Switch in biochemical and metabolic processes (Dat *et al*. 2004).
- A selective synthesis of about 20 anaerobic stress proteins (ANPs) which enables oxygen-independent energy generating metabolic processes under conditions unfavorable for aerobic energy production (Subbaiah and Sachs 2003).
- Morphological and anatomical changes comprising formation of hypertrophied lenticels,
- Initiation of adventitious roots
- The development of aerenchyma (Vartapetian and Jackson 1997; Jackson and Colmer 2005; Folzer *et al*. 2006)..

Changes in soil properties due to waterlogging

- Water saturates the soil pores,
- Gases are displaced,
- A reduction in gas diffusion occurs
- Phytotoxic compounds accumulate as anaerobic conditions prevail.

Fig. 1. Main physico-chemical events taking place in the rhizosphere during soil waterlogging



Waterlogging effect on soil pH

- It is negatively correlated with soil redox potential (Singh 2001; Zarate -Valde et al. 2006).
- Soil pH generally tends to increase towards neutrality upon water logging (Lu et al. 2004).
- The increase in pH may be explained by the dissolution of carbonate and bicarbonate early during water logging (Lu et al. 2004).
- Soil pH affects the turnover of soil organic matter and processes such as mineralization, nitrification and urea hydrolysis (Probert and Keating 2000).

These changes affect the capacity of plant to survive such conditions. In response, a) the stomatal resistance increases, photosynthesis b) root hydraulic conductivity decline c) the translocation of photo assimilates is reduced.

Changes in the root environment during waterlogging

As water saturates the soil, and the air spaces are filled, leading to the modification of several soil physico-chemical characteristics (Kirk et al. 2003; Dat et al. 2004). The first event that takes place is the increased presence of H_2O: soil water saturation later characterizes flooding.

Soil redox potential (Eh) is often considered the most appropriate indicator of the chemical changes taking place during soil flooding (Pezeshki and DeLaune 1998). Soil redox potential declines during water logging (Pezeshki and DeLaune 1998; Pezeshki 2001; Bovin et al. 2002; Lu et al. 2004). It is not only an indicator of O_2 level under anaerobic conditions (Pezeshki and DeLaune 1998) but the reducing conditions lead to a high competitive demand for O_2, thus affects the availability and concentration of different plant nutrients (Pezeshki 2001). Changes in soil redox potential are influenced by the presence of organic matter, Fe and Mn (Lu et al. 2004). Soil reduction induces the release of cations and phosphorous through absorption of ferrous ion and dissolution of oxides (Boivin et al. 2002). Soil reducing conditions favor the production, of ethanol, lactic acid, acetaldehyde and acetic acid and formic acid.

Reduction in stomatal conductance

There is a reduction in stomatal conductance (Sena Gomes and Kozlowski 1980; Pezeshki and Chambers 1985; Folzer et al. 2006). Water logging may not only increase stomatal resistance but also limit water uptake thus leading to internal water deficit (Jackson and Hall 187; Ismail and Noor 1996; Pezeshki et al. 1996; Pezeshki 2001; Nicolas et al 2005; Folzer et al 2006; Perent et al. 2008a).

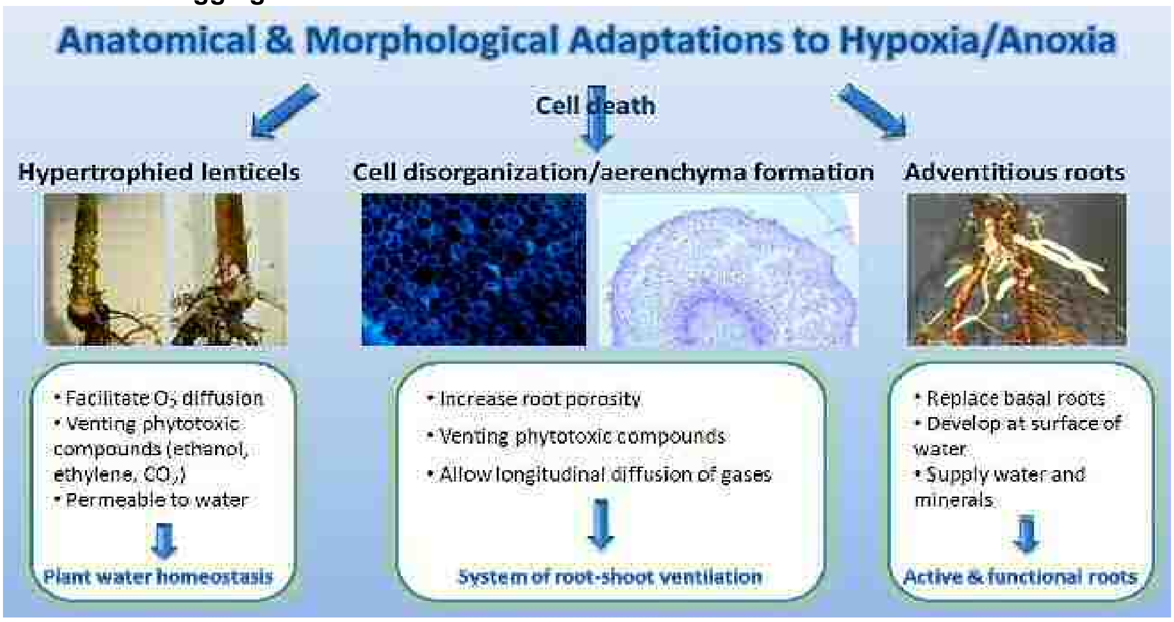
Reduction in hydraulic conductivity

Low O_2 levels may reduce hydraulic conductivity consequent to a decrease in root permeability (Clarkson et al 2000; Else et al, 2001). The decrease in Lp may be linked to aquaporin by cytosolic pH (Tournaire-Roux et al. 2003).

Regulation of pH

The regulation of plasma membrane intrinsic proteins (PIPs) by pH is especially relevant under anoxic conditions (Postaire et al. 2007), as a conserved histidine residue at position 197 in the intracellular Loop D has been identified to be the major pH-sensing site under

Fig. 2. Main physico-chemical events taking place in the rhizosphere during soil waterlogging



physiological conditions (Tournaire-Roux et al. 2003; Kaldenhoff and Fischer 2006; Secchi et al. 2007).Thus, it seems that the reduced Lp throughout in plant under soil water logging conditions is most probably linked to inhibition of water transport by aquaporins

Reduction in radial water movement

The reduction in radial water movement may in part be explained by the presence of cross-sectional oxygen gradients in the root tissue. In flooded soils, an O_2 gradient exists between the stale, which may be under anoxic conditions and the cortical cells which may only be under hypoxic conditions (Thomson and Greenway 1991; Colmer 2003). Thus this difference in tissue microenvironment may also contribute to cross-sectional difference in cellular energy levels and subsequent declines in root Lp.

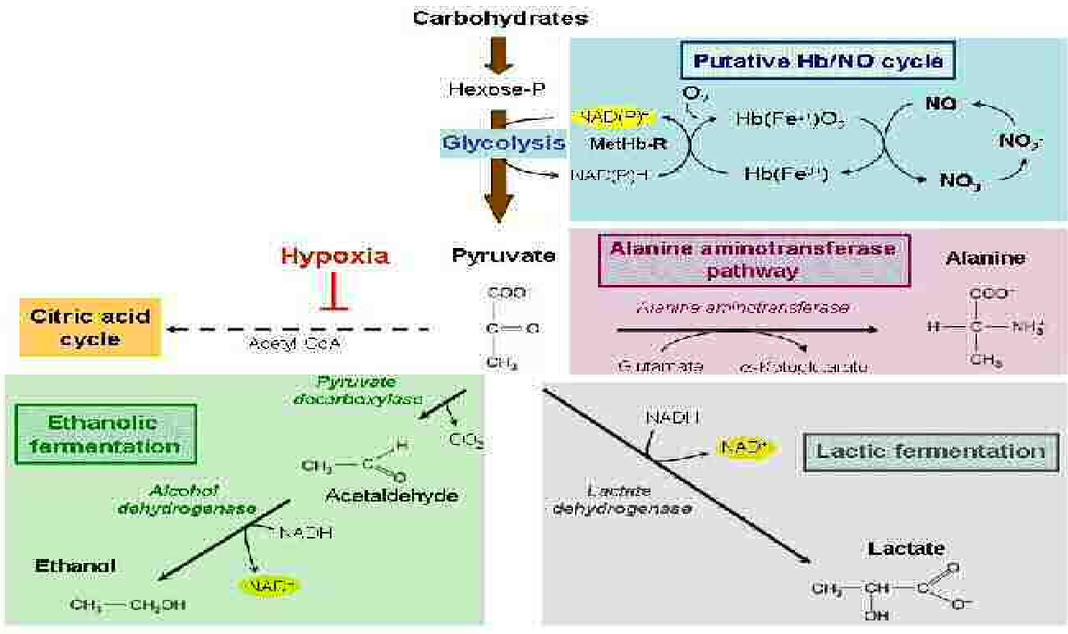
Metabolic responses and adaptations to hypoxia and anoxia

The immediate consequence of soil waterlogging is a period of hypoxia and this cellular oxygen deficiency is termed “hypoxia” when oxygen levels limit mitochondrial respiration is followed by a strong decline in O_2 leading to anoxic conditions (Blom and Voesenek 1996) and respiration is completely inhibited, it also declines, the electron flow through the respiratory pathway, thus diminishing ATP production, while chemical oxidizing power (i.e. nicotinamide adenine dinucleotide NAD^+) must be generated via alternative pathways that do not use O_2 as terminal electron acceptor (Roberts et al. 1984; Drew et al. 1994; Drew 1997; Summers et al. 2000). Adenosine diphosphate (ADP) oxidative phosphorylation becomes limiting, plants shift their metabolism from aerobic respiration to anaerobic fermentation (Peng et al. 2001; Fukao and Bailey-Serres 2004). The fermentative pathway serves as a metabolic safe route and includes two steps:

- Carboxylation of pyruvate to acetaldehyde (catalyzed by pyruvate decarboylase, PDC)
- Reduction of acetaldehyde to ethanol with concomitant oxidation of NADPH to $NASD(P)^+$which is catalyzed by alcohol dehydrogenase (ADH) (Vartapetian and Jackson 1997; Kingston- Smith and Theodorou 2000; Nakazono et al 2000).

The fermentative metabolic route allows the synthesis of only 2 moles of ATP against 36 per mole of glucose produced during aerobic respiration. To compensate the deficit in energy, glycolysis is accelerated, leading to the depletion of carbohydrate reserves (“Pasteur effect”). The enzymes that participate in the fermentation pathway belong to a group of approximately 20 ANPs, selectively induced during hypoxic stress, whereas overall protein synthesis is reduced (Sachs et al. 1980; Chang et al. 2000). ANPs which are induced mainly under hypoxia include enzymes of glycolysis, ethanolic fermentation, processes related to carbohydrate metabolism others involved in aerenchyma formation (xyloglucans endotransglycosylase) and cytoplasmic pH control (Vartapetian 2006).

Fig. 3. Schematic diagram of the main metabolic pathways proposed during plant flooding stress



Rapid reduction in photosynthesis

- O_2 deficiency generally induces a rapid reduction in the rate of photosynthesis in flooding tolerant plants
- Reduced stomatal aperture (Huang et al. 1997; Gravatt and Kirby 1998; Pezeshki and DeLaune 1998; Malik et al 2001).
- A decrease in leaf chlorophyll content,
- Early leaf senescence
- Reduction in leaf area may also contribute to inhibition of photosynthesis at a later stage (Sena Gomes and Kozlowski 1980; Cao and Conner 1999).

When hypoxia or anoxia occur the pH of the cytoplasm shows an early decrease that is attributed to an initial production of lactic acid by fermentation. Because O_2 is lacking under hypoxic conditions, it has to be substituted by alternative electron acceptors. In fact nitrate has long been considered as a terminal electron acceptor for plant mitochondria under hypoxic or anoxic conditions (Vartapetian and Polyakova 1998; Vartapetian et al. 2003).

Physiological changes due to waterlogging

Biochemical changes occurring when plants are subjected to flooding stress is the production of ROS (Reactive Oxygen Species) viz superoxide, singlet O_2, hydrogen peroxide and hydroxyl radical. These ROS are highly reactive and can after normal cellular metabolism through oxidative pathway damage lipids proteins and nucleic acid (Mc Karsre and Leshem 1994). Malanoaldehyde content a product of lipid peroxidation is considered as an indicator of oxidative damage. One of the most important changes under stress is the decrease of total chlorophyll content (Lewitt 1980). Lipid peroxidation is the natural metabolic process under normal aerobic conditions due to ROS action (Blokhina et al 2003). Lower the levels of malanoaldehyde indicate better oxidative stress tolerance.

There is a decrease in leaf chlorophyll content, SOD and CAT activities, root oxidizability accumulation of leaf malanoaldehde, greater ethylene production and reduction in leaf photosynthetic rate. Plant senescence is associated with the degradation of chlorophyll, the accumulation of MDA and ethylene production. Enhancement of leaf ethylene production is the pronounced physiological charactereistic during early phase of WL at various growth stages. WL also breaks down the balance of endogenous hormones. GA α cytokinin content decrease while abscissic acid ethylene content.

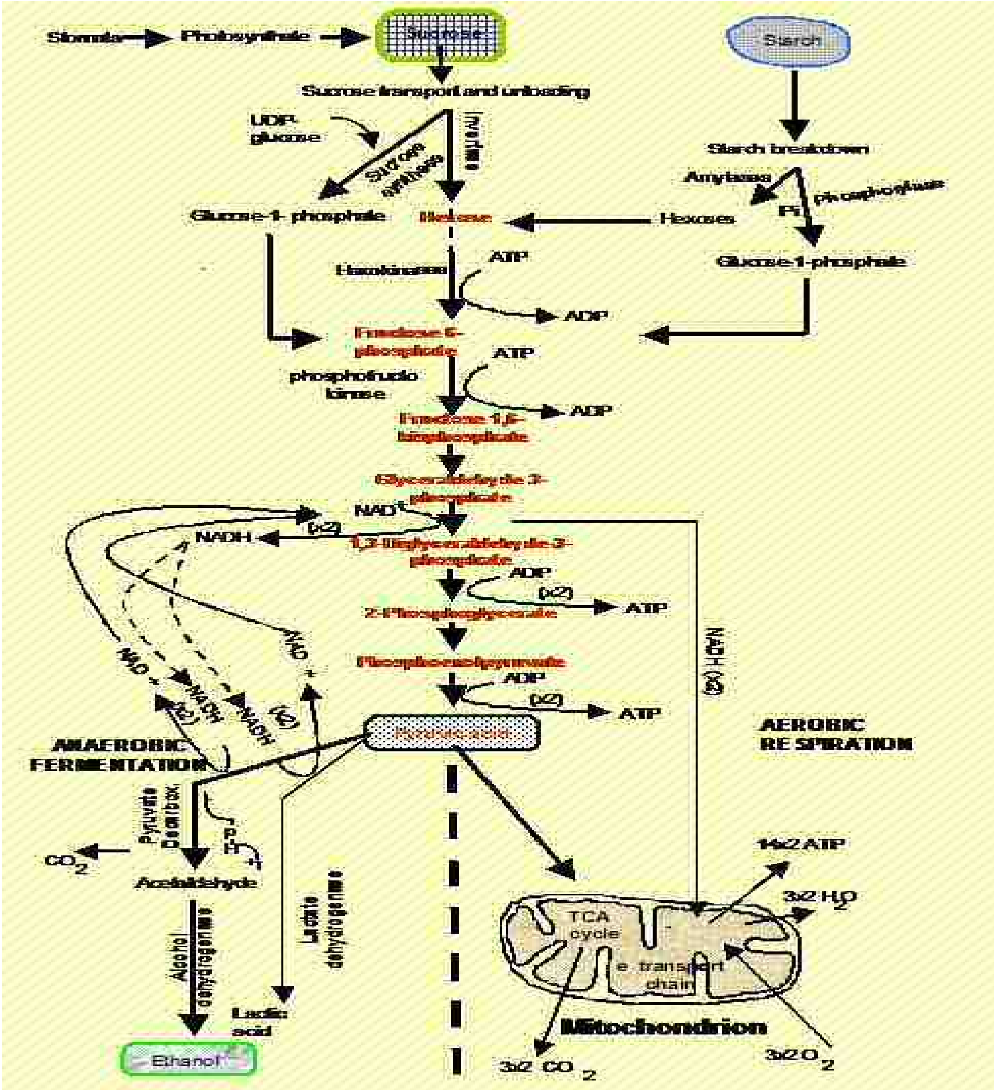
How Absence of oxygen kills the roots

An absence of oxygen is usually fatal to growing root tips, small amount of external oxygen help in keeping them alive. The main reason of growth arrest is principally due to;

1. Demand of ATP exceeds the supply
2. Self poisoning by products of anaerobic metabolism.

ATP supply and Demand:

Fig. 4 Depiction of various pathways from starch and sucrose that generate ATP and dispose of reducing power by oxidizing NADH aerobically or anaerobically



Anaerobic roots generate ATP mainly by glycolysis this pathway also feeds pyruvic acid into ethanolic feementation. Glycolysis being a cytoplasmic pathway forms pyruvic acid from glucose forming 2 ATP from each molecule of glucose and this forms about only 6% of ATP generated by mitochondria during aerobic respiration. Hence here the glycolysis is highly inefficient. It also requires pyridine nucleotide coenzyme in its oxidized form (NAD+) and this is generated anaerobically from chemically reduced NADH during ethanolic for lactic acid fermentation. Hence metabolic processes consuming ATP are suppressed due to insufficient production of ATP in anaerobic cells for survival after a few hours. There is an inability to restrict ATP utilization to essential life processes is a reason for death of flooded root tips.

Early cell death can only be avoided if the small amount of energy is redirected to permit a few critical anaerobic proteins which support glycolysis and fermentation and prevent excessive acidification of cytoplasm and vacuole and maintain membrane integrity. The decrease in membrane integrity is one of the critical consequences of ATP imbalance for viability of root cells. It is a consequence of lipid hydrolysis mediated by libolytic acyl hydrolase. When the integrity the cell is irrecoverably damaged.

The capability of ATP generation capacity of glycolysis fermentation depends on glucose α – precursors shortage of sugar due to anaerobic arrest of starch breakdown and sugar uploading in roots shortens the survival duration.

Self poisoning

Anaerobic roots may also die due to self poisoning by products of anaerobic metabolism the notable toxin being excess proteins acidifying cytoplasm and vacuole. The other possible toxin is acetaldehyde during alcoholic fermentation the enzyme alcohol dehydrogenase converts acetaldehyde into ethanol which exceeds that of the enzyme promoting acetaldehycle production from pyruvic acid. The third possible toxin is nitric oxide which is a gaseous form of free radical formed by reaction of nitrate reductase which has an ability to kill cells

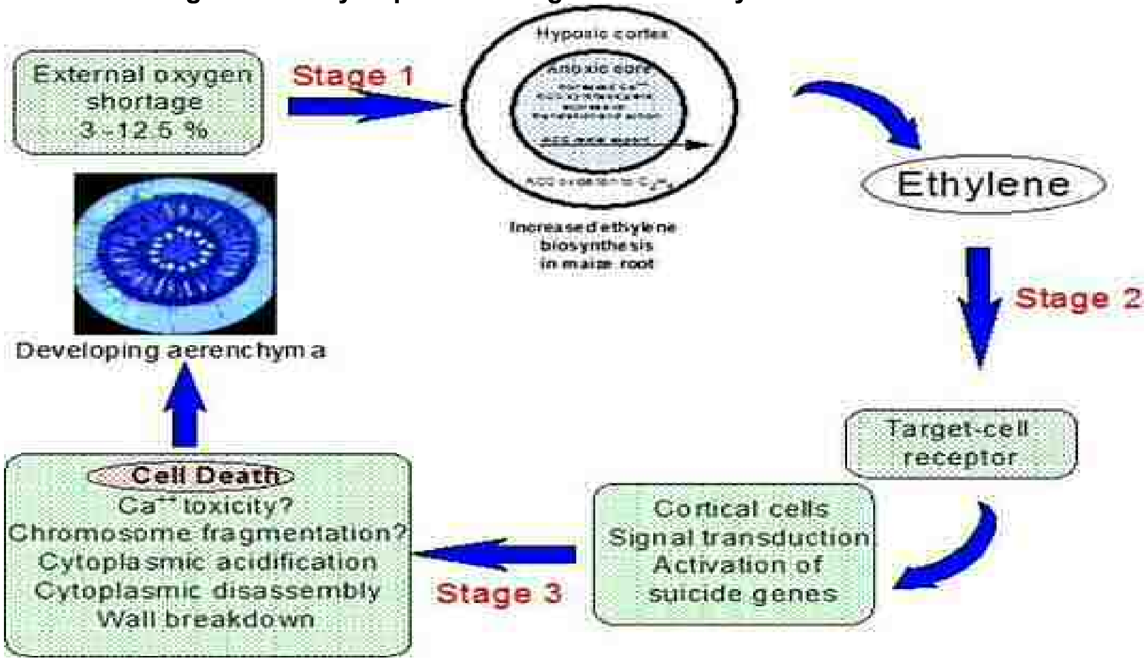
When the stress is prolonged it may lead to

- The inhibition of photosynthetic activity of the mesophyll (Huang et al 1994l Liao and Lin 1994; Pezeshki et al. 1996), as well as reductions in the metabolic activity and the translocation of photo assimilates (Pezeshki 1994; Drew 1997; Pezeshki 2001; Sechs and Vartapetian 2007).
- The outcome of a decline in photosynthesis on plant growth and development may lead to concurrent physiological disfunctions
- Inhibition of water transport and changes in hormone balance (Vuylstaker et al. 1998; Kato-Noguchi 2000a; Else et al. 2001; Gunawardena et al. 2001).
- In order to maintain its metabolic activity, the plant has to draw on its carbohydrate reserves. The level of carbohydrate reserves may be a crucial factor in the tolerance to long term flooding (Detter et al. 1997; Ram et al. 2002).
- Plant may have high sugar reserves, but these must be available and converted readily through and efficient glycolytic pathway.
- The availability of photo assimilates to the cells under anaerobiosis is the limiting step for survival under flooding conditions (Pezeshki 2001). Water logged soils tend to reduce the t4anslocastion of photosynthetic products from “source” leaves to “sink” roots (Barta and Sulc 2002; Yordanova et al 2004). As a result, the maintenance of photosynthetic activity and accumulation of soluble sugars to roots is clearly an important adaptation to flooding (Chen et al. 2005).

Overall, the main effects of flooding are

- Less availability of O_2 in the submerged plant part are gases which diffuse 10000 times faster in air than in water. The effect on cellular metabolism is concentration dependent and the gradual decline in O_2 availability in the root environment has varying effect on plant metabolism
- Normoxia allows aerobic respiration and metabolism to proceed normally and most of the ATP is generated via oxidative phosphorylation,
- Hypoxia occurs when the reduction in available O_2 starts to be a limiting factor for ATP production through oxidative phosphorylation and,
- Anoxia when ATP is only produced through fermentative glycolysis as no more O_2 is available.
- Due to anaerobic conditions in the waterlogged soil, there is an increasing

Fig.5 Summary of possible stages in aerenchyma formation in roots



amount of by-products of fermentative metabolism accumulating in the root environment and the levels of CO_2, methane and volatile fatty acids increase (Pezeshki 2001).

- There is a decline in available energy thus affecting cellular processes leading to water and nutrient imbalances or deficiency (Dat et al. 2006).
- This environmental change makes the plant more prone to other stresses, particularly pathogen infection (Munkyold and Yang 1995; Yanar et al. 1997; Balerdi et al 2003).

Morphological adaptations to soil water logging

Important morphological adaptation to flooding is the development of adventitious roots which functionally replace basal roots (Bacanamwo and Purcell 1999; Gibberd et al 2001; Malik et al 2001). The formation of these specialized roots takes place when the original root system becomes incapable of supplying with the required water and minerals to the shoot (Mergemann and Sauter 2000). Decay of the main root system may be considered as a sacrifice to allow a more efficient use of energy for the development of a more adapted root system (Dat et al 2006) Adventitious roots are commonly formed near the base of the stem or in the region where lenticels are abundant, and their growth is lateral, parallel to the water/soil surface. Their presence at the interface between the water saturated soil and atmosphere reflects their importance in replacing the normal root system both underwater and following retreat of the water table. The ability to produce adventitious roots is commonly associated with enhanced tolerance to flooding and their development has commonly been associated with ethylene production (Voesenek et al. 1993; Mergemann and Sauter 2000; Steffens et al. 2006)

Anatomical acclimation through aerenchyma formation

The most important responses to water logging is the development of gas spaces (aerenchyma) in the root cortex The development of aerenchyama may be a response to flooding in both flood tolerant and flood intolerant species (Vartapetian and Jackson 1997; Schussler and Longstreth 2000; Chen et al 2002; Evans 2004). Aerenchyma formation is an adaptive response in flood tolerant species only, (Kludze et al 1994; Pezeshki 1996). The increase in porosity may enhance venting toward the shoot and the atmosphere of phytotoxic compounds, produced in the roots (i.e. ethanol, methane) (Visser et al. 1997; Visser and Pierik 2007) and/or enhance the longitudinal diffusion of gases in the roots, thus increasing their aeration (Laan et al. 1991; Evans 2004). Proportion of aerenchyma is considered as a key discriminating factor between wetland and non-wetland plants (Vasellati et al. 2001).

The presence of large interconnected intercellular gas filled species which usually extends from shoots to the root tip is a feature shared by most of the species. The spaces are created by cell separations resulting from differential rates of division or expansion by neighbouring cells or from the death of certain cells. Sufficient oxygen can diffuse through such tissues from the aerial shoot o satisfy the respiratory needs of root axes The effectiveness of oxygen transport is increased in rice where oxygen losses to the soil are inhibited by a barrier to outer radial diffusion any oxygen leaking radially out of roots into anaerobic soil oxidizes the rhizosphere thus decreases injury from chemically reduced toxin

Most species are intolerant to soil water logging as these do not posses extensive aerenchyma but in some as maize aerenchyma in roots can be stimulated during early stages of water logging this morphological acclimation is the result of spatially targeted process of cell death localized in the root cortex and stimulated by an increase in ethylene concentration brought by entrapment and faster biosynthesis which is favored by low but not extinguished oxygen supply the additional ethylene is trapped within the flowed roots acts on targeted cells in the cortex resulting in dissemblance creating longitudinal inter connected gas spaces. This lysigenous aerenchyma is the outcome of an ordered structural degradative change which commences within six hours and the cell is destroyed in 2-3 days. The major changes are.

- Acidification of cytoplasm
- Posible loss of control of cyto plasmic ca++
- Loss of microtubute orientation
- Plasma membrance invagination
- Formation of membrane bound vesicle.

The development of aerenchyma or lacunae tissues is not unique to roots. They are also observed in the leaf sheath following submergence, forming and interconnecting system of shoot-root ventilation (Jackson and Armstrong 1999; Fabbri et al. 2005). Aerenchyma increases tissue porosity which itself can be initiated as a result of osmotic dependant changes in cell shape (Justin and Armstrong 1987; Folzer et al. 2006). The changes in cell shape and assemblage in the root cortex are most likely linked to enhanced cell wall loosening enzyme activity and with suberin deposition in the exodermises (Colmer 2003; De Simone et al 2003; Armstrong and Aremstorng 2005; Enstone and Peterson 2005).

The development of a suberized exodermis correlates with the development of aerenhyma in maize (Enstone and Peterson 2005) and is associated with a decline in radial loss of root O_2 (Visser et al, 2000; Armstrong and Armstrong 2005). Such a barrier on the periphery of the cortex may not only reduce the loss of O_2 to the rhizosphere but could also protect the plant from phytotoxins produced by microorganisms in the environment surrounding the roots (Soukup et al 2002; Armstrong and Armstrong 2005; Soukup et al 2007).

In the development of aerenchyma at least two types of developmental processes are involved. The first is the constitutive development of arenchyma as it occurs whether or not the plant is under waterlogged conditions. It forms by cells separating during tissue development. The cell death type taking place through cell separating is termed schizogeny (Formed by cell separation) and is developmentally regulated and independent of any external stimuli. It is the outcome of highly regulated tissue specific patterns of cell separation. The other type of cell death process is termed lysogeny (formed by partial breakdown of the cortex), resembles programmed cell death, typically observed during the hypersensitive response of plant pathogen interactions (Mittler et al 1997; Parent et al. 2008b Pellinen et al. 1999; Dat et al. 2001; Dat et al 2003; Van Breusegem and Dat 2006). The active cell death process which takes place during aerenchyma development is genetically controlled

Specific physiological responses of wheat to waterlogging

- Chlorosis and early senescence of lower leaves
- Decreased plant height, reduced root and shoot growth
- Delayed ear emergence, lower number of spike-bearing tillers reduced grains per spikelet and kernel weight and decrease in yield by 35-45% .
- Reduced diameter of metaxylem and protoxylem vessels of the nodal roots enhanced formation of aerenchyma cells in the cortical tissue of seminal and nodal roots
- Reduced rooting depth and increased root porosity, reduced root respiration, plant photosynthesis, stomatal conductance and transpiration
- Waterlogging inhibits the transport of sugars from the shoots to the roots by more than 79% in seedlings.
- Ethylene production increases and acts as a trigger (Not promoter) of accelerated wheat plant senescence. Ethylene is more pronounced in older leaves than in younger ones
- Exogenous cytokinins applied to wheat seedlings at the onset of waterlogging delays degradation of chlorophyll and other biochemical process Nitrogen remobilization from lower leaves is accelerated on flooded soils and induces chlorosis

Agronomic practices known to reduce waterlogging

- Seedling and planting dates to coincide with reduced rainfall patterns is one way to avoid waterlogging
- Application of nitrogen fertilizer after waterlogging has been shown to reduced the detrimental effects of this stress
- Waterlogging under optimum soil nutrient (N) supply conditions result in less growth restriction than under a sub-optimal nutrient supply
- Doubling the concentration of nutrients supplied to the plants under waterlogging reduced the photosynthetic rate, chlorophyll content and number of nodal roots, while improves shoot N status and growth
- Green manures, straw and animal manures increase the availability of Fe and Mn several fold under flooded conditions and improves soil physical factors and reduce soil surface crusting, .
- .The furrow or bed planting system has significant yield advantages,. Furrows also make it possible to drain fields or keep a large portion of the root system out of waterlogged soils

Conclusion

- The changes taking place in the root zone and their perception by the plant are clearly essential for the establishment of an appropriate response.
- The alteration in gas diffusion, the soil chemical environment (pH, Eh) and the accumulation of toxic substances by-products of anaerobic processes coupled to the decline in O_2 are clearly keys to the capacity of a plant to set up the right response.
- These adaptive features include changes in metabolism which may help preserve the plant cell integrity. The fermentative pathway can help maintain the cell pH but also ATP homeostasis.

- The glycolytic pathway to lactate and to ethanol, nitrate reduction could be used as an alternative respiratory pathway to help maintain redox potential and energy homeostasis under hypoxic and anoxic conditions.
- Higher carbohydrate reserves and/or their efficient use, maintenance of photosynthesis and plant water status through shoot elongation or aquaporin gating may greatly improve plant survival to submergence.
- Morphological changes as lenticels formation, aerenchyma development, adventitious roots initiation and/or root suberization can not only ameliorate the rate of O_2 diffusion to the submerged growing parts but also help alleviate water and nutrient deficiencies.
- Most of these adaptive features have been well characterized in model species adapted to flooding conditions such as maize, and rice however the exact role of lenticels and the molecular processes involved in aerenchyma formation still need further scrutiny.

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Factor Affecting Micronutrients Availability in Soils

G.S. Rathore

Ex-Professor & Head
Department of Soil Science & Agricultural Chemistry
JN Krishi Vishwa Vidhyalaya, Jabalpur – 482004 (M.P.)

I. Soil factors

Many soil factors influence the availability of micronutrients to plants. Among the most important factors are soil solution pH, calcium carbonate, organic matter and interaction among nutrients present in soil solution.

Soil pH: pH is the master variable which governs the solubility and consequently the availability of micronutrients to plants. In general each unit increase in pH decreases the solubility of divalent cations 100 times. Deficiencies of micronutrient cations (Zn, Cu, Fe and Mn) are expected to be frequently encountered in neutral to alkaline soils. In sharp contrast, availability of molybdenum increases with the rise in pH. Boron normally becomes less available to plants with increasing soil pH. The reduction in B availability following liming is caused mainly by B adsorption on freshly precipitated AL $(OH)_3$ with maximum adsorption at pH 7.

Calcium carbonate: Above pH 7.4 or above, because of the low solubility of micronutrient cations at high pH, more incidences of their deficiencies would be expected. Adsorption of micronutrients cations particularly zinc by carbonates of Mg and Ca may also lower the availability of Zn in calcareous soils.

Soil texture: The available information points out that finer fractions of soil contain and retain more micronutrients than the coarse fractions. Therefore micronutrients deficiencies are not noticed more frequently in case of heavy textured soils.

Organic matter: A high positive correlation between organic matter content and extractable micronutrients has been reported by several workers. Exposed sub-soils are mostly Zn deficient due to their very low organic matter content. In some high organic matter soils available Cu was inversely related to organic matter contents.

Interaction among nutrients: Metal cations can interact with Fe to induce Fe stress in plants. Fe deficiencies can result from an accumulation of Cu after extended period of Cu fertilization. In addition Fe deficiencies are caused by excess of Mn, Zn, Mo and P. zinc uptake is inhibited by excess metal cations including Cu^{2+}, Fe^{2+} and Mn^{2+}, possibly because of competition for the some carrier site. High P availability can induce Zn deficiency commonly in soils that are marginally Zn deficient. Copper absorption by plant roots is depressed by high concentration of Zn, Fe and P in soil solution and may intensity Cu deficiency. Increasing N supply to crops impedes translocation of Cu from older leaves to new growth. High levels of Cu, Fe or Zn can reduce Mn uptake by plants. Addition of acid forming NH^{4+} to soil will enhance Mn uptake. Low tolerance to B occurs when plants have a low Ca supply when Ca availability is high, there is a greater requirement for B. the occurrence of Ca^{2+} in alkaline and recently over limed soils will restrict B availability, thus high Ca^{2+} can protect crop from excess B. at low levels of B, increased rates of applied K any accentuate B deficiency symptoms. The effect of K may be related to its influence on Ca absorption. In contrast increased K rates may accentuate B toxicity at high levels of B supply. Mo absorption by plants is enhanced by P probably due to exchange of absorbed $M_0O4^{\ 2-}$. In contrast, high levels of SO_4^{2-} in solution depress Mo uptake by plants. Both Cu and Mn also can reduce Mo uptake, however Mg has the opposite effect and will encourage Mo absorption by plants.

II. Environmental factors

Environmental factors such as soil moisture content, temperature and light greatly influence the availability of micronutrients and consequently micronutrient deficiency or toxicity symptoms in plants. This lecture emphasizes the role of environmental factors in micronutrient nutrition of plants.

Zinc

1. Temperature: Absorption of Zn is probably metabolically controlled and therefore Zn absorption should increase as root temperatures increase. Martin et al. (1965) reported that (i) zinc deficiency symptoms are more severe at low soil temperature (ii) plants are less likely to respond to Zn fertilizers at a high soil temperatures even though the yield potential is higher at elevated temperature (iii) added P is more likely to induce Zn deficiency at a low soil temperature and (iv) zinc concentration and uptake are usually increased at a high soil temperature

Mycorrhiza associated with the root are believed to enhance the uptake of Zn and other elements. VAM infection is severely reduced at low soil temperatures. Therefore, reduced VA-mycorrhizal infection may be involved in low soil temperature induced Zn deficiencies. Temperature influences the production of phytochelatins (found in rots of angiosperms) and phytosidero-phores (produced by members of the Gramineae) which are also important in translocation and uptake of some micronutrients including Zn.

Kumar and Sharma (1987) in their study on influence of mulching on Zn uptake by winter maize in calcareous soils of Bihar reported that the soil temperature was affected only by the level of mulch and not by irrigation. The temperature was significantly higher under mulch than under no mulch condition. Uptake of Zn increased significantly as a result of mulch and Zn application. Values of Zn uptake by grain were 105.4 and 151.4 g/ha under no mulch and mulch condition, respectively.

2. Soil Moisture: Plants do not show an increased incidence of Zn deficiency under dry land condition, when subsoil moisture is adequate to support plant growth. Since Zn reaches plant root mainly by diffusion at decreased soil moisture levels, greater frequency of Zn deficiency in susceptible crops would be expected by this water use pattern. Nambiar (1976), however, found that significant amounts of 65^{+} Zn were absorbed from dry zones even when soil water suction exceeded 15 bar. He speculated that mucilage permitting rhizospheres provided sufficient liquid continuity between the solution in fine soil pores and within root cells to permit Zn absorption.

Zinc deficiency in rice is accentuated by flooding this may probably due to increased pH values resulting from the use of high HCO_3 water and reduced availability of Zn due to precipitation of Zn or possibly the formation of organic Zn S complexes. On the other hand on the other hand. Sajwan and Lindsay (1986) concluded that the increased Zn deficiency in flooded rice was due to higher levels of Fe^{++} and Mn^{2+} suppressing the uptake of Zn^{2+} and to precipitation of Zn as $ZnFe_2O_4$ or a similar frankalinite like solid material.

3. Light: it has been reported that reduced or intermediate light intensities increased the severity of Zn deficiency in subterranean clover and due to reduced root growth and restricted uptake of soil Zn under conditions of low light intensity.

Copper :

1. Temperature : the absorption of Cu by plants is probably metabolically controlled (Mengel and Kirkby 1987). Soil temperature may also influence Cu uptake by plants by affecting availability of organically bound Cu. Organically bond Cu in soil is present in both soluble and insoluble forms. Copper concentration of corn tissue in a field experiment was not consistently affected by an increase of soil temperatures from 16 to 35^0C.

2. Soil moisture : Kubata et. al (1963) found soil moisture to have no consistent effect on the Cu concentration of the soil solution or on the Cu conc. Of alsike clover grown on several soils in the green house. However, poonamperuma (1985) reported that complete flooding of soils reduces the water soluble Cu level due to intense reduction and $S^{=}$ formation.

Iron:

Climatic factors greatly affect the occurrence of Fe deficiency in plants under field conditions. Plants species and even cultivar of the same species vary in their susceptibility to Fe deficiency. Marschner (1986) has divided plants into two categories based on variations in Fe efficiency. Plants with strategy I-type are mostly dicotyledonous species, and resistance to Fe deficiency is associated with the enhancement of the release of H^{+} and phenolic components, and increased Fe^{3+} reduction at the plasma membrane. Most of the plants with strategy II-type responses are members of the Gramineae, and resistance to Fe deficiency is associated primarily with increased release of non proteinogenic amino acids (phyto siderophores) from roots.

1. Temperature: Since Fe absorption in an active process and metabolic activity is required for the transport of Fe from roots to shoots, temperature is likely to influence the occurrence of Fe deficiency. Temperature influence the severity of Fe deficiency chlorosis in plants in the following ways (i) low soil temperature, apart from reducing root growth, also reduces root metabolic activity and consequently Fe stress response in non graminaceous plants (ii) low soil temperature reduces the production of phytosiderophores, and the resultant mobilization and uptake of soil Fe by members of the Gramineae (iii) high soil temperature decreases Fe uptake by members of the Gramineae by increasing the microbial decomposition of phytosideropheres (iv) low soil temperature increases HCO_3 levels in the soil solution and the severity of Fe deficiency by increasing the solubility of CO_2 in soil solution (v) high soil temperature could increase HCO_3 levels and severity of Fe deficiency by stimulating microbial activity and CO_2 production (vi) high soil temperature increases the uptake of P by plants and the severity of P induced Fe deficiency and (vii) high soil or aerial temperatures stimulate relative growth rates and induce Fe deficiency.

2. Soil moisture: On high pH and calcareous soils in arid regions, irrigation water and soils high in bicarbonate (HCO_3^-) may aggravate Fe deficiencies. Bicarbonate ion can be formed in calcareous soils by the reaction $CaCO_3 + CO_2 + H_2O \rightarrow Ca_2+ + 2HCO_3^-$. This reaction is promoted by the accumulation of CO_2 in excessively wet and poorly drained soils. Consequently any compact, heavy textured calcareous soil is potentially Fe deficient.

Iron chorosis is also associated with cool, rainy weather when soil moisture is high and soil aeration poor. Also, root development and nutrient absorption are reduced under the cool, wet conditions, which contribute to Fe stress.

Soil moisture variability does not greatly influence the seventy of Fe deficiency chlorosis in plants with strategy II type of Fe stress response, presumably due to the minor effect of HCO_3 on this type of response.

Soil water status, through its effect on pH and Fe reduction, greatly influences the availability to rice plants. Many rice cultivars frequently display Fe deficiency chlorosis in upland conditions. The occurrence of such a problem under low land condition is rare and is restricted to rice growing in alkaline soils low in organic matter.

Low land rice growing on certain acid soils, especially acid sulpate soils, can develop an abnormality due to Fe toxicity because water logged condition can result in the large quantities of soluble Fe due to enhanced reduction of soil Fe.

Light : Light variability is also important in Fe availability to crop plants. Fe deficient plants grown under LPS (low pressure Na lamp) lamps, released much less reluctant from their roots and reduced less Fe3+++ to Fe2+ in their roots than comparably treated plants grown with a CWF (cool white fluorescent lamp.)

Manganese

1. Temperature: Maganese uptake is under metabolic control and consequently its uptake should be reduced at low root temperatures. Temperature may influence the solubility of soil Mn and indirectly affect plant Mn uptake. Reid and Racz (1985) reported that an increase in soil temperature from 10 to 25^{0}C approximately tripled Mn accumulation in tops of barley grown on an organic soil. Microbial activity which is markedly affected by temperature, is known to both mobilize and immobilize soil Mn. In addition, release of root exudates into the soil is also known to solubilize MnO_2 and is probably temperature dependent.

2. Soil Moisture: Excess soil moisture restricts the diffusion of O_2 within soils and favour the reduction of compounds containing Mn. Deficiencies rarely seen in crops such as rice, which is adapted to flooded conditions. However Mn may occasionally be deficient in certain degraded light textured paddy soils from which soluble Mn has been eluviated over time. Manganese deficiency may also occur in upland growing in spots that fluctuate between well drained and water logged conditions, a situation that favours Mn reduction and its eluviations. Water logging or extended wet periods under field conditions caused Mn toxicity in apples and in alfalfa at soil pH value >5.5 a value normally considered to be a limit for acidity induced Mn toxicity.

Anand Swaroop (1987) reported the results of a field experiment conducted for four years to evaluate the effect of exchangeable sodium percentage (ESP) levels of 82, 72, 65, 35, at three period of submergence 0, 15 and 30 days prior to transplanting (pressubmergence) on the train formation and availability of Fe and Mn to rice crop. Pressubmergence increases rice yields at all ESP levels, the effect. Being more pronounced at high ESPS. The beneficial effects could be attributed to an increase in the availability of Fe and Mn, and to the reduction in the sodicity because of hydrolysis. The presults suggest that a period of 15 to 30 days presubmergence is an important requirement to obtain better yield of rice on calcareous sodic soils of the Indo-gangetic alluvial plains of Notrhern India.

3. Ligh: Some researches indicate that Mn toxicity and Mn deficiency are intensified under high and low light conditions, respectively. Shading reduced the concentration of Mn and decreases the incidence of Mn toxicity in bean (phaseolus vulgaris L.) and corn plants. Shading also reduced the conc. Of Mn in corn plants, however, Mn toxicity symptoms in both species were more severe at high light. In contrast rice accumulated more Mn under shaded than under full light conditions.

Boron

1. **Temperature:** Boron uptake is largely a physical process involving the absorption of unionized H_3BO_3 and subsequently passive movement of B in the transpiration stream. The relation between temperature and B uptake is complex and influenced by the effect of root and aerial temperature on the rate of transpiration.

2. **Soil water content:** Moisture stress in surface soils accenturate B deficiency in many crops including sugar beet, alfalfa. Drought

stress affects the incidence and severity of B deficiency more than that of any other micronutrient. B deficiency restricts root growth according to Batey (1971) turnip (Bassicarapa) in wales normally become B deficient on soils with <0.3 mg kg^{-1} of extractable B. However, deficiency in dry summer was observed in fields with extractable B levels of 0.5 to 0.6 mg kg^{-1}. Another theory concerning the cause of drought induced B deficiency involves moisture stress that restricts the mineralization and availability to plants of organically bound B in soil.

Born toxicity in plants is chiefly affected by the concentration of B in soil water. Since the distribution of B in plants is related to transpiration patterns, tips and margins of older leaves are first affected. Increasing transpiration as a consequence of high temperatures and low humidities probably accentuates the occurrence of B toxicity in irrigated areas in cases where concentration of B in irrigation water is high.

3. **Light:** In general, high light intensity and long day conditions accentuation B deficiency and reduce the severity of B toxicity.

Molybdenum

Environmental factors apparently have a relatively small direct role on the incidence of Mo deficiency. Mo deficiency is most pronounced in high rainfall areas, but the effect is generally related to adsorption of MoO_4 by soil constituents under acid conditions.

Soil and climatic factors inducing micronutrient deficiency in plants

1. **Zinc**
   - Low soil zinc
   - Calcareous soils
   - High soil phosphorus
   - Coc temp eratures
   - Compacted soil horizon
   - Where surface soil has been removed in land leveling operations
2. **Manganese**
   - Alkaline soils
   - High soil iron, copper or zinc
   - Low light intensity
   - Low soil temperature
3. **Iron**
   - Low soil iron
   - Free calcium carbonate in soil
   - Moisture extremes
   - High amounts of Cu, Zn, Mn & Mo
   - High soil P
   - Poor aeration (excess of Co_2)
   - Temperature extremes
   - Excess soil acidity
   - Heavy manuring in alkaline soils
   - Root damage
4. **Copper**
   - Low soil Cu
   - High soil P
   - High soil Zn
   - High soil N
5. **Molybdenum**
   - Low soil Mo
   - Acidity below pH 5.5
   - High free Fe
6. **Boron**
   - Low soil boron
   - Areas of moderate to heavy rainfall
   - Nearly neutral or alkaline soils
   - High light intensity

Source: Micronutrients in Agriculture – A Publication of Soil Science Society of America, Wisconism, U.S.A.

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Microorganisms for Augmenting Plant Nutrient Supply in the World of Depleting Natural Resources

Ramesh Chandra

Professor & Head
Department of Soil Science
G B. Pant University of Agriculture and Technology, Pantnagar -263145, Uttrakhand

Modern agriculture is heavily dependent on the fossil fuel based inputs such as inorganic fertilizers, pesticides, herbicides and energy intensive machinery. Large scale use of chemical fertilizers causes the problem of pollution and deterioration of soil structure. The use efficiency of chemical fertilizers in crops is generally low as they have varying fate in soils. The nitrogenous fertilizers are subjected to leaching, denitrifiacation and volatalization losses while phosphatic fertilizers under go process of fixation in soil. In dry land and rain-fed agriculture, moisture is also a limitation in use of inorganic fertilizers. It has been projected that if fertilizer production and consumption continued with current rate, there will be a gap of about 7 m t in requirement and supply of plant nutrients for crop production (Tandon, 1997). In past years, cost of chemical fertilizers has increased tremendously and it becomes difficult by the farmers to use balanced dose of plant nutrients in their crops. There is need to search additional sources of plant nutrients to bridge the gap in the fertilizer production and consumption. In a country like India, where majority of farmers are marginal having small holdings, use of microorganisms in conjunction with organic and inorganic fertilizers offer a great opportunity for sustainable crop production. Microorganisms in the soil constitute less than 0.5% (w/w) of the soil mass; yet they have a major impact on soil properties and processes.

The diverse soil microorganisms interact with one another, with non-living soil particles sand, silt and clays and with plants and animals in the ecosystem forming a complex system of biological activity. Environmental factors, such as temperature, moisture and acidity, as well as anthropogenic actions, in particular, agricultural practices affect soil biological communities and their functions to different extents. An understanding and management of soil biological properties has therefore emerged in the past decade as a key area of concern to realize the potential of soil organisms for sustainable soil health/ quality and crop production. Soil organisms carry out both beneficial and harmful functions and influence the development of soil structure, aeration, organic matter transformations, crop production, plant and animal health, and environmental quality. Some of the important functions carried out by soil organisms are:

- Some microorganism such as fungi, algae and bacteria secrete polysaccharides and influence soil structure by favouring soil aggregation. This directly affects various soil physical properties such as porosity, water holding capacity, infiltration rate, etc. and determines vulnerability to soil erosion;
- Soil organisms are central to decomposition processes and plant nutrient cycling in soil. They carry out mineralization and immobilization of some mineral nutrients, especially nitrogen, phosphorus and sulphur governing their availability to plants. They, thus, affect plant growth and productivity as well as the release of pollutants in the environment, for example the leaching of nitrates into water resources;
- Certain soil organisms are detrimental to plant growth by causing plant diseases or inhibiting seed germination, plant growth and development by producing phytotoxic substances. However, they can also protect crops from pest and disease outbreaks through biological control and reduced susceptibility (induced systemic resistance);
- The activities of certain organisms determine the carbon cycle - the rates of carbon sequestration and gaseous emissions and soil organic matter transformation;
- Microbes have unique ability to return the nitrogen in soil from air through process of biological nitrogen fixation. BNF reportedly brings about 175 10^{9} Kg N annually to soil from atmosphere (Burns and Hardy, 1975).
- Some soil organisms have ability to form complexes of heavy metals limiting their availability for plant uptake, while others can solubilize insoluble nutrient sources in to soil releasing their nutrients in to plant usable form.
- Symbiotic associations, especially of rhizobia bacteria and Mycorrhiza, with crop plants play a key role in the uptake of nutrients and water, and contribute to the

maintenance of soil porosity and organic matter content, through their growth and biomass;

- A group of soil microorganisms, referred as plant growth promontory rhizobacteria (PGPR), secrete plant growth hormones such as IAA, GA, cytokinin and enhance seed germination, root development and plant growth.
- Soil organisms are also useful to reduce or eliminate soil pollutants resulting from accumulations of toxic chemicals or other hazardous wastes (bioremediation).

The most commonly studied beneficial interactions includes the arbuscular mycorrhizal (AM) symbiosis between the higher plants and fungi and nodule symbiosis between legumes and bacteria belonging to α- and ß-proteobacteria. Several other genera of soil bacteria, including *Pseudomonas* and *Bacillus* species, can stimulate root proliferation or have antagonistic effects on soil borne pathogens. The micro-organisms and their products, also interact with plant roots in a variety of positive, negative, and neutral ways. Such interactions can influence plant growth and development, change nutrient dynamics, and alter a plant's susceptibility to disease and abiotic stress. Some of the major strategies involving microorganisms having significant potential in improving the plant nutrition are discussed hereunder:

Biological nitrogen fixation

Biological N_2 fixation (BNF) has been estimated to contribute more than 175 million tones of N (Burns and Hardy, 1975). The contribution of legume-rhizobia associations alone is about 40 % of total BNF. In the presence of a suitable host the bacteria infect the plant through the root hair. The specificity between host legume and and rhizobia is governed by various flavonoid and isoflavonoid molecules released from roots in rhizosphere, which induce expression of *nod* (nodulation) genes by bacteria in rhizobia. This results in the formation by the bacterium of lipo-oligosaccharide Nod factors, the precise structure of which determines the host range and specificity of the association. Although accurate estimation of BNF in field grown legumes is not possible, estimates indicated the fixation of 3-450 Kg N ha^{-1} through this association in different legume crops under diverse agro-climatic conditions (Peoples *et al.* 1995). Crop management, however, is very important aspect for the efficiency of symbiosis. The efficiency of legume *Rhizobium* symbiosis depends upon the host crop and its compatibility with the *Rhizobium* bacteria, crop management and several soil factors like available soil nitrogen, soil moisture, pH, temperature etc.

Dudeja *et al.* (2011) compiled the results of field demonstrations on *Mesorhizobium* inoculation in chickpea conducted under AICRP on chickpea at farmers field farmers fields in different parts of India. It was concluded that the response to mesorhizobial inoculation varied from farmer to farmer across the location, and increase in grain yield ranged from 65–401 kg/ ha, corresponding to 9–33% increase in grain yield over the uninoculated control (Table 1).

Table 1. Response of chickpea to mesorhizobial inoculation at the farmers' fields during the past 25 years

Location	No. of trials	Increase over uninoculated control			
		Range		Over all range	
		kg/ ha	Per cent	kg/ ha	Per cent
Badnapur	60	40-190	3-5-19	120	15
Bharari	3	120-400	24-26	250	25
Durgapura	31	20-597	3.7-30	250	22
Gulbberga	12	90-600	13.1-67	250	23
Hisar	24	0-340	0-47	200	15
Ludhiana	45	30-600	8-39	240	17
Pantnagar	4	100-150	10-12	230	11
Sehore	23	120-300	10-20.7	220	18
Overall	202	65-401	9-33	210	18

Dudeja *et al.* (2011)

Dobereiner and her co-workers isolated a number of diazotrophic bacteria e.g. *Azotobacter, Azospirillum, Herbaspirillum*, *Gluconoacetobacter*. Out of these *Azotobacter and Azospirillum* are known to economize the nitrogen in cereals, vegetables besides synthesis of various growth promoting substances, auxins, cytokinins, antifungal compounds etc. The amount of nitrogen fixed by these microorganisms ranged 15-25 kg N/ ha/ year depending upon the strains, crop type, soil and environmental conditions and crop management practices.

Microbial Phosphorus solubilization

Phosphorus limits the plant growth as most phosphorus present in soil is unavailable to plants, making fertilizer use efficiency low. Need for using phosphate-solubilizing bacteria (PSB) was realized, since nearly16-20 % of P is available to the plant when single super phosphate (SSP) is used as P source and remaining gets fixed in the soil. Several bacteria, particularly those belonging to genera *Pseudomonas* and *Bacillus* and fungi belonging to *Penicillium* and *Asprergillus* genera have the ability to solublize the insoluble inorganic phosphorus in soil to make it available for plants. The mechanisms of solublization appear to be either acid production or chelation of metal and release of phosphorus. Higher P application in the legumes enhances nodulation and nitrogen fixation. Different fungal phosphate solubilizers such as *Aspergillus awamorii* and bacterium *Pseudomonas striata* and a mycorrhizal fungus were tested with positive results of enhanced nutrient uptake and crop yield of chickpea. Organized trials were conducted with 20 and 40 kg P_2O_5/ha as SSP with and without mesorhizobial and PSB inoculation in 1994–1996 in different centres. The results showed that the use of SSP with biofertilizer inoculation enhanced the yield by about 20% (Khurana *et al*. 1999). Beneficial effects of mesorhizobial and PSB inoculation at different levels of SSP encouraged the microbiology group to conduct experiment in collaboration with Agronomists of the centre for 4 years (1996–2000) at Hisar and Sehore centres with two levels of two P sources – rock phosphate (low cost) and diammonium phosphate (DAP, higher cost) with two PSB inoculants. Analysis of the overall data provided interesting results:

- Availability and uptake of P and other nutrients were enhanced by the use of phosphate solubilizers (*Bacillus megaterium* or *B. polymyxa*) inoculation.
- When no P source was used, inoculation with PSB inoculants enhanced the chickpea grain yield by 9.4%.
- Application of rock phosphate with PSB inoculants enhanced the chickpea grain yield up to 34.8%, compared to the yield of only 24% with P source alone.
- Application of DAP with PSB inoculants enhanced the chickpea grain yield by 46.1%, compared to a yield of 30.7% with a P source alone.
- Use of PSB inoculants resulted in saving of about 20 kg P_2O_5/ha.

Phosphate mobilization by mycorrhiza

Some fungi forms symbiotic association with plants and helps in assimilation of phosphorus and other nutrients like Zinc, Iron, Manganese. Such fungus-root association is called Mycorrhiza. Over 80% of land plants are able to form mycorrhizal associations. In these associations there is a bidirectional flow of nutrients. Carbon flows out from the plant host to the fungus, and mineral nutrients flow from the fungus to the plant. It is estimated that between 4% and 20% of net photosynthate can be transferred from the plant to its fungal partner. In return, the mycorrhiza can become the primary organ acquiring mineral nutrients. The establishment of the mycorrhizal network offers a number of basic advantages for the acquisition of mineral nutrients: (i) fungal hyphae extend beyond the area of nutrient depletion surrounding the root; (ii) fungal hyphae greatly increase the surface area for the absorption of nutrients relative to non-mycorrhizal roots; (iii) hyphae are able to extend into soil pores that are too small for roots to enter; and (iv) some mycorrhizal fungi can access forms of N and P that are unavailable to non-mycorrhizal plants, particularly organic forms of these nutrients. Mainly there are two type of Mycorrhizae: (i) ectomycorrhiza: Generally found in trees and is important for forest trees. (ii) Endomycorrhza: They are found in majority of crop plants and play role in supply of phosphorus and other nutrients. Among these Arbuscular Mycorrhiza (AM) are common in field crops.

Plant Growth Promotory Rhizobacteria

The group of beneficial free living soil bacteria capable of stimulating the growth of plants is referred as Plant Growth Promoting Rhizobacteria (PGPR). It includes the bacteria belonging to genera *Acetobacter, Actinoplanes, Bacillus, Cellulomonas, Pseudomonas and* others in addition to nitrogen fixers, P-solubilizers/ mobilizers etc. The major mechanisms responsible for stimulation of plant growth by PGPR include production of plant growth promoting substances, siderrophores, increased availability and uptake of nutrients; and suppression of growth of pathogenic microorganisms. PGPR strains of Pseudomonas were tested at different centres – Bangalore, Coimbatore, Dholi, Gulbarga, Durgapura, Hisar, Ludhiana, and Sehore. Rhizobial inoculation increased the yield by 12.4%, but the combined use of PSB and PGPR resulted in an increase by 22.1% in the grain yield of chickpea.

Microbial inoculants for composting/ Organic residue decomposition

Composting is an age old practice for conversion of bio-degradable wastes into manures. This is a microbial process where a community of microorganisms comprising of bacteria, fungi, actinomycetes and yeast decompose the organic materials and synthesize a highly stable product called humus. The use of compost inoculants is known to speed up the process. These are *cellulolytic* and *lignolytic* micro o*rgankisms* like *trichurus spiralis, paeciliomyces fusisporus, trichoderma* and *Aspergillus spp.* inoculation with *measophilic cellulolytic* fungi are known to reduce the time needed for completion of the process ad improve the quality of final product (Gaur 1982). It is evident from published records that the main target of isolations was the fungi. Most of the organisms were mesophilic fungi, but a few thermophilic strains such as *Aspergillus fumigatus* and *Humicola lanuginosa* also proved beneficial as inoculants. Out of the collection of mesophilic fungi, some of the strains, namely, *Trichurus spiralis, Paecilomyces fusisporous, Aspergillus awamori* and a few species of *Aspergillus, Penicillium, Trichoderma* and *Humicola lamuginosa* proved superior over other. *Aspergillus awamori*, which had earlier been isolated to be good phosphate dissolving fungus and utilized frequently as inoculants. Hameeda et al (2006) reported that application of three three PGPB, *Serratia marcescens* EB 67 (56%), *Pseudomonas* sp. CDB 35 (52%), and *Bacillus circulans* EB 35 in combination of farm waste compost, rice straw compost, Gliricidia vermicompost showed enhancement in root length and dry biomass IAA above the threshold levels.. Application of *Azospirillum* spp. along with composts alleviated the noxious effect of composts and enhanced germination of wheat (Bacilio *et al.* 2003). Such PGPB can be applied as additional inoculants along with composts and make a synergistic treatment for improving plant growth.

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Limiting Factors - in Relation to Crop Growth

A.K. Naidu

Professor & Head
Department of Horticulture
JN Krishi Vishwa Vidhyalaya, Jabalpur – 482004 (M.P.)
e-mail:- drnaiduak@gmail.com

DEFINITION:

"Limiting factors are environmental influences that constrain the productivity of organisms, populations, or communities and thereby prevent them from achieving their full biological potential which could be realized under optimal conditions."

CLASSIFICATION OF LIMITING FACTORS:

Limiting factors can be classified as *"biotic"* and *"abiotic"* limiting factors.

1. ABIOTIC LIMITING FACTORS:

"Abiotic factors are those non-living physical and chemical factors which affect the ability of organisms to survive and reproduce."

EXAMPLES:

- Light intensity
- Temperature range
- Type of soil or rock
- pH level (acidity or alkalinity)
- Water availability
- Dissolved gases
- Level of pollutant etc.

Abiotic factors vary in the environment and determining the types and numbers of organisms that exist in that environment.

2. BIOTIC ENVIRONMENTAL FACTORS:

"Biotic factors are all the living things or their materials that directly or indirectly affect an organism in its environment."

EXAMPLES:

- Parasitism
- Disease
- Predation
- Intra and interspecific competition
- Ammensalism
- Mutualism etc.

ABIOTIC ENVIRONMENTAL FACTORS

1 . LIGHT

The radiant energy from the sun is the basic requirement for the existence of life on the earth. This source of energy is of fundamental importance to the photosynthetic production of food by plants and also on animal life.

Light Variations in Different Environments:

Light energy varies with different media. The transparency of air and water is important in regulating the amount and quantity of light that may be available in particular habitats.

For example; the intensity of light reaching the earth's surface varies with the angle of incidence, degree of latitude and altitude, season, time of day, amount absorbed and dispersed by atmosphere and a number of climatic and topographical factors such as fog, clouds, suspended water drops, dust particles, etc.

Effect of Light on the Plants:

Light energy influences almost all the aspects of plant life directly or indirectly. Thus, it controls plant's structure, form, shape, physiology, growth, reproduction, development, local distribution, etc.

On the basis of light factor certain ecologists have classified plants into;

- ***Sciophytes***
- ***Shade loving***, *or* ***photophobic plants*** which have best growth under lower intensities of light.
- ***Photophilous plants*** which have best growth in full sunlight.
- ***Light affects directly the following physiological processes of the plants;***

It is an essential factor in the formation of ***chlorophyll*** pigment in chlorophyllous plants.

It has a very strong influence on the number and position of ***chloroplasts***. The upper part of the leaf which receives full sunshine has larger number of chloroplast which are arranged in line with the direction of light. In leaves of plants which grow under shade, chloroplasts are very few in number and are arranged at right angle to the light rays, thus, increasing the surface of light absorption.

Light has its most significant role in ***photosynthesis***. During photosynthesis, the green plants which are the "primary producers" of an ecosystem, synthesize their carbohydrate food from water and CO2 in the presence of sunlight. Thus, during photosynthesis, the solar radiant energy is transformed into the chemical or molecular energy which remains stored in chemical bonds of carbohydrates and this chemical energy is utilized by other chlorophyllous and non-chlorophyllous parts of plants, all animals, bacteria and viruses.

Light also influences certain chemical compounds of plants which affect the differentiation of specialized tissues and organs.

Leaf structure too is influenced by the intensity of light.

The development of flowers, fruits and seeds is greatly affected by light intensity. Diffused light or reduced light promotes the development of vegetative structures and causes delicacy. For example, vegetative crops such as turnips, carrots, potato and beets give highest yield in regions with high percentage of cloudy days. Intense light favors the development of flowers, fruits and seeds life activities.

Effects of Light on Animals:

Light affects divergent aspects of animal's life. It influences cellular metabolism, growth, pigmentation, locomotion, reproduction, ontogenetic development, and also controls the periodicity and biological clocks of animals. Some of its significant effects can be discussed as follows :

1. Effect of light on protoplasm:

Though the bodies of most animals remain protected by some sort of body covering which save animal tissues from the lethal effects of solar radiations. But, sometimes sun rays penetrate such covers and cause excitation, activation, ionization and heating of protoplasm of different body cells. Ultraviolet rays are known to cause mutational changes in the DNA of various organisms.

2. Effect of light on metabolism:

The metabolic rate of different animals is greatly influenced by light. The increased intensity of light results in an increase in enzyme activity, general metabolic rate.

3. Effect of light on pigmentation:

The darkly pigmented skin of human inhabitants of the tropics also indicate the effect of sunlight on skin pigmentation.

4. Effect of light on animal movements:

Oriented locomotory movements towards and away from a source of light is called ***phototaxis***. Positively phototactic animals such as *Euglena, Ranatra*, etc., move towards the source of light, while, negatively phototactic animals such as planarians, earthworms, slugs, copepodes, siphonophores, etc., move away from the source of light.

The light directed growth mechanisms are called ***phototropisms*** which occur in sessile animals. Phototropisms also include responsive movement of some body part of some active animals to the light stimulus, such as the movement of flagellum of *Euglena* towards light and movements of polyps of many coelenterates.

5. Effect of light on development:

Light in some cases (*e.g., Salmon* larvae) accelerates development, whereas, in other (*e.g, Mytilus* larvae) it retards it.

2 . TEMPERATURE

Temperature is one of the essential and changeable environmental factors. It penetrates into every region of the biosphere and profoundly influences all forms of life by exerting its action through increasing or decreasing some of the vital activities of organism, such as behaviour, metabolism, reproduction, ontogenetic development (*viz.,* embryogenesis and blastogenesis) and death.

Temperature is a universal influence and is frequently a limiting factor for the growth or distribution of animals and plants. Normal life activities go on smoothly at a specific temperature or at a specific range of temperatures. This is called the ***optimum temperature*** or the optimum range of temperature. Organisms react to any rise or fall of the optimum temperature range and biotic communities more often encounter alterations only due to extremes of temperature (*viz.,***minimum** or **maximum** temperatures).

Temperature Fluctuations in Different Environments:

Environmental temperatures fluctuate both daily and seasonally. Different environments such as freshwater, marine and terrestrial environments, are subjected to varied responses to fluctuating temperature. The minimum temperature in the sea is–3 C, while in freshwater pond it never goes below 0 C. The maximum temperature of ocean generally goes up to 36 C.

Range of Temperature Tolerance:

Life in this universe exists within a range of—200 to 100 C. Though normal life persists within narrow temperature limits of about—10 to + 50 C. Individual species survive in a smaller range.

The organisms (microbes, plants and animals) which can tolerate very large fluctuations in temperature are called

eurythermal organisms. For example, cyclops, toad, wall lizard, grass snake, man, etc., are the eurythermal animals.

The organisms which can tolerate only a small variation in temperature are termed

Stenothermal organisms. The common stenothermal animals are fishes, snails, coral reefs, etc.

Factors or Variables Affecting Organismal Response to Temperature:

The response of an organism to temperature is affected by a number of factors such as **thermal** history, genetic differences, diet, size, stage in life cycle, sex, moulting, parasitism, hormones, etc. E.g. Goldfish showed increased resistance to high temperature when placed on a high fat diet.

Effect of Temperature on Plants and Animals:

Temperature has been found to affect the living organisms in various ways. Some of well-studied effects of temperature on living organisms are the following :

1.Temperature and cell:

The minimum and maximum temperatures have lethal effects on the cells and their components. If too cold, cell proteins may be destroyed as ice forms, or as water is lost and electrolytes become concentrated in the cells; heat coagulates proteins.

2. Temperature and metabolism:

Most of metabolic activities of microbes, plants and animals are regulated by varied kinds of enzymes and enzymes in turn are influenced by temperature, consequently increase in temperature, up to a certain limit, brings about increased enzymatic activity, resulting in an increased rate of metabolism. For instance, the activity of liver arginase enzyme upon arginine amino acid, is found to increase gradually and gradually, with the simultaneous increase in the temperature from 17 C to 48 C. But an increase in temperature beyond 48 C is found to have an adverse effect on the metabolic rate of this enzymatic activity which retards rapidly.

3. Temperature and sex ratio:

In certain animals the environmental temperature determines the sex ratio of the species. For example, the sex ratio of the copepod Macrocyclops albidu is found to be temperature dependent. As the temperature rises there is a significant increase in number of males. Similarly in plague flea, Xenopsylla cheopis, males outnumbered females on rats, on days when the mean temperature remains in between 21–25 C. But the position becomes reverse on more cooler days.

4. Temperature and animal behaviour:

Temperature generally influences the behavioural pattern of animals. Certain snakes such as rattle snake, copper heads, pit vipers are able to detect mammals and birds by their body heat which remains slightly warmer than the surroundings. Even in the dark these snakes strike on their prey with an unnerving accuracy, due to heat radiation coming from the prey. The arrival of cold weather in temperate zones causes the snakes to coil up and huddle together.

- ***Temperature and moisture:***

The differential heating of the atmosphere resulting from temperature variation over the earth's surface produces a number of ecological effects, including local and trade winds and hurricanes and other storms, but more importantly it determines the distribution of precipitation.

Thermal Adaptations of Plants and Animals:

Most animals and plants of different ecological habitats have developed various sorts of thermal adaptations during the course of evolution to overcome the harmful effects of extremes of temperature.

Some of the significant thermal adaptations of plants and animals are the following;

1. Formation of heat resistant spores, cysts, seeds, etc: Some of the animals and plants produce heat resistant cysts, eggs, pupae, spores and seeds which can tolerate extremes of temperatures.

2. Removal of water from tissue*:* Dried seeds, spores and cysts avoid freezing because there remains no liquid in them that can freeze.

3. Dormancy: Dormancy includes two already discussed phenomena namely ***hibernation*** and ***aestivation****:* During both kinds of dormancies metabolic rate becomes reduced, body temperature becomes low and heart beat rate is also reduced.

4. Thermal migration: Thermal migrations occur only in animals. The journeys taken by animals that enable them to escape from extremely hot or cold situations are referred to as ***thermal migrations***. For example, desert animals move to shaded places to avoid burning heat of noon and some animals such as desert reptiles and snakes become nocturnal to avoid heat of the day.

3 . HUMIDITY OF AIR

*"Atmospheric moisture in the form of invisible vapour is known as **humidity**."* The humidity of air is expressed in terms of values of ***relative humidity*** which is the amount of moisture in air as percentage of the amount which the air can hold at saturation at the existing temperature. Daily variations in relative humidity values depend upon the type of habitat conditions. In plains and deserts, it may show variations during day, whereas in oceanic islands there is little variation, being same throughout the year.

Humidity plays an important role in the life of plants and animals:

It affects the life processes such as transpiration, absorption of water, etc. Some plants such as orchids, lichens, mosses, etc., make direct use of atmospheric moisture. In fungi, and other microbes, humidity plays an important role in germination of spores and subsequent stages in life cycle.

4. FIRE

Fire is an interesting ecofactor. Fire is of a common occurrence in natural vegetation all over the world; it is more common in drier habitats than the wet. Lightening is the commonest natural ***cause of fire initiation***. Our earth's surface is hit by lightening every second in one or another part of the globe and many of these are of great magnitude. Other causes of fire are abrassive effects of falling rocks or of dried plant material such as bamboos, or spontaneous combination of very dry and hot material or by volcanic activities. Most forest fires are now man-caused, *i.e.,* by incendiarists (such as poachers), debris burners, smokers, campers, short-circuiting of high-tension electric lines, and nearby railway lines.

Effects of Fire:

Fire has direct (*e.g.,* lethal) as well as indirect effects on plants and wild-life. Some well confirmed indirect effects of fire on plants are as follows :

1. Fire causes injury to some plants, resulting large scars on their stems. Such scars may serve as suitable avenues of entry of parasitic fungi and insects.
2. Fire arrests the course of succession and modify the edaphic environment very much.
3. Fire brings about distinct changes of such ecofactors as light, rainfall, nutrient cycles, fertility of soil, litter and humus contents of soil, pH, water holding capacity and soil fauna (earthworms,nematodes, arthropods, etc.) Soil fungi are reduced while bacteria increase due to post-fire changes in the soil. The microclimate too is greatly changed due to addition of ash, loss of shade, loss of raindrop interception, accelerated erosion, etc.
4. Fire plays an important role in the removal of competition for surviving species. ***Fire tolerant plant*** species generally increase in abundance at the expense of those killed by fire (***fire-sensitive plants***) due to considerable reduction in competition and possibly due to alteration in other conditions.

Adaptations to Fire:

In frequent fire prone areas certain plants develop the following adaptations :

A. Certain trees, particularly conifers such as *Pinus* and *Larix* and dicots such as *Quercus* develop fire resistant bark with insulating effect against heat. These trees also have tall trunk with the crown restricted to upper zone only. This helps in escaping the destructions against surface and ground fires.

B. In some plants leaves are fire-resistant due to poor contents of such compounds such as resin or oil, and may check surface fires.

C. Some plants as *Pinus rigida* and species of *Eucalyptus* have adventitious or latent axillary buds which may develop into new branches. Similarly *Betula papyrifera* and *Vaccinium* spp. may develop new shoots after fire kills the older ones.

D. *Epilobium anguistifolium* acts as a fire indicator species. It grows in patches and in dormant condition. In case of fire, these plants rapidly grow while other plants die due to fire.

5. WIND FACTOR

"The strong moving current of air is called wind."

It is an important ecological factor of the atmosphere affecting variously the plant life on flat plains, along sea coasts and at high altitudes in mountains. Wind is directly involved in transpiration, in causing several types of mechanical damage and in dissemination of pollen, seeds and fruits. Wind also modifies the water relations and light conditions of a particular area. The movement or velocity of wind is affected by such factors such as temperature, atmospheric pressure, geographical features (including topography), vegetation masses and position with respect to sea shores. Air moves from a region of high pressure to low pressure.

Winds result in various physical, anatomical and physiological effects on plants:

➢ ***Physical effects :***

1. such as breakage and uprooting; deformation; lodging or flattening of herbaceous plants such as wheat, maize, sugarcane, etc.; abrasion of buds of plants (by wind-carried soil particles), erosion and deposition of soil around plant roots; plant injury due to salt spray along sea coasts.

2. Anatomical and ***physiological effects*** such as formation of dense, reddish xylem called ***compression wood*** on the compressed side of wind deformation, desiccation due to increased rates of evaporation and transpiration which are caused by strong winds and ***dwarfing*** of trees on sea coasts, arctic or alpine timberline due to prolonged dehydration and consequent loss of turgidity under the influence of drying winds.

BIOTIC EMVIRONMENTAL FACTORS

Organisms do not exist alone in nature but in a matrix of other organisms of many species. Many species in an area will be unaffected by the presence or absence of one another (This is often termed ***neutralism***), but in some cases two or more species will interact. The evidence for such interaction is quite direct: populations of one species are different in the absence and in the presence of a second species.

INTERSPECIFIC INTERACTIONS:

The interactions between species may have positive or negative results. Following six general types of interactions have been described:

A. Positive interactions

1. Mutualism

2. Commensalism

3. Protocooperation

B. Negative interactions

1. Exploitation

I. Social parasitism

II. Parasitism

III. Predation

2. Amensalism and antibiosis

3. Competition

A. POSITIVE INTERACTIONS:

In case of positive interactions, populations help one another and either one or both the species are benefited. Positive interactions may be of the following types:

1. *Mutualism:*

Mutualism is an obligatory positive interspecific interaction that is strongly beneficial to both species. In past, it was termed ***symbiosis***. This benefit may be regarding the food, shelter, etc. A common example of mutualistic association is of ***lichens***.

Lichens:

They form the examples of mutualism where contact is close and permanent as well as obligatory. The body of lichens is made up of a matrix formed by a fungus, within the cells of which an alga is embedded. The fungus makes available the moisture and minerals to the algae, which prepare food by photosynthesis. In nature, neither of the two can grow alone independently. Lichens tend to grow abundantly on bare rock surfaces.

2. Commensalism:

Commensalisms like associations also exist between a variety of microorganisms and higher plants. For example, the zone of soil around the roots of higher plants, characterized by intense microbial activity, called the ***rhizosphere****;* the surface proper of the roots growing in soil the ***rhizoplane****;* the boundary layer of air over the green leaves with active microbes—the ***phyllosphere****;* and the leaf surface—***phylloplane****,* constitute important ecological niches, where occur rich populations of microorganisms including fungi, actinomycetes and bacteria. The living roots and leaves of higher plants are known to continuously diffuse various metabolic products, mainly sugars and amino acids.

These are sources of nutrition for microorganisms present there in.

B. NEGATIVE INTERACTIONS:

In case of negative interactions, one or both species are harmed in any way during their life period. These types of interactions are termed as ***antagonism***. The negative interactions include the following three broad categories:

1. Exploitation:

In exploitation, one species harm the other by making its direct or indirect use for support, shelter or food. It is of following types:

(a) Social parasitism:

Social parasitism describes the exploitation of one species by another, for various advantages. It is a kind of parasitism in which the parasite foist the rearing of its young into the host.

Classification of parasites:

Parasites exhibit a tremendous diversity in ways and adaptations to exploit their hosts. The parasites may be ***viral parasites*** (*e.g.,* bacterial, plant and animal viruses*),* ***microbial parasites*** (*e.g.,* bacteria, protozoa, fungi, etc.),

phytoparasites (*e.g.,* plant parasites) and ***zooparasites*** (*e.g.,* animal parasites such as platyhelminthes, nematodes, arthropods, etc.). They may parasitize microorganisms, plants and animals. They may occur on the outside of the host ***(ectoparasites)***or live within the body of the host (**endoparasites**).

(b) Parasitism:

Parasitic adapatations:

While studying parasitism as a biotic factor influencing the life and activities of parasites and hosts we often encounter adaptations, both offensive and defensive, being developed by the host, as well as by the parasite. An endoparasite entering a host often meets with the antibodies or phagocytic cells produced by the host. The ectoparasites, and endoparasites have following parasitic adaptations:

1. In parasitic animals, a reduction of organs of special sense of nervous system, and of locomotory organs occurs.
2. Most ectoparasites develop some clinging organs such as hooks, suckers, etc., to get attached with the body of their hosts. They also develop special piercing and sucking organs to suck the blood of animals or sap of plants.
3. Most endoparasites exhibit anaerobic respiration, high rate of reproduction, parthenogenesis, hermaphroditism, intermediate host and a complicated life-cycle.
4. Some endoparasites, such as tapeworm, have become so adapted to the host that they no longer require a digestive system. They simply absorb their food directly through their body wall.
5. Further, parasites that live within the bodies of plants and animals possess cuticles or develop cysts resistant to the digestive enzymatic action of the host.
6. Many parasites pass their entire existence in a single host; others require one, two, even three intermediate hosts. It is of ecological significance that both primary and intermediate hosts of a parasite occur in the same habitat or community. Even then the hazards to successful passage from one host to another are so great and mortality so high that enormous quantities of offspring are produced to ensure that at least a few individuals will complete the cycle.
7. Parasites are transferred from one host to another by active locomotion of the parasite itself; by ingestion, as one animal sucks the blood of or eats another; by ingestion as an animal takes in eggs, spores, or encysted stages of the parasite along with its food or drinking water; as a result of bodily contact between hosts; or by transportation from host by way of vectors.

(c) ***Predation*****:**

Predation occurs when members of one species eat those of another species. Often, but not always, this involves the killing of the prey.

Types of predation:

Most of the predatory organisms are animals, but there are some plants also. Four types of predation have been recognized.

Herbivores are animals that prey on green plants or their seeds or fruits; often the plants eaten are not killed but may be damaged.

2. Typical predation occurs when carnivores prey on herbivores or on other carnivores.

3. Insect parasitism *is another form of* predation in which the insect parasite lays eggs on or near the host insect, which is subsequently killed and eaten.

4. Cannibalism is a special form of predation in which the predator and prey are from the same species.

Significance of predation:

Predation is an important ecological process from three points of view.

1. Effect of predation on a population may be to restrict distribution or reduce abundance. If the affected animal is a pest, predation appears useful. If it is a valuable resource such as caribou, the predation seems undesirable.
2. Along with competition, predation is the second major process which affects community structure.
3. Predation is a major selective force and may explane predator-prey coevolution (Evolutionary changes in two or more interacting species are called ***coevolution.)***

(A) Predation in animals.

A predator animal tends to be larger than its prey. The main components of predation are predator and prey. A successful **predator** has following characteristics:

1. The hunting ability of a predator remains well developed.
2. By their hunting activities predators can be regarded as specialized or generalized.

Specialized predators:

These are those adapted to hunt only a few species. They are forced to move where the vulnerability of a staple prey item drops to a point where the predator population cannot support itself. For example, Peale's falcon shows a marked preference for ducks and pheasants. Deer exhibits a pronounced preference for certain species of browse.

Generalized predators:

These are not so restricted in diet, adjust to other food sources. The horned owls have a large range of collective prey available. Foxes can shift to vegetable and carrion diet, should conditions require it.

3. Hunting ability and success of predator involve the development of a searching image on the part of the predator.
4. Though a predator may have strong preference for a particular prey, it can turn in the time of relative scarcity to an alternate, more abundant species that provides more profitable hunting. For example, if rodents are more abundant than rabbits and quail, foxes and hawks will concentrate on them instead of game animals.
5. Habitat preferences or overlapping territories can bring predator and prey into close contact, increasing prey risks.
6. Age, size, and strength of prey influence the direction that predation takes. Predators select food on the basis of size. Mountain lions, for example, avoid attacking large healthy elk, which they cannot successfully handle, and concentrate instead on deer and young or feeble elk.
7. Predators hunt only when it is necessary for them to procure food. The searching rate of predator is influenced by the speed of the predator relative to the speed and escapes reactions of the prey, to the distance at which predators' first notice and attack the prey, and to the proportion of attacks that result in successful capture. Like the predators, the prey has its certain defensive specializations.

(B) Predation in plants:

Plants provide the following examples of their predation:

1. Carnivorous fungi:

A number of fungi such as species of, *Dactylaria, Arthrobotrys, Zoophagus,* etc., capture insects, nematodes and other worm-like animals. Such fungi use specialized structures such as **traps** or **snares** which are formed on their mycelia to capture the nematodes.

2. Competition:

The presence of other organisms may limit the distribution of some species through ***competition***. Such competition can occur between any two species that use the same sorts of places. Note that two species do not need to be closely related to be involved in competition. For example, birds, rodents and ants may compete for seeds in desert environments. Competition among animals is often over food, water and mates. Animals may also do competition for space, *i.e.,* nesting sites, wintering sites, safer sites from predators. Plants can compete for light, water, nutrients, or even for pollinators and/or attachment sites. Competition is an important process affecting the distribution and abundance of plants and animals. There are two different types of competition, defined as follows:

(a) ***Resource competition*** (also called scramble competition) occurs when a number of organisms (of the same or of different species) utilize common resources that are in short supply.

(b) ***Interference competition*** (also called contest competition) occurs when the organisms seeking a resource harm one another in the process, even if the resource is not in short supply.

Note that the competition may be:

- **Interspecific** (between two or more different species)
- **Intraspecific** (between members of the same species).

Micronutrient Management in Salt Affected Soils for Higher Crop Production

K.P. Patel

Principal Scientist
Department of Soil Science & Agricultural Chemistry
Anand Agricultural University, Anand (Gujarat)

Introduction

Some amount of salt is always present in soil but when the concentration of these salts is low, they are not harmful for the growth of plants. However, with the increase in salt content of soil to high levels, plant growth is adversely affected, which, in turn, decreases the productivity, of agricultural crops. The extent of reduction in growth and decrement in productivity, however, depends upon many factors such as kind and content of salt constituents, soil texture, distribution of salts in soil profile, species of crop plants grown, level of soil-water-crop management and climatic conditions. Soils, in which concentration of salts is so high as to adversely affect plant growth and crop productivity, are called salt-affected soils from agriculture point of view. The major salts which lead to the formation of salt-affected soils include chloride, sulphates, carbonates and bicarbonates of calcium, magnesium and sodium. The contents of potassium salts are generally low. Under dry arid conditions, large amounts of salts of boron, nitrates and fluorides can also accumulate. The role of these salts in soil salinization depends upon the kind of salts, their relative amounts in soil, degree of their solubility and toxicity to plants (Bajwa and Swarup, 2009).

In arid and semiarid regions of the world, salinity and sodicity is a permanent problem inherited due to climatic conditions (high temperature and low rainfall). The net movement of the water is upward. The salts dissolved in the water accumulate slowly and gradually on the surface of the soil as the water evaporates. Soil salinity increases due to capillary rise from the saline water table and concentration of irrigation water in the field. Maximum soil salinity, therefore, exists in complete desert conditions like in Chile, the Sahara, China, India, Pakistan and other countries (Zaka *et al.* 2005). These salt affected soils need special attention for their management to get higher production of crops.

Extent of salt affected soils in India

Salt- affected soils are an important ecological entity in the landscape of any arid and semi-arid region. In India nearly 9.38 million ha area is occupied by salt-affected soils out of which 5.5 million ha are saline soils (including coastal) and 3.88 million ha alkali soils (IAB 2000). These occur from Jammu & Kashmir (Ladakh region) in north to Kanyakumari in south and Andaman & Nicobar Islands in the east to Gujarat in the west (Dagar, 2005). However, widely differing estimates about the area of salt-affected soils in different states of India are found in various reports, and hence accurate data are yet to be generated. However, approximation about these areas, made by Central Soil Salinity Research Institute, Karnal, is given in **Table 1.** Most of these areas are lying barren or produce very low and uneconomical yields of various crops due to excessive accumulation of salts (Sharma *et al.*, 2004). Moreover, this area is expected to increase with spread of water logging and salinity due to increase in canal irrigation and extensive exploitation of poor quality water for agriculture in non-canal commands.

Table 1. Area of salt-affected soils in India

State	Area ('000 ha)
Andhra Pradesh	394
Bihar	85
Goa	17
Gujarat	1649
Haryana	555
Punjab	480
Jammu & Kashmir	80
Karnataka	179
Kerala	45
Madhya Pradesh	242
Maharashtra	127
Orissa	135
Rajasthan	1183
Tamil Nadu	470
Uttar Pradesh	958
Andaman & Nicobar Islands	1
Delhi	0.6
Pondicherry	0.3
Total	**7421**
Source: Sharma (1998)	

Management of salt affected soils

Development of salinity, sodicity, waterlogging and toxicity problems in soils not only deteriorates the quality and quantity of produce and limits the choice of cultivable crops, many a times the effects become so severe that lands eventually go out of cultivation. The appropriate management of the constrained soil resources for the economic agricultural production is the main emphasis in agriculture. The prominent approaches for reclamation of salt affected soils are chemical, biological and agronomic. The combination of these approaches not only increases the efficiency but also reduce the time of reclamation. The crop production and fertilizer use efficiency of these soils can be increased by integrated approach i.e. use of amendments preferably gypsum and organic/ inorganic manures which helps in maximizing and sustaining yields, improving soil health and input use efficiency.

When think of salinity management technologies we often think of chemical amendments in alkali soils, and drainage and leaching of saline soils to make hospitable environment to plant growth. These are high cost technologies. Besides the cost, availability of ample fresh water supply is a pre-requisite. Most of the salt affected areas in arid and semi-arid regions particularly in Rajasthan, Gujarat, Western Haryana and Uttar Pradesh are not so favourably situated in respect of fresh water availability. The rainfall is scanty and the evapotranspiration is very high. The only source of water in these areas is highly saline groundwater (or seawater in coastal areas). Practicing normal agriculture in such hostile environment is difficult if not impossible.

Therefore, we need excellent inventories on salt-affected soils and poor quality waters, develop cheaper options for reclamation of alkali soils through the biological route, develop and adopt preventive strategies to check waterlogging, scientific water management practices, cheaper drainage technologies, eco-friendly options for use of saline drainage water, improved technology of skimming good quality water in coastal areas, and find solutions for the problem of excess water in monsoon and deficit in winter in coastal saline soils.

Organic materials and the action of plant roots improve biological activity in soil. The decomposition of materials increases the concentration of CO_2 and organic acids in the soil which help in mobilizing Ca by dissolving calcium compounds. This can be accomplished by green manuring, incorporation of crop residues, application of FYM, pressmud and other organic materials. The effectiveness of an organic material in reclaiming alkali soils depends on the amount of CO_2 produced and reduced conditions through drop in redox potential under submerged conditions. Under field conditions, it has been observed that gypsum (50%GR), pyrite equivalent to gypsum on sulphur basis and FYM @ 30 Mg ha^{-1} were equally effective in increasing yields when a period of 30 days submergence prior to planting of rice was allowed (Swarup, 1981). The reduction in pH and ESP was, however, largest in gypsum-treated soil, followed by pyrites.

Soil of affected area should be tested for gypsum requirement (GR). However, generalized GR based on soil type and degree of sodicity is depicted in **Table 2**. Agricultural grade gypsum or phosphogypsum should be incorporated into soil @ 75% GR at least 15-30 days before planting of *kharif* crop. The treated field should be kept submerged with good quality water for facilitating reaction and subsequent leaching of by-product salts. Treated field should be planted to rice during *kharif* season followed by wheat during *rabi.* Fields with marginally alkaline pH can support a wheat crop even without treatment. However, the productivity of the crop and nutrient use efficiency will improve significantly if soil is treated with gypsum or phosphogypsum at moderate (1-1.5 t ha^{-1}) rates either in *kharif* season or before planting irrigated wheat crop. Application of gypsum to such soils at moderate rates (1-1.5 t ha^{-1}) is bound to improve nutrient use efficiency and crop productivity.

Table 2. Generalized gypsum requirement (t ha^{-1}) for reclamation of sodic soils

Soil Type	Initial exchangeable sodium (%)					
	15	**20**	**25**	**30**	**40**	**50**
Loam	0.50	1.50	2.00	3.00	5.00	6.50
Clay loam	0.75	2.00	3.35	4.50	7.00	10.00
Clay	1.00	2.75	4.50	6.00	9.50	13.00
Source: Bhatt (2011)						

Availability of micronutrients

Boron, chlorine, copper, iron, manganese, molybdenum and zinc are essential micronutrients for plant growth that are required in only small amounts of 5 to 100 mg kg^{-1} dry plant tissue. They are referred to as micronutrients, or minor or trace elements in contrast to the elements (macronutrients) required in much larger amounts. Micronutrients occur in both organic and inorganic forms in the soil. The soils whose parent materials originally contain low amounts of micronutrients are most likely to show micronutrients deficiency under acid leaching as well as under intensive cropping. Certain soil conditions induce micronutrient deficiency or toxicity to a growing crop. Micronutrient deficiencies occur on:

i) Soils with very high pH

ii) Light textured soils with low pH, developed under very high rainfall,

iii) Intensively cultivated soils receiving high analysis NPK fertilizers for growing improved crop varieties, and

iv) Organic soils.

Table3. Soil factors influencing the availability of soil micronutrients

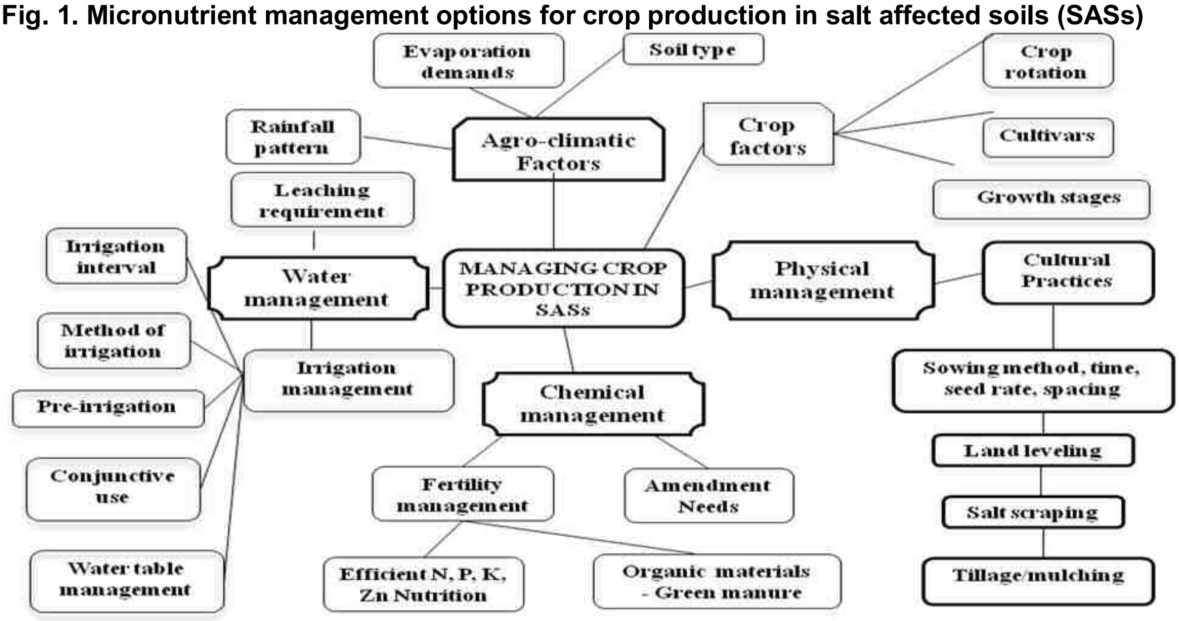
Element	Interacting soil factors	
	Essential	**Probable**
Zn	pH, lime	P
Fe	-	pH, lime
Mn	pH	Organic matter
Cu	-	Organic matter , Fe
Mo	pH	Fe, P, S
B	Texture, pH	Lime
Source: Cox and Kamprath (1972)		

The availability of micronutrients to the plant is determined by interacting soil factors such as pH, organic-matter content, clay content, presence of carbonates and partial pressure of CO_2, electrical conductivity, and by the quality and biochemistry of the water **(Table 2)**. The chemical and physical properties of salt affected soils may vary based on their origin and nature of parent materials **(Table 3)**. Saline soils can be extremely acidic as in saline acid sulfate soils and can be alkaline as in saline sodic soils, organic matter content ranges from very low to peaty, and nutrient status is equally varied. Zn deficiency is a common micronutrient disorder in all types of saline soils, while Fe toxicity is common in acid sulfate saline soils. The P deficiency is another growth-limiting factor on these soils (Neue, *et al.*1998).

Micronutrients cations are converted to their oxides or hydroxides of comparatively lower solubility in sodic and saline –sodic soil. Cations of low oxidation states of Fe, Mn and Cu are more soluble than those of higher oxidation states at normal pH range of soils. It is observed that high pH of soil favours oxidation whereas low pH conditions are favorable for the reduction. Enhanced availability of nutrients in pre-submerged FYM-treated plots has been observed; resulting in better rice growth. Excess Na on the soil-exchange complex of sodic soils causes dispersion of soil particles and intensifies soil reduction, resulting in low E_h values. Since, Fe and Mn availability is controlled largely by pH and redox equilibria, drop in E_h of sodic soils upon flooding is extremely beneficial during rice cultivation (Swarup, 1985; 1988; 1992).

A deficiency or toxicity of a particular micronutrient in plant may result from the interactions between micronutrient supply and soil chemistry. Under the waterlogged situation of rice cultivation such problems disappear mainly due to rise in soil pH. Iron toxicity in rice is observed in soils rich in Fe, under highly reducing conditions due to the presence of easily decomposable organic matter. Under such soil conditions, Fe-induced Zn-deficiency is also expected. Micronutrient cations are usually held very strongly by the organic ligands. The solubility of native forms of micronutrient cations in soils is determined by simultaneous equilibria of several competing reactions such as their surface chemical bonding, precipitation of their

Fig. 1. Micronutrient management options for crop production in salt affected soils (SASs)



solid phases and solution phase chelation of metal cations (Sinha *et al.*1978).

The presence of sufficient amount of available micronutrients in soil is not enough to provide adequate micronutrient nutrition to plants. Synergistic and antagonistic reactions are also involved in micronutrient uptake and metabolism. For example, following antagonistic effects have been well established on the uptake of micronutrients by crop:

- Excess of P adversely affects utilization of Zn, Fe and Cu
- Excess of Fe adversely affects utilization of Zn and Mn
- Excess of Zn, Mn and Cu induces Fe-deficiency in crops
- Excess of S and Cu induces Mo-deficiency in crops
- Excess of lime induces deficiency of all micronutrients

Management of micronutrients in salt affected soils

Once a deficiency is reliably identified, it can generally be corrected by chemical amendments that suit the plant demand and farmer options. The amount, form, mode and timing are critical, especially if multiple nutrient stresses and antagonisms among nutrients are present. In intensive and high production cultivation, the addition of macronutrients and often also micronutrients may be required—irrespective of soil supplying capacities and cultivar tolerance to balance high demand **(Fig.1)**.

Toxicities are more difficult to handle than nutrient deficiencies. Direct toxicity occurs when excess element is absorbed and retards physiological functions or becomes lethal to the plant. Indirect toxicity may occur through interactions—excess uptake of one nutrient may hamper the uptake, transport, and utilization of another nutrient and may result in its deficiency. Iron toxicity can be corrected by liming, drainage, prolonged submergence and organic matter amendments to remove or render Fe less available. In most cases, Fe toxicity cannot be fully remedied by soil and nutrient management, and cultivar tolerance is essential for stable and productive crop especially rice cultivation.

Swarup (1991) observed remarkable decrease in soil pH (8.9) and ESP (29) from initial values of 9.9 and 78, respectively due to application of Gypsum + FYM+ Zinc (5 mg kg^{-1}) over Gypsum + GM (*Sesbania aculeata*) and alone Gypsum application. It was observed that available DTPA-Zn content in soil increased due to application of gypsum with and without Zn. Availability of soil DTPA-Zn further increased significantly when the manure was added with gypsum and it ranged from 0.9 to 1.0 ppm. The sole application of Fe and Mn along with FYM could not increase yield of rice and wheat but their combination with Zn + FYM increased yield of rice (6.07 t/ha) significantly over control in saline soil. Dravid and Goswami (1986) noticed that under saline soil condition, addition of phosphorus minimized the reduction in Zn uptake to the extent of 44.7, 39.8 and 29.3% at 60, 90 and 120 kg P_2O_5 ha^{-1}, respectively as compared with 69.1% in no-P control mainly due to enhancement in yield.

Table 4. Soil stresses associated with salt affected soils

Stress	Soil Type			
	Saline Soils			Sodic Soil
	Coastal	Inland	Saline-Sodic	
EC (> 4 dSm^{-1})	x	x	x	√
pH (basic)	√	√	x	x
ESP (>15)	√	√	x	x
B toxicity	x		x	x
Fe toxicity	√	√	√	√
Al toxicity	√	√	√	√
Mn toxicity	√	√	√	√
H_2S toxicity	√	√	x	√
N deficiency	√	x	x	x
P deficiency	√	x	x	x
K deficiency	√	x		
Si deficiency	x	√	√	√
Zn deficiency	x	x	x	x
Fe deficiency	√	x	x	x
Low base saturation	√	√	√	√
Source: Neue and Singh (1984)				

Swarup and Singh (1990) observed that application of green manure with P application @ 12 kg ha^{-1} in wheat reduced pH (8.7), ESP (19) and increased organic carbon content (0.35%) in sodic soil over control as well as fallow practice. Singh (2010) observed that maximum decrease in pH (1.14) and ESP (31) and increase in infiltration rate (4.63 cm ha^{-1}) was recorded in treatment of deep tillage + GR-50% + Green manuring + Mustard straw @ 10 t ha^{-1} followed by deep tillage + GR-50% + Green manuring over control and other treatments.

Soil salinity may reduce Zn uptake due to stronger competition by salt cations at the root surface. External Zn application could mitigate the adverse effect the adverse effect of NaCl by inhibiting Na and/or Cl uptake or translocation. In the salt affected areas, Zn application could alleviate possible Na and Cl injury in plants. Application of $ZnSO_4$ @ 20 kg ha^{-1} helped in partial alleviation of the adverse effects of salinity on plant growth of wheat. The enhancement in economic yield of wheat per plant due to application of $ZnSO_4$ under salinity **(Table 4)** was significantly more in susceptible variety than the tolerant varieties NW 1012 and KRL 19, respectively (Singh *et al.* 2010).

Table 5. Effect of soil amendments and Zn nutrition on yield of rice

Treatment	Zn level (mg kg^{-1})	Grain Yield (g pot^{-1})	Straw Yield (g pot^{-1})
Control	0	4.5	8.0
	5	5.0	9.2
		(4.8)	(8.6)
Gypsum	0	37.1	39.0
	5	43.5	44.9
		(40.3)	(42.0)
Gypsum + Green Manure	0	45.5	46.9
	5	45.8	47.0
		(45.6)	(47.0)
Gypsum + FYM	0	48.0	48.8
	5	48.5	48.9
		(48.3)	(48.9)
Main effect mean for Zn	0	33.7	35.7
	5	35.7	37.5
LSD (P=0.05)	Treatment	2.5	3.0
	Zn	1.5	1.6
	Interaction	NS	NS
Source: Swarup, 1991			

Sodic soils occurring in Indo-Gangetic alluvial plains of northern India are characterized by high pH (>8.5) and high exchangeable sodium percentage (>15) throughout the soil profile, adverse physical properties and poor fertility status. Moderate to severe Zn deficiency in rice, especially, in high yielding varieties at 20-25 days crop growth stage, results in poor yields. Zinc deficiency, because of high pH, is expected in these soils and is one of the important factor responsible for poor plant growth. However, under submerged soil conditions of rice, pH decrease in sodic soils (Swarup, 1985) and Zn availability is likely to increase. It has been observed that unless amendments were added to these soils, no crop growth was possible in initial year. A study carried by out in such soils (Swarup, 1991) suggested that Zn application did not help in improving crop growth unless gypsum was applied **(Table 5)**. The perusal of findings revealed that green manure and farm yard manure can effectively supply Zn from the native as well as applied sources to plants in sodic soils **(Table 6)**. However, beneficial effect of Zn application to rice grown on these soils can only be realised if it is applied with gypsum.

Swarup (2000) also observed the beneficial effect of organic manure (FYM or Green Manure) when applied after mixing in the soil at half the rate of the chemical fertilizers (N_{60} P_{13} K_{21}), which also increased available Zn content of soil over chemical fertilizers alone **(Table 7)**. Polara *et al.* (2002) found that combination of FYM and Gypsum (100% GR) application noticed increase in Fe, Zn and Mn contents higher by 78, 89, and 92 respectively over control in wheat grain. In general, treatments receiving gypsum@ 75 or 100% GR coupled with leaching recorded 1.5 to 2.5 times higher nutrient uptake than that recorded under only leaching treatments. Polara *et al.* (2004) also noticed that the uptake of all the micronutrients (Fe, Zn, Mn and Cu) by fodder sorghum increased significantly with the increase in intensity of leaching with 4 L pot^{-1} to 5.32 L pot^{-1}. The residual effect of FYM (25 Mg ha^{-1}) and gypsum (100% GR) also increased micronutrients uptake by fodder sorghum.

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Singh *et al.* (2004) reported that application of Pyrites @ 2 t ha^{-1} + SPM @ 10 t ha^{-1} recorded maximum uptake of Zn (1.04 and 1.51 kg ha^{-1}), Fe (3.13 and 4.77 kg ha^{-1}) and Cu (0.35 and 0.51 kg ha^{-1}), respectively in first and second year over control. Whereas treatment with Pyrites (2 t ha^{-1}) + FYM (10t ha^{-1}) recorded highest value of Mn uptake. Bathar and Patel (2005) suggested that application of FYM @ 10 t ha^{-1} and Zn application @ 5 kg ha^{-1} brought significant improvement in Zn content in grain and straw. Sharma *et al.* (2005) reported that water stagnation in pigeon pea field for 1, 2, 4 and 6 days caused depletion in oxygen diffusion rate reduced ions uptake especially of Zn, Cu and increased absorption of Fe and Mn over no water stagnation.

Singh *et al.* (2010) reported that the balanced application of micronutrients with

Table 6. Effect of micronutrients and FYM on the grain yield of rice and wheat

Treatment ($mg\ kg^{-1}$)	FYM ($t\ ha^{-1}$)	Rice ($t\ ha^{-1}$)		Wheat ($t\ ha^{-1}$)	
		1983	1984	1982-83	1983-84
Control	0	3.92	5.28	2.10	2.01
	10	4.18	5.43	2.25	2.20
Fe_{20}	0	3.95	5.30	1.95	1.98
	10	4.25	5.50	2.15	2.25
Mn_{20}	0	3.99	5.35	2.10	2.10
	10	4.27	5.58	2.35	2.28
Zn_5	0	4.15	5.48	2.25	2.22
	10	4.46	5.68	2.40	2.39
Fe + Mn + Zn	0	4.35	5.57	2.18	2.28
	10	4.66	6.07	2.35	2.42
CD (p=0.05)	Micronutrient	0.21	0.20	0.14	0.15
	FYM	0.26	0.23	0.15	0.17

Source: Swarup (1991)

Table 7. Effect on yield and soil fertility status with different treatments in salt affected soil under Rice-Wheat System

Treatment Nutrients	Yield ($t\ ha^{-1}$)		Organic Carbon ($g\ kg^{-1}$)	Available Zn ($g\ kg^{-1}$)
	Rice	Wheat		
Control	3.25	1.36	3.0	0.75
N_{120}	4.67	3.25	3.1	0.74
$N_{120}\ P_{26}$	5.46	4.99	3.1	0.75
$N_{120}\ P_{26}K_{42}$	5.54	5.07	3.2	0.76
N_{60} P1$_3$ K_{21}	4.70	3.37	3.0	0.74
$N_{60}\ P_{13}\ K_{21}$ +GM	5.56	3.62	3.2	0.85
$N_{120}\ P_{26}\ K_{42}$ + GM	6.52	5.29	3.4	0.86
$N_{60}P_{13}K_{21}$ + FYM	5.09	3.63	3.5	0.87
$N_{120}P_{26}\ K_{42}$ + FYM	5.94	5.13	3.6	0.89
$N_{180}P_{39}K_{63}$	6.01	4.96	3.2	0.74
CD	0.55	0.48	0.3	0.11

Source: Swarup (2000)

NPKS increased uptake of Zn (229.0 g ha^{-1}) and Mn (311.1 g ha^{-1}) in potato crop over state recommendation and farmer's practice. According to Sindhu *et al*. (2007), application of organic amendments appeared to have a beneficial effect on improving the efficacy of spent wash which followed an order BC > GLM > FYM. The increase in organic carbon content, marked reduction in ESP and pH of sodic soil was observed due to spent wash application over control. In a study conducted by Shinde *et al.* (1993) on few black soils of Maharashtra, application of spent wash resulted in increased EC as well as available K content in the saturation extract of soil. Further, there was enhancement in available N, P and DTPA-extractable Fe, Mn and Zn contents in the soil after the harvest of sorghum.

Shivakant and Rajkumar (1994) opined that, gypsum @ 100 per cent GR proved significantly superior and most effective in increasing uptake of Fe, Mn and Zn and yields of rice in salt affected soil by improving soil properties. Prasad *et al.* (1982) reported that, pyrites application resulted in sharp decrease in pH and EC with marked increase in available P, K, Fe and Zn contents.

Selection of crops and cultivars

The most modern concept of micronutrient management in soil is to grow such varieties of crop which have the ability to extract the required micronutrients from insoluble sources. Such crop varieties are to be developed by combining nutrient utilization efficient varieties with those having high yield attributes by genetic engineering. A few such crop varieties are available now for cultivation in Australia and the USA without micronutrient fertilizer application. A proper choice of crops is very important considering the soil conditions and agro-climatic situations. The CSSRI has identified several promising salt-tolerant trees (both fruit and forest trees), grasses and arable crops (both conventional and non-conventional). The relative tolerance of different crops to sodicity and salinity has been evaluated. Many salt-tolerant varieties of rice (e.g. CSR 10, SCR 11, CSR 13, CSR 27 for inland situations and CST 7-1, CSR 4 and CSR 6 for coastal areas), wheat (KRL 1-4) and mustard (CS-52, CS-330) have been developed and released. Several varieties of rice for shallow and semi-deep water have been developed for coastal areas. A few important cultivars of sugarbeet, cotton, barley, tomato and linseed have been identified elsewhere for moisture and salinity stress. The efficient varieties/genotypes of some important crops have been screened out for different micronutrients under saline soil condition. These varieties are for Fe in sorghum (S 59-3); Mn in wheat (WH 542, HD 2329) and B in chickpea (DHG83-12, C235 (2), DHG83-4) as well as in pigeon pea (Da-6-4, Bahar (2), Pusa-2).

Conclusion

Higher soil pH, EC, ESP, oxidation state are the major constraints in solubilization and mobilization of the micronutrients in salt affected soil thereby reducing their availability to plants. Application of organic manure/amendments *viz.* FYM, Green manure, Bio compost etc. and industrial wastes like spent wash, press mud etc. are beneficial for amelioration of saline and saline-sodic soils. Chemical amendments like gypsum and pyrites are found beneficial in enhancing micronutrients uptake by crops in salt affected soils. Use of suitable biofertilizers in combination with fertilizers also helps in increasing availability of micronutrients in saline soils. Micronutrient fertilizers application needs to be kept at higher rate from normal recommendation in salt affected soils to manage the deficiencies of micronutrients. Micronutrient fertilizers like $ZnSO_4$, $FeSO_4$ and $MnSO_4$ can be judiciously used in conjunction with organic and chemical amendments to get higher crop yields in salt affected soils. Growing of micronutrient efficient salt tolerant varieties of different crops is more advantageous to get higher yield of crops in salt affected soils.

Future thrust

There is a need to have a fresh look on mapping of the actual area of salt affected soils in the country using advance techniques of GIS. Soil and area specific varietal screening is necessary to identify suitable crops/varieties for growing in salt affected soils. Appropriate area specific amelioration techniques needs to be developed and large scale reclamation programme should be implemented to bring the salt affected soils under normal condition. Also, breeding of micronutrient efficient varieties of crops are required for better utilization of native micronutrients. Appropriate technologies needs to be developed for increasing higher FUE in salt affected soils. The technologies of tissue culture must be evolved for suitable salt-tolerant trees and crops of high economic value. In the global climate scenario of rise in temperature and sea-level, plants tolerant to high temperature and submergence for longer period (including sea water) must be identified, collected, protected, multiplied and conserved. These must be used to evolve new varieties for such situations. Attention should also be paid on developing high yielding varieties of crops for growing in alkali soils without application of amendments.

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Impact of Soil and Crop Management Practices on Soil Microorganisms

Ramesh Chandra

Professor & Head
Department of Soil Science
G B. Pant University of Agriculture and Technology, Pantnagar -263145, Uttrakhand

Soil microorganisms play a very important role in soil fertility not only because of their ability to carry out various biochemical transformations, but also due to their importance as a source and sink for mineral nutrients. They also improve physical and chemical properties of soil. Microbes including bacteria, fungi and actinomycetes are principal decomposers of organic residues resulting into the formation of humus with the release of several plant nutrients. The microbes also produce polysaccharides that bind soil particles together and help in improving soil structure and in preventing erosion. Several groups of microorganisms have the potential to enhance the growth and health of crop plants. Among the organisms that should fit well into agricultural crop production systems are free-living, associative and symbiotic nitrogen fixers, phosphate solubilizers, mycorrhizal fungi, cellulolytic and ligninolytic microbes, plant growth promoting rhizobacteria, pathogen antagonists and hormone producers to different agriculture management practices. The present lecture deals with the response of agriculturally important microbes to different agricultural management practices.

Biological activity in soil is largely concentrated in the topsoil, the depth of which may vary form a few to 30 cm. In this soil the biological components occupy a tiny fraction (<0.5%) of the total soil volume and make up less than 10% of the total organic matter This living component of the soil organic matter consists of 5-15% of plant roots and 85-95% of soil organisms. The soil organism component contains 5-10% macro and mesofauna and 75-90% microorganisms. Soil microorganisms (predominantly bacteria and fungi) thus make up the bulk of the biomass of organisms in the soil and are responsible for 80-90% of the soils biological activity. Much of this biological activity is associated with processes, which regulate nutrient cycling and the decomposition of organic matter.

Estimation techniques

Direct estimation of microbial population by microscope is time taking and cumbersome method and does not give reliable results. Serial dilution pour plate method using specific growth medium is generally used for estimation of different microorganisms in soil. This is a simple, but also time consuming method and estimate lower population than the actual. Recently, the study of the soil microbial biomass has received much attention because of the development of number of techniques which allow it to be measured in situ, as it gives a more accurate estimate of the total soil microbial population. Soil microbial biomass may be defined as the living part of the soil organic matter excluding plant roots and soil animals larger than $5x10^3$ µm. It thus comprises the soil fungi, bacteria, algae, actinomycetes, protozoa yeast and viruses. Measurement of soil respiration is another parameter which has been widely used by microbial ecologists as an index both of microbial activity and microbial biomass. However, microbial respiration in the field is subject to enormous fluctuations. Despite this soil respiration (i.e. CO_2 evolved or O_2 consumed) coupled with total amounts of microbial biomass i.e. biomass specific respiration, has been found to be an ideal parameter to assess the microbial status of the soils. A large number of enzymes are also produced by micro-organisms, which may exist intracellularly or extracellularly in soil. Many of these enzymes have significance in nutrient transformation, but dehydrogenase, phosphatase and β-glucosidase activities have been linked with the contents of microbial biomass and amount of these enzymes in soil have been found good indicator of total microbial activity.

Soil and Crop management practices and Soil Microorganisms

Changes in environment affect both the number and kinds of soil organisms. Various agricultural management practices like tillage, cropping systems, fertilizer application cultivation practices, soil organic amendments and pesticide application alter the microbial dynamics in the agro ecosystem. Changes in soil micro flora may have an important bearing on the productivity of soil since they influence crop production by acting as catalysts for nutrient transformations.

Tillage

Conventional tillage is practiced to destroy weeds, incorporate plant residue into the plough layer, and destroy plant residues harboring plant pathogens and to provide better soil structure for easy emergence of seedlings and for proper root growth. Labile organic reserves in soil generally decrease with cultivation and cropping and therefore, microbial biomass and microbial activities have been found more in undisturbed soils. These effects of tillage are largely confined to the surface (5-10 cm) soil layer and little or no difference were observed in soil layers below the depth of ploughing. Doran (1980) reported an increase in phosphatase and dehydrogenase activities and contents of moisture and, organic C and N in the surface (0 to 7.5 cm) of no- till soil compared to conventional tillage. However, at the 7.5 to 15 cm and 15 to 30 cm depths these trends were reversed and microbial populations, enzyme activities and moisture and organic C and N contents were the same or higher for conventional tillage than for no-till soil. These differences in soil microbial population and enzyme activities are due to change in soil water content, organic C and N levels and pH. Moisture appears to be the primary factor influencing microbial populations under no till conditions. Thus conventional tillage stimulates microbial activities to a deeper soil depth than with no-till soil. Exact tillage prescription for different soils would be different. It is therefore suggested to adopt minimum tillage practices.

Crop rotation

Cropping systems influence the microbial biomass and the soil productivity to a great extent. Monoculture a practice of growing one crop year after year on the same piece of land is a result of newer innovations in the field of agriculture. This involves use of pesticides, inorganic fertilizer and generally decrease microbial biomass C. It has also been reported that rotation length, fallow substitute crops and fertilization also affect the biological properties of the soil. Soil under continuous cropping has higher biomass C and N than soil under fallow and cropping + fallow soils. These variations could be explained in terms of substrate availability. Yadav *et al*. (1977) while studying the effect of different cropping sequences on chemical and microbiological properties reported maximum total N and organic matter content under early pigeonpea-lentil-greengram rotation. However the population of bacteria was maximum under pigeon pea-maize-wheat rotation and that of fungi under maize-lentil rotation. Population of actinomycetes was not affected by different cropping sequences.

It is always advisable to grow diversified crops on the farm depending on the soil type and climate to keep soil healthy and get more profit. Apart from many other advantages this practice suppresses plant diseases and avoids build up of insect pests. Allelopathic compounds do not build up in soil as various type of rhizospheric microbe multiply and use the exudates. Legumes support more microbial population than cereals (Chandra, 1995).

Organic manures and crop residues

Manures and plant residues have a major role in maintaining soil organic matter content. Soil microorganisms grow rapidly during early phases of decomposition of plant residues and consequently some of the available soil nutrients, particularly N, P and S, get immobilized because the microbial biomass which develops on the decomposing residues needs more nutrients than are provided by the residue alone. Immediately after incorporation into the soil plant materials are subjected to the transformation and decomposition processes of the heterotrophic microflora, and as a result, the population of bacteria fungi and actinomycetes increased with application of plant residues and FYM. It was also observed that exhaustion of the available carbon led to decrease in microbial biomass.

Green manuring

One of the most beneficial crop management systems is the incorporation of a leguminous green manure crop into soil to supply N and organic matter. This practice serves as an alternative to inorganic N fertilization. The legumes used for green manuring are fast growing and have an efficient nitrogen fixing system. The significant increase in the microbial biomass, bacterial population and dehydrogenase activity due to addition of *Sesbania* green manure has been observed due to the increase in the availability of carbon and nitrogen for microorganisms. While studying the effect of summer crops and their residue on sustainability of rice – wheat cropping system in Delhi soils, it was observed that the incorporation of green manure legumes like *Sesbania rostrata* or green gram crop at 75 days of their growth recorded higher microbial activity in terms of CO_2 evolution and dehydrogenase activity in soil and microbial biomass (Tilak *et al*. 1999). Their results indicated that the microbial activities in treatments where the plant residue of green gram was incorporated was similar to that obtained after *Sesbania* green manuring and the effects were significantly higher than that obtained from summer fallow. Incorporation of green manure in terms of green gram or *Sesbania aculeata* or *S. rostrata* enhanced the bacteria fungal *Azotobacter, Azospirillum* and phosphate solubilizing bacterial population in soil over fallow.

Crop covers

A crop between major crops in a season is termed as cover crop. It is always advisable to keep the field under vegetative cover to avoid loss of soil due to erosion and nutrients due to leaching and soil loss. The cover crop also adds organic matter through rhizodeposition and leaf fall. It also supports growth and activity of varied type of soil biota. While studying the effect of summer crops and their residue on sustainability of rice – wheat cropping system in Delhi soils, it was observed that the incorporation of green manure legumes like *Sesbania rostrata* or green gram crop at 75 days of their growth recorded higher microbial activity in terms of CO_2 evolution, dehydrogenase activity and microbial biomass in soil (Tilak *et al*. 1999).

Inorganic fertilizers

Application of inorganic fertilizers is the quickest and surest way of providing plant nutrients for obtaining higher crop yields. Results of the long term experiment conducted with the application of N and P fertilizers did not show significant increase in the organic C content of soil but the total N, microbial biomass C and N increased significantly The organic carbon only slightly increased on the addition of heavy doses of N, P and K fertilizers. The total viable bacterial numbers increased with the addition of fertilizers and the highest population was detected in treatment with normal doses of NPK. However, on the other hand the continuous use of acidic or acidogenic fertilizer may causes a drop in soil pH and microbial biomass C. The effects of fertilizer applications on soil microbial biomass were due to an increase in root biomass, root exudates and crop residues thus providing increased substrate for microbial growth. Chandra *et* el (2008) observed highest population of soil microorganisms, biomass carbon and Dehydrogenase activity in rhizosphere of sugarcane and wheat fertilized with recommended NPK and residues in the form of sugarcane trash or *Sesbania* green manure. Selvi *et el.* (2004) also confirmed the similar findings in finger millet-maize-cowpea sequence at Coimbatore and reported that bacteria, fungi and actnomycetes proliferated well under continuous application of NPK and FYM. The total viable bacterial numbers increased with the addition of fertilizers and the highest population was detected in treatment with normal doses of NPK. However, on the other hand the continuous use of acidic or acidogenic fertilizer may cause a drop in soil pH and microbial biomass C. The effects of fertilizer applications on soil microbial biomass were due to an increase in root biomass, root exudates and crop residues thus providing increased substrate for microbial growth.

Application of sewage sludge

Land application of sewage sludge is becoming popular as a convenient and practically feasible method of sludge disposal. Such disposal of sewage sludge to agricultural soil helps in decreasing the inputs of inorganic fertilizers and in maintaining and/or improving soil physical properties .However, sludges often contain appreciable amounts of heavy metals, e.g. Zn, Cu, Ni, Cr, Cd and Pb. Although there is little information how sludge appliation affects soil microbes, there is conflicting evidence of both stimulation and inhibition of soil microbial activity following sludge applications. For example Frankenberger *et al.* (1983) found increased microbial activity at higher sludge loading rates (e.g. 22.2, 44.4 and 100 mg sludge g^{-1} soil) while Chander and Brookes (1993) reported adverse effects of heavy metals in sewage sludge on microbial population.

Pesticides and other Agro-chemicals

Pests are an integral part of agricultural and different chemicals are used to control them. Although, certain pesticides are not directly applied to the soil, it is the eventual sink in one way or other. There has been little progress in understanding the influences involved in soil pesticide microflora relationships. Most pesticides applied at rates approximating those used in field applications caused only slight change in population and activities of micro-organisms, however, affected soil microorganisms adversely at high rates of application. Wardle and Parkinson (1990) reported the effects of three post- emergence herbicides (2, 4-D, Picloram and glyphosate) on certain microbial variables. They concluded that the changes in microbial parameters measured as microbial numbers and soil respiration, occurred only at herbicide concentrations of much higher than that used for field application and the side effect of these chemicals were probably of little ecological significance.

Use of biofertilizers

Biofertilizers are live preparations of bacteria, fungi and blue green algae, which enhance plant growth by way of increasing the nutrient availability to crop plants through processes like fixing atmospheric N, dissolving phosphate present in soil or secreting plant hormones like IAA, cytokinin, GA etc. Although, micro-organisms applied through biofertilizers are present in the soil naturally, but some time their population is either low or ineffective. It is, therefore, advised to apply these organisms in the form of biofertilizers in the crops. The benefits of biofertilizers are usually not as visible as that of chemical fertilizers, except in some specific conditions. The increases in crop yields with biofertlizers use generally range around 10-15 % depending on organisms, soil and crop management conditions. They stimulate plant growth, activate soil biologically, restore natural soil fertility and provide protection against drought and some soil borne diseases. Different types biofertilizers added through seed or soil do their specific job and persist in soil may be in lesser number. Through continuous application of these specific microbes become indigenous population of the soil.

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Chemistry of Micronutrients Elements in Soils

G.S. Rathore

Ex-Professor & Head
Department of Soil Science & Agricultural Chemistry,
JN Krishi Vishwa Vidhyalaya, Jabalpur – 482004 (M.P.)

Chemically the fundamental property of all elements is their electronic configuration which determines chemical periodicity. Some basic chemical properties of the micronutrient elements and their electronic configurations are presented in table 1, 2, 3 & 4. The elemental properties that depend on electronic structure includes atomic and ionic radii, ionization energy, electron affinity, electronegativity, standard redox potential, valance (oxidation state), enthalpies of fusion, vaporization and sublimation, binding energy, enthalpy of solvation, ion mobility, enthalpies of compound formation and lattice energies. Many of these properties have been used by various authors to interpret the geochemical behavior of elements.

Boron (p - block element)

The group (13) elements are B, Al, Ga, In and Tl (see periodic table). Atomic size increases in this sequence. B shows little similarity to other members of the group, apart from the fundamental similarity of the outer electronic configuration ($s\,p^1$). It is the only element whose out shell vacancies out number the valance electrons without imparting metallic properties. Yet it is also not typically non metallic, because its electrons are not localized in covalent bonds in the elemental state. Therefore, B is considered to be a metalloid, as its electro negativity (2.0) is close to the border line between metallic and non-metallic elements. The quoted ionic radius for B has little meaning since B is always covalent in its compounds. The three valance electrons of B can be delocalised between 3 or 4 orbitals to form triangular sp or tetrahatral sp^3 hybrids structural units that occur in all the common borate minerals. Since B has the ability to accept on electron pair, it is a weak Lewis acid. Crystal chemistry of borates is generally similar to that of silicates and can substitute for Si in silicates and aluminositicates.

Manganese, Iron, Copper and Molybdenum (d-block transitional elements)

Manganese, iron, copper, zinc and Mo all have electronic configuration involving 3d and in case of Mo 4d orbitals. All except Zn have incomplete d orbitals and are correctly transitional elements (i.e. show characteristic of multiple oxidation state). Zinc with its complete $3d^{10}$ 4s outer electron configuration is not a transitional element, and invariable shows an oxidation state of II in its compounds.

The highest valency exhibited by an element in the first transition series is equal to the sum of all 3d and 4s electrons. This state does not exist for Fe and Cu and for Mn the VII oxidation state is not found in nature. High oxidation states decrease in stability from left to the right in the series. Increasing oxidation number makes the oxids of an elements increasing acidic, while halides become more covalent and susceptible to hydrolysis. For oxy-anions, the higher valence states (i.e. grater than III) are characterized by tetrahedral coordination, with oxides formed in lower valence state having octahedrally coordinated atoms. Complexes in aqueous solutions or in crystal structures. With 4, 5 or 6 coordinated cations are found for state (II) and (III). Oxidation state (I) is only found in nature for Cu. All three elements (Mn, Fe, Cu) form aquous ions of the type $[M(6H_2O)_6]^{2+}$.

In the second transition series in which Mo is present the lower oxidation states are generally less stable, and higher oxidation states are more stable than the equivalent elements in the first series. For example, Mo (III) is relatively unimportant in the chemistry of that element, whereas the trivalent state plays a great role in the chemistry of Cr. By contrast, Mo (VI) is very stable, particularly as the MoO_4^{2-} ion which unlike the first row ions CrO_4^{2-} and MnO_4^- is not a powerful oxidizer and so has a quite a diverse chemistry.

Zinc (d-block transitional element)

Elements of this group, Zn, Cd, and Hg have a $d^{10}s$ outer electronic configuration. By mobilization of the two s electrons, all can achieve the oxidation state (II). In addition Hg(I) exists. Because of the stability of the filled d shell, these elements show few of the characteristics of transition elements.

Zinc has much greater similarity with the Mg because the two have isomorphous compounds. However, Zn is more covalent than Mg (electro negativity of Zn = 1.8 and Mg = 1.2).

The Zn (II) forms mainly tetrahedral complexes e.g. [Zn $(H_2O)_4^{2+}$].

Natural occurrence of micronutrient elements in earth crust, rocks and soils

Chemical composition of the earth crush consists 46.6%, oxygen 27.7%, silicon 8.1%, aluminum 5.0%, iron, 2.1%, magnesium 3.6%, calcium 2.8%, sodium 2.6%, potassium and 1.5% other trace elements on weight basis. On the volume basis oxygen occupies 89.8%, silicon 2.4% and 7.8% is occupied by the remaining elements in the earth crust.

The abundance of micronutrient elements in earth crust, rocks, minerals and soils is described in table 5 and 6.

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Efficient Recycling of Organic By-Products from Agro-Industries for Sustainable Crop Production

Mohan Singh

Principal Scientist
Indian Institute of Pulses Research, Kanpur (U.P.)

Abstract

Agro-industries are playing pivotal role in the transformation of rural economy. Adding value to the farm produce through processing results into the generation of several by-products often termed as wastes. These are in fact misplaced resources containing valuable plant nutrients and precious organic matter essentially required for the improvement of soil quality and nutrient supply potential. Presently these wastes are either dumped in pits or heaped on soil surface causing serious environmental pollution. Composting technologies provides opportunity to transform these wastes into valuable marketable produce. The present paper discusses some of the wastes generated by agro-industries and their use for the production of quality compost for use in crop production.

Agro-industries, like sugar, dairy and milk processing units, eggs and boiler production houses etc. are vital for value additions to the farm produce. Presently, much emphasis both by government and private sector is given to the development of industries utilizing farm produce as raw materials. This sector is playing pivotal role in transforming rural economy as well. In recent years, some environmental concerns have however, emerged out due to unscientific disposal of the by product or the so called “wastes” of these agro-industries.

Increased demands for the processed food have increased scale of production several folds. A sugar industry with 8000-12000 TPD (Tones per day cane crushing) is more economical compared to 2500-5000 TPD. Likewise, a dairy with 100 to 200 milking cattle is operated more economically compared to small holdings of 10 to 20 cattle. A poultry farm with 20000 to 50000 birds is a common feature in the poultry industry. Even farm with more than 50,000 birds are not uncommon in some part of the country. Fruit and vegetable industry is fast progressing in different parts of India. Under such scenario, agro-industries not only produce marketable products but also generate sizeable amounts of biodegradable wastes containing valuable plant nutrients embedded in organic matter. For example, in sugar mills, sugarcane processing results into the generation of molasses, press mud, bagasse, ash and large volumes of effluents beside the main product sugar which is hardly 8-9% of the cane weight. Remaining 90% of the cane weight emerges out as either solid or liquid wastes. Furthermore, sugar, the main product of the cane processing contains only carbon, hydrogen and oxygen (CHO). Prior to the development of industrial alcohol production, molasses was a waste of sugar industry. Now days even bagasse is a precious raw material for electricity production or paper making. Therefore, once a by-product may be considered as “wastes” of the industry but with the advancement in technology it can be utilized for some economic activity which is environment friendly.

Wastes are therefore an integral part of the value addition cycles operative in different industries and are **defined as misplaced natural resources.** For sustainable development of agriculture, it is therefore essential that all the plant nutrients embedded into the wastes of the agro-industries are effectively recycled into the farm production system. Efficient wastes management strategies are highly industry specific due to diverse nature and composition of wastes. Even presence of harmful metals and xenobiotic substances demands for adoption of specific processes of their treatment before utilization in fields for crop production. Normally, volume reductions with incremental enhancement in their nutrient supplying potential coupled with reduction in its potential adverse effects on soil quality are the major objectives for adopting the technology of agro-industrial wastes recycling in agriculture. Some times, wastes of two or more industries are mixed together to take complementary advantages for the production of a marketable produce. Fly ash of thermal plants is mixed with sludge or solid wastes of fermentation industry to produce enriched compost of higher nutrient content (Christopher *et al*. 2001). Spent wash, a liquid waste of distillery is mixed with the press mud of sugar mill to produce enriched compost (Pandey and Sinha, 1995). There are number of similar processes generally termed as “Co-composting” wherein two or more wastes are composted together to produce quality compost. This compost has potential to supplement nutrients demands in agriculture for different crops and economical to adopt the process. If agricultural activities are to remain sustainable, recycling of nutrients and organic matter in agro-industrial wastes must therefore occupy the central position while developing the nutrient supplying systems for crops in areas where agro-industries are concentrated. There is however an urgent needs to make **paradigm shift in the policy of "wastes disposal" being recommended by regulatory bodies to different industries**. Wastes utilization rather than disposal should be the thrust area.

Efficient utilization of agro-industrial wastes offers several direct and indirect benefits. In short term, direct benefits may not be attractive economically but in long term indirect benefits in terms of improvement in quality of land and water resources would make the economic advantages more attractive. Long term beneficial utilization of industrial wastes depends on greater understanding of the nature and characteristic of wastes and scientific evaluation of the possible impact on soil quality traits and improvement in crop yields. The present paper outlines the potential availability of wastes from different agro-industries, their characteristic and also proposes some of the appropriate technologies for their transformation into marketable produce.

Agro-industries by-products:

Dairy and poultry are important agro-industries in rural areas producing considerable amounts of wastes. In addition several other organized sectors such as sugar industry, fruits and vegetables processing, leather industry etc. are some of the promising agro-based industries operating at different scales and generating bio-degradable wastes of diverse nature and variable quantity. These wastes are required to be processed through technologies that do not pollute the environment. Despite strict pollution control measures enforced by Government agencies, number of agro-based industries seldom processes these by-products and either stores them as heap in open areas or pits or disposes them in water bodies. Thus, agro-industrial wastes are posing serious threat to the environment.

Dairy Industry

Under intensive farming, confined animal operations with inadequate land base are quit common. Indian dairy industry is presently producing 70 million tons of milk per annum. Co-operative movement in dairy industry has been very successful with the establishment of large and small-scale dairy farms with livestock density from 30 to 100 cattle heads per farm. Most of these farms store cattle dung and other wastes in pits or pile up in open areas.

Improper storage and handling of wastes either in pits or low lying areas results in considerable losses of nutrients either through leaching or volatilization of NH_3 and denitrfication. Studies have shown the soil, air and water pollution due to unscientific methods of wastes disposal (Dalal *et al*. 2009). All these wastes, if treated properly through technologies like advance methods of composting or co-composting have potential to improve the supply of the quality compost for use in agriculture. This will make significant changes in the transformation of a potential polluter industry to a producer of quality input for agriculture. Regular use of organic rich materials would not only bridge the gap between demands and supply of different plant nutrient but effectively control the degradation of soil and water bodies.

Poultry industry

Poultry industry is an important agro-industry in India. Indian poultry industry, in the last 30 years has emerged as strong, dynamic and fastest growing sector in agriculture. Presently Indian poultry industry is fifth largest in the world producing 34 billion eggs and 9th in poultry meat production. Poultry industry generates number of wastes in quite large amounts with high nutrients content. It is estimated that about 2.3 million tones of poultry liter is produced in the Indo-Gangatic Region of India alone. Poultry litter has low N/P ratio and therefore 45-65% of total nitrogen is readily mineralized within 60-90 days after incorporation into the soil. Composting of poultry litter with crop residue of high C:N ratio and addition of minerals such as rock-phosphate and pyrites however helps to conserve the nitrogen content by lowering the volatilization losses of nitrogen as NH_3 during the composting process(Table 1).

Table 1. Organic matter and nitrogen losses during composting of poultry wastes

Treatment	% loss OM		% loss of N	
	30 days	120 days	30 days	120 days
Poultry waste (PW)	33.94	70.85	34.75	66.98
PW + RP + Pyrite	41.25	65.60	28.25	43.06
PW + Paddy Straw (PS) (1:1)	56.87	77.18	47.61	65.43
PW + PS + RP + Pyrite	36.15	63.47	19.36	33.42
PW + PS (1:4)	51.17	67.84	37.25	50.55
PW + PS (1:4) + RP + Pyrite	47.12	65.85	23.82	30.65

RP = Rock phosphate

High temperature during the composting process also inactivates the pathogens normally reported to be present as contaminants in the litter. Beneficial effects of poultry litter application in fields or its use after composting is well documented (Preusch *et al.* 2002). Singh *et al.* (2009) reported that field application of poultry litter @ 5Mg h^{-1} along with fertilizer N (40 kg h^{-1}) increased rice yield and nutrient uptake equivalent to the application of the recommended doses of NPK (120-26-25) in the rice-wheat cropping sequence in the sandy loam soils (Table 2). The residual effect in wheat was equivalent to the 30 kg N h^{-1} and 13 kg P h^{-1}. It was further observed that after three annual cropping cycles and poultry litter application, mean soil organic carbon increased by 17%, Oleson's P by 73% and K by 24%.

Table 2. Effect of Poultry liter (5Mg/h) on grain yields of rice and wheat

Crops		Rice Yield (q/h)			WheatYield (q/h)		
Rice	Wheat	1st yr	2nd yr	3rd yr	1st yr	2nd yr	3rd yr
Control	Control	43.7	42.8	36.2	16.8	18.9	21.3
N_{120} P_0	N_{120} P_{26}	61.6	68.7	57.3	42.6	41.8	55.9
$PL_5N_0P_0$	N_0P_0	53.0	59.8	48.2	18.7	21.1	25.1
$PL_5N_{60}P_0$	N_0P_0	63.7	70.0	58.8	42.0	38.4	49.5
$PL_5N_{60}P_0$	$N_{90}P_{13}$	63.5	71.2	62.7	41.0	40.5	56.3
$PL_5N_{60}P_0$	N_{90}P26	67.6	71.6	64.3	40.3	41.6	53.7
$PL_5N_{40}P_0$	$N_{90}P_{13}$	64.8	71.1	62.4	40.6	41.0	55.9

There was a positive balance of 44 kg P h^{-1} y^{-1} on annual application of poultry litter @ 5 Mg h^{-1} in rice-wheat sequence. The long term impact of this practice on produce quality and biodiversity of soil biota has however not been evaluated in details (Acosta and Harmel, 2006). Poultry litter contains both pathogenic microorganisms and metals. Effect of direct application of poultry litter on quality of produce as well as soil is little understood and need to be assessed on long term basis before recommending direct application of poultry litter in fields.

Co-composting of poultry liter with crop residues to produce quality compost

Poultry wastes contain droppings of birds and bedding materials rich in nitrogenous compounds. Significant losses ranging between 40-60% of initial N content have been reported during storage, handling and application of poultry wastes in the fields (Brinson *et al.* 1994). Therefore, co-composting of poultry wastes with farm residues and mineral additives like rock phosphate and pyrite provides an opportunity to reduce volatilization losses of nitrogen and produces nutrient rich compost.

Poultry wastes mixed with rice straw (in the ratios: 1: 4 w/w) were composted with and without additions of rock phosphate (12.5%) and pyrite (10%). This mixture of poultry wastes and rice straw was mixed with cattle dung, mature compost and soil in the ratio of 8:1:0.5:0.5 before placement inside the pit. Moisture was adjusted between 60-75% WHC by addition of water. Material was mixed intermittently during composting at an interval of 15 days with moisture adjustment between 60-75%. Temperature builds up rapidly inside the pit. Cumulative loss of organic matter within 120 days period ranged between 65 to 77%. Composting of poultry waste alone with initial N content ranging between 1.98 and 2.31% resulted in maximum N losses of 67% of its initial content within 120 days. Mixing of poultry waste with rock- phosphate and pyrites (10%) lowered N losses from 67% to 43% (Table 1). Mixing of poultry wastes with rice straw in the ratio of 1 :4 (w/w) also helped in conserving the nitrogen by reducing N losses. Mixing poultry wastes with rice straw (1:4 w/w) and addition of rock phosphate (12.5%) and pyrite (10%) was most beneficial in controlling N losses during composting. N losses decreased from 67% to 30% due to amendment with rice straw, pyrite and rock-phosphate. The composition of nutrient in the manure at the end of composting period showed that C: N ratio and N content of manure prepared after mixing rice straw (1:4 w/w), rock phosphate and pyrite were 15 and 2.0% compared to 17.0 and 1.85% in the compost made out of poultry wastes alone (Table 3).

Table 3. Chemical composition of enriched compost prepared from rice crop residues and poultry litter

Treatments	C (%)	N (%)
Poultry waste (PW)	31.5	1.85
PW + Rock phosphate (12.5% w/w) + Pyrites (10% w/w)	32.5	2.46
PW + Rice residues + Water hyacinth (1:2:2)	31.5	1.75
PW + Rice residues + Water hyacinth (1:2:2)+ Rock phosphate (12.5% w/w) + Pyrites (10% w/w)	30.5	2.15

Poultry waste with rice straw and water hyacinth

Mixing poultry wastes with rice residues and water hyacinth in the ratios of 1:0.5:0.5 or 1:2:2 also helped in conserving the nutrients. Compost prepared from poultry wastes, rice residues and water hyacinth along with amendment with rock phosphate and pyrite was rich in nitrogen, phosphorus and citrate soluble P.

Sugarcane trash

Poultry wastes mixed with sugarcane trash in the ratios of 1:4 (w/w) and mineral additives like rock phosphate (12.5%) and pyrite (10% w/w) produced compost of higher nutritive values. Poultry waste mixed with trash (1:4) and with additions of rock phosphate and pyrite produced manure containing N, 0.97%, P2O5, 4.0% with C:N ratio 29.0. Addition of pyrite to the poultry waste however produced manure with higher N, 1.95%, P2O5, 8% and C:N ratio 24.

Beneficial effects of these nutrients rich compost have been observed in number of crops. Normally, phosphorus requirements of the crops are fulfilled 100% by using such nutrients rich compost along with 25% reduction in the use of nitrogen fertilizers.

Plantation crops

Plantation and spices crops are important commercial crops grown in Assam, Kerala, Karnataka, Tamil Nadu and West Bengal. Large quantities of biodegradable wastes viz. coir dust, husk, dried leaves, prunings, coffee husk, tea wastes, oil palm wastes, etc. are available for recycling of organic matter and nutrients. Recycling of these wastes after composting has potential to supplement the nutrients requirements of crops. Nair *et al*. (1997) reported that 165 thousand t of N + P_2O_5+ K_2O can be supplied through wastes of plantations crops.

Very large quantities of wastes and organic materials are also generated from the processing of palm oil and rubber. These biodegradable wastes are rich in nitrogen and contains 1,194 mg N/l with solid contents of 67,000 mg/l. The soil-plant system is effective in removing N in the effluent. Results from field monitoring also indicated little to nil groundwater contamination from the application of moderate amounts of rubber effluent. Uncontrolled application could, however result in excessive amounts of the effluent being leached into the groundwater and in surface runoff. Mulching with pruning and wastes of plantation crops at a rate of up to 40 t ha^{-1} has improved oil palm growth and yields. Yield increase due to mulching exceeds the effects of fertilizers alone. In cocoa and coconuts, the principal waste materials are the cocoa pods and coconuts husks and recycling of these nutrient rich materials in the fields is also beneficial to the crops.

Fruits and Vegetables

India produces around 33.0 million tones of fruits and 50 million tones of vegetables annually. It is estimated that roughly 10 to 15 per cent of total produce is available either as residues or biodegradable wastes for recycling in agriculture. In addition, fruits and vegetables processing results in the production of around 5.0 million tones of solid wastes. Most of these wastes are lignocellulosic in nature and contain macro and micro-nutrients. Tomato processing wastes are rich in hemicellulose and proteins. All these are biodegradable and have potential to supply organic matter and nutrients in agriculture after composting.

Leather Industry

The vast cattle population in India provides sufficient raw materials for the leather industry. There are roughly 3000 tanneries processing about 6000 tones of hides and skins annually. Large amount of solid and liquid wastes are generated in tanneries containing heavy metals as well as plant nutrients. Solid wastes contain very high concentration of nitrogen because of protein (> 40%), lipids and carbohydrate contents. It is estimated that about 0.1 million tones of solid wastes are generated in tanneries annually. Co-composting of these solid wastes with crop residues of high C:N ratio could provide good quality compost for use in agriculture. Problems of heavy metals associated with leather industry wastes could be effectively managed through co-composting and bioremediation.

Fermentation and Pharmaceutical Industry wastes

India has made rapid progress in the production of drugs and other chemicals using fermentation processes of different substrates. After production of useful products, the left out materials contain large amount of organic matter and minerals in solid and liquid form. It is estimated that with one Kg of antibiotic produced through fermentation, there is generation of around 7000 to 8000 litter of waste water with solid content ranging between 40000 to 50000 mg/l and BOD load of about 30000 to 60000 mg/l. This waste water also contains around 2-6% N (Dry weight basis) beside nutrients essentially required for plant growth. Presently this water is subjected to wastes water treatment plants and discharged in sewage water. Judicious use of this waste water for enriching the compost prepared from crop residues and city wastes could enhance the manurial value of the compost.

Sugar Industry Wastes

Sugar industry is one among the largest agro-industry in India. Presently over 448 sugar mills and 283 distilleries are working in different parts of the country. The products of this industry are sugar and alcohol. Both the products contain only carbon, oxygen and hydrogen. Thus entire nutrients harvested in the form of sugarcane ultimately find their way into wastes, either solid or liquid. Solid wastes of sugar mills are press mud and bagasse. They are produced in very large quantities. Press mud is a low density, soft, amorphous waste containing sugars, fibers, wax and minerals. It contains N, 1-2%; P,1.0-2.0% and K, 0.3-1.8% (dry wt. Basis). Bagasse is another solid waste produced in sugar industry. This is primarily used as captive fuel for generation of electric energy and as raw material for paper industry. Ash produced after burning the bagasse in furnaces also contains N, 0.06%; P_2O_5, 0.9% and K_2O, 1.0%. Unlike coal ash of thermal power stations, bagasse ash is free from heavy metals. In 2001 bagasse ash production in India was at the level of 6.0 lac tones. At the present level of ash production, there is a possibility of providing around 5 thousand tones of phosphorus and 4 thousand tones of potassium for agriculture through use of bagasse ash alone.

Liquid wastes

Sugar industry liquid wastes are of two distinct types. One produced during processing of cane and other produced during fermentation of molasses for alcohol production. A sugar mill with 5000 TCD capacity generates around 2500 M^3 of effluent per day. This effluent contains biodegradable organic carbon and minerals. These substances contribute towards high BOD and COD load of effluent. Organic load in effluent is due to sugars and other biodegradable materials. Besides these organic substances, it also contains nitrogen phosphorus; potassium and other minerals. Therefore, it is safe to use in agriculture for increasing the availability of nutrients and organic matter. Use of sugar mill effluent for composting of solid wastes will not only make available water and nutrient but also conserve the natural resources.

Distillery effluent

Alcohol production from molasses results in the production of effluent with very high BOD and COD load and minerals. It is called as spent wash or distillery effluent. About 16 litters of effluent are produced for each litter of alcohol produced from molasses. Production of spent wash will increase with the increase in the alcohol production. Spent wash contains organic matter and minerals like nitrogen, potassium and sulphur etc. It has potential to supply around 61 thousand tones of nitrogen and 52 thousand tones of potassium. Spent wash is used in composting f crop residues and other solid wastes like press mud for the production of nutrient rich compost (Table 4).

Table 4. Nutrient composition of manure produced through co-composting of crop residues with spent wash

Treatments	(mg g^{-1})			C:N	Mineral-N (mg kg^{-1})
	N	P_2O_5	K_2O		
Crop residue	9.4	3.1	5.6	22.8	36.0
Crop residue + spent wash	12.6	3.8	16.0	16.0	52.2
Crop residue + spent wash + R.P. + Pyrite	14.4	35.0	13.0	13.0	56.5
Mustard crop residue	9.0	2.8	23.4	23.4	29.9
Mustard crop residue + spent wash	12.1	3.5	16.6	16.6	45.4
Mustard crop residue + spent wash + R.P. + Pyrite	14.3	33.9	13.0	13.0	48.0
C.D at 5%	1.5	0.5	7.5	-	1.5

Co-composting of spent wash, crop residues, rock-phosphate and pyrites results into the production of compost with N, 1.5%; P_2O_5, 3.5% and K_2O, 1.3%.

All these agro-industries wastes are in fact the store house of plant nutrients and valuable organic matter essential for the maintenance of soil health and quality. These wastes can be transformed into a marketable produce through the process of co-composting.

Composting

Composting is an age-old practice for the conversion of biodegradable wastes into manures. This waste management option is currently preferred over burning and dumping in landfill sites. Composting provides multiple benefits to the society compared to other alternatives like burning, dumping in land fill areas or direct application in the localized areas.

This is a microbial process where a community of microorganisms comprising of bacteria, fungi, actinomycetes and yeast decompose the organic materials and synthesize a highly stable product called humus. A succession of microbial growth and activity among the bacteria, fungi, actinomycetes, yeasts etc. take place during the process, whereby the environment created by one community invites the activity of successor group. Different types of microorganisms are therefore active at different time & site in the decomposing materials depending upon the characteristics of food materials available, oxygen supply and moisture content.

Composting methods developed for waste management aims to

- ❖ Reduction in volume and stabilization of bio-degradable components in wastes
- ❖ A product free from pathogen, weeds and disease producing microorganisms.
- ❖ Elimination of environmental pollution through odors gases, leachates & bio-aerosols.
- ❖ A value added product with multiple uses in agriculture, land sapping, bioremediation etc.

These objectives are achieved satisfactorily through composting of wastes under aerobic conditions. In some case, anerobic composting methods like methanogenesis is combined with aerobic methods to handle large volumes of liquid wastes and extract the energy from the process.

Composting process utilized for waste management is therefore generally defined as "**The biological decomposition and stabilization of organic substances, under**

conditions that allow development of thermophillic temperatures as a result of biologically produced heat, to produce a final product that is stable, free of pathogens and plant seeds, and can be beneficially applied to land". Development of thermophilic temperature (60-65^{o}C) as a result of biologically produced heat sanitizes the material. Generations of odorous compounds and leachates are also minimized under aerobic composting.

Aerobic composting process under different methods/ technologies has two distinct stages of high significance

1. Thermophilic stage (Sanitization)
2. Mesophilic stage (Decomposition)

Thermophilic (60-65^{o}C):

This is the first phase of composting wherein microorganisms decompose the easily degradable organic substances producing heat as a result of intense metabolic activity. Temperature rises from 30-35^{o}C to 55-60^{o}C within 2-7 days depending upon the air supply, moisture content, windrow dimensions and chemical characteristics of waste. In majority of cases with moisture content between 55-60% and air space between 20-30% in the windrow, a temperature rise from 35^{o}C to 55-60^{o}C is achieved within 2-3 days. The population and microbial species community involved during thermophilic stage are distinct and mainly comprised of thermotolerant fungi and thermophilic bacteria and actinomycetes.

Mesophilic stage (30-45^{o}C):

The thermophilic stage is followed by second stage of active biodegradation. During this second stage of composting, the pool size of readily available carbon and nutrients sources become limiting for growth & activity of microorganisms, causing a decline in heat output. A rapid transition from thermophilic to mesophilic stage leads to a shift in the population and species composition of microorganisms. The compost materials become dark brown during this stage due to humus synthesis. A stabilized product as a result of intense microbial metabolic activity is produced during this stage.

Curing Stage:

This is very important phase in composting process. Microbial population and species diversity involved in degradation of complex polymers such as cellulose, lignin, hemicelluloses etc. increase strongly during this phase. The microbial population at this stage varies from 10^{8}-10^{9} cells/g materials. Bacteria represent 80% of this population. Most of the population is involved in the C-cycle through proteolytic, ammonifying, amylolytic and aerobic cellulolytic activities. Free-living N-fixing, denitrifiers, sulfate reducers and sulfur oxidizers are also important constituent of the total microbial population active during curing stage. Microbial mediated degradation and synthesis process operating during the curing stage finally results into production of stable and mature compost.

Factors Influencing Composting Process: The major factors are: 1. Air supply, 2. Moisture content, 3. Particle size of waste, 4. Temperature, 5. Acidity/Alkalinity, 6. Chemical characteristics

Air supply:

Composting process requires adequate supply of oxygen for bio-degradation activity by microorganisms. Under aerobic conditions decomposition rate is much faster than under limited oxygen supply or anaerobic conditions. Anaerobic conditions stimulate generation and release of odorous compounds from the decomposing materials. Anaerobic conditions are normally created due to utilization of oxygen present in air spaces within the pile by microorganisms and production of CO_2 during the decomposition. As the O_2 concentration falls below 5-10% in the air space compared to the 21% in air outside, the anaerobic microorganisms starts building up their population and results in foul smell. Oxygen level in air spaces is maintained within the windrow through turning & mixing at regular intervals. Oxygen requirement during composting however varies depending upon stage of composting, particle size of wastes and moisture content in wastes.

Moisture:

This parameter is most vital for optimization of composting process and rate. It is related to number of other important parameters such as air supply and exchange of gases, temperature buildup and growth & activity of microorganisms. Moisture content in decomposable materials is maintained between 55-60% for the maximum growth and activity of microorganisms. If moisture level drops below 40%, microbial growth and activity decline considerably. Moisture content below 20% restricts the decomposition process due to decline in microbial activity. Moisture content >60% tends to reduce air filled spaces inside the pile and anaerobic conditions are build up. This also results in production of leachates in high amounts.

Temperature:

Temperature is most critical parameter for sanitization, degradation and stabilization of organic matter during composting. Temperature between 55-65^{o}C is best for sanitization of wastes such as USW and agro-industrial wastes. At these temperature diseases producing microorganisms are killed and weeds are destroyed. A rise in temperature >70^{o}C inhibits the microbial growth and restrict species diversity and overall decomposition rate (Riddech *et al*. 2002).

The temperature at which decomposition rate is maximum during composting is between 35-45^{o}C. Temperature maintenance within the windrow is regulated by frequency of turning and mixing. Turning frequency is adjusted such that thermophilic range is maintained for a minimum duration of 15 days. Thereafter the temperature is maintained between 35-45^{o}C for accelerating decomposition by mesophilic group of microorganisms.

Other parameters:

The pH, particle size of the decomposable materials, N content and C:N ratio in wastes are also important parameters regulating composting. High N content (>2.0%) usually results in greater N losses through volatilization of NH_4 during composting. A C:N ratio between 25-30 is suitable for maximum growth & activity of most of the decomposing microorganisms involved in the process of composting. It must however be noted that moisture, aeration and temperature are most critical parameters regulating the rate of decomposition during composting process. To accelerate the rate and reduce the days for stabilization of the organic matter, these three parameter needs to be monitored and maintained during active stages of materials sanitization and decomposition.

Conclusion

Agro-industries are vital for value addition to the farm produce and for improving the rural economy. Numbers of by-products during the processing of the farm produce are generated in agro-industries that are presently classified as wastes. In fact these are misplaced resources of economical values. Large numbers of plant nutrients are embedded in the precious organic matter that is biodegradable. Composting helps in transformation of these biodegradable wastes into quality compost containing plant nutrients and good quality humus. Both the constituents of the compost are essential for the sustainable crop production.

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Technology for Nutrient Enrichment of Compost and Improvement in its Quality

Mohan Singh

Principal Scientist
Indian Institute of Pulses Research, Kanpur (U. P.)

Abstract

Composting is an age old and environment friendly technology adopted worldwide for transforming biodegradable wastes into a marketable product termed as compost. Enrichment of compost is aimed to increase its nutrient supply potential in agriculture. It ensures a regular generation of revenue by converting wastes into a value added marketable product of definite quality.

Composting is a natural process in which several micro and macro-organism works in a cooperative manner to breakdown complex organo-mineral compounds such as lingo-cellulose complex present in wide range of organic wastes. During this decomposition process nutrient are mineralized and become readily available for plant growth.

Compost enrichment technologies worked on the principal of co-composting two or more wastes materials of agriculture or agro-industrial by products. The present paper discusses the importance of enrichment technology for improving the compost quality and its beneficial effects on crop growth.

1. Introduction

Compost, manures and organic fertilizers are now being recommended and also utilized widely for increases crop productivity and improves soil and environmental quality. Compost availability has increased in recent times due to large-scale conversion of farm, agro-industrial and urban wastes into compost. The term compost is generally used interchangeably with manures and organic fertilizers. **Compost could be manure but all manures are not compost. Similarly, compost could be organic fertilizer but all organic fertilizers are not compost**.

Compost is a product of a decomposition process in which thermophilic phase sanitizes the materials and produce a product of predetermined quality. **Compost is always free from weeds and diseases causing microorganisms whereas a manure or FYM may be contaminated with weeds and plant disease causing microorganisms**. Enrichment of compost for increasing the nutrient content has always been of great interest for their well known advantages of economizing the fertilizer uses in agriculture. Mining wastes including certain low quality ores such as rock-phosphate are used to increase phosphorus content in the compost. Similarly other wastes of agro-industries such as spent wash, press mud, poultry wastes etc. are also co-composted with farm wastes for increasing the nutrient supplying potential of the compost. The present paper discusses the technology available for enriching the compost with nutrients and increasing its quality.

2. What is Compost?

Compost is a brown to near black humus like material, which is biologically stable, easier to handle than manure and other organic sources, free from weeds and diseases causing microorganisms, stores well and odor-free product of economic importance. **The process of conversion of biodegradable wastes into such end product is termed as composting (Fig 1)**.

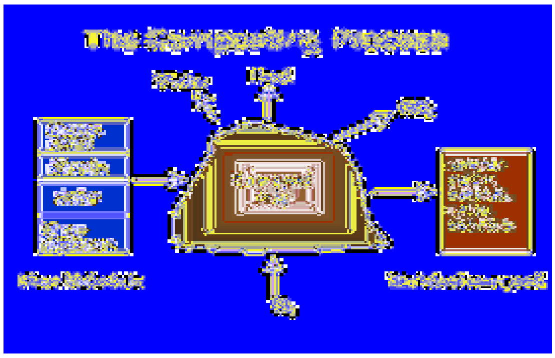


Fig.1 The composting Process

In order to develop large scale commercial composting plants and for maximization of the rate of composting process as a whole, a definition widely utilized for maximization of composting process has been accepted world wide. It defines composting as **a biological decomposition and stabilization of organic matter in wastes, under conditions that allow development of thermophilic temperature (55^0 – 65^0 C) for a minimum duration of 3-4 weeks as a result of biologically produced heat to sanitize the material and minimize the generation of odorous compounds and leachates and leads to a final product that is stable, free of**

pathogens and plant seeds, and can be beneficially applied to land.

3. Principles of Composting Process

Composting is a highly complex biodegradable process carried out by a diverse group of microorganisms capable of degrading simple and complex organic substances. A succession of microbial growth and activity among the bacteria, fungi, actinomycetes, yeasts etc. takes place during the process, whereby the environment created by one community invites the activity of successor group. Different types of microorganisms are therefore active at different time & site in the composting mixture depending upon the food materials availability, oxygen supply and moisture content in the decomposable materials.

The decomposing materials during composting pass through two distinct stages of high significance (Fig. 2).

- Thermophilic stage (Sanitization)
- Mesophilic stage (Decomposition)

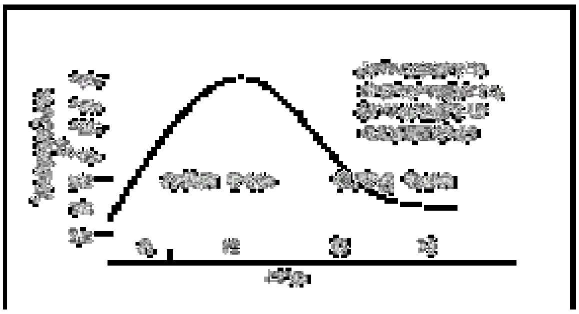


Fig. 2 Temperature changes during composting process

3.1 Thermophilic

This phase of composting starts immediately after windrow or pile formation. Microorganisms' growth and activity increases utilizing easily degradable organic substances. Metabolic heat produced as a result of intense metabolic activity increases the pile temperature. Temperature rises from 30-35^{o}C to 55-60^{o}C within 2-7 days depending upon the air supply, moisture content, windrow dimensions and chemical characteristics of wastes.

3.2 Mesophilic

This stage of composting is real stage of decomposition of complex organo-molecules like lingo-cellulose complex. A rapid transition from thermophilic to mesophilic stage leads to a shift in the population and species composition of microorganisms. A diverse group of microbial decomposition process operates during this stage leading to the production of dark brown humus like materials and compost gets stabilized.

The curing stage or compost maturation is another important stage in which degradation of complex polymers such as cellulose; lignin, hemicelluloses etc increase drastically. The microbial population at this stage varies from 10^{8}-10^{9} cells/g wastes. Bacteria represent 80% of this population. Most of the population involved in the C-cycle had proteolytic, ammonifying, amylolytic and aerobic cellulolytic capacities. Free-living N-fixing, denitrifiers, sulfate reducers and sulfur oxidizers are important constituent of the total microbial population. A large variety of microbial mediated degradation and synthesis process operate during the maturity phase.

4. Compost Enrichment Technology

Feedstock utilized for compost preparation is most critical input determining the nutrient composition and quality of the compost. **It is difficult to prepare a high quality compost from low quality feedstock.** Therefore, feed stock characteristic are amended with certain other materials such as mineral ores or fertilizers for improving the compost quality. Common feed stocks are farm wastes like crop residues, poultry litter, cattle wastes, and food processing wastes, and other agro-industrial and urban wastes. These wastes materials are mixed in different proportions depending upon their chemical characteristic that leads to the production of quality compost.

The mixing of feedstock is aimed to lower C: N ratio ranging from 25 to 40 to accelerate growth and activity of microorganisms and the rate of nutrients mineralization from the wastes. Nitrogen content and C: N ratio of crop residues and other wastes are two very important chemical parameters regulating the rate of decomposition during composting. Higher 'N' content (>2.0%) usually results in greater losses through volatilization of NH_4 during composting. C: N ratio from 25-40 is most suitable for maximum growth & activity of most of the decomposing microorganisms involved in the process of composting. As a general rule, if C: N ratio is greater than 40:1, microorganisms will be starved for the supply of the nitrogen and this will be rate-limiting factor. If the C: N ratio is lower than 20:1, nitrogen supply will be in excess and substantial proportion of it would be lost during the composting. Therefore, ideal C: N ratio for composting has been observed to be from 25:1 to 35:1..

4.1 Phosphocompost Production Technology

Rice straws or farm wastes are valuable resource for the preparation of good quality compost having nutrient contents higher than FYM or ordinary compost. Straws usually contain high C:N ratio. This can be lowered for favourable C:N ratio by either use of nitrogen fertilizer or residues from legumes crops or water hyacinth. Rice straw, chopped is amended with nitrogen (1% w/w), Phosphate rock (10-25% w/w); Pyrite (5-10% w/w) and mixed with soil, matured compost and cattle dung in the ratio of 8:0.5:0.5:1.0.

Fig.Enriched compost production technology

The whole mixed materials are either heaped layer by layer over the ground or put inside a pit. Sufficient water is added to each layer to bring its moisture content between 60-75% WHC. Mixture of decomposing microorganisms and phosphate solubilizing fungi like *Aspergillus awamori* are sprayed on the decomposing material. The material is turned after 30, 60 and 90 days intervals. Chemical analysis of the composted materials showed that it contains N, 1.4-2.0%; P_2O_5 3-7%; K, 1.5-2.0% with C:N ratios ranging between 8-15 (Table 1).

In other rapid method of composting, rice straw was soaked in a solution made by dissolving 164 g urea in 15 litre solution and adding spores and mycelium of *A. awemori*. Ten kg rice straw is soaked overnight in this solution. Rock phosphate is mixed with decomposing materials and inoculums of microorganisms like *Bacillus polymyxa* and *Pseudomonas straita* were added after 20-30 days. After 40-45 days of decomposition, inoculum of *Azotobacter chrococcum* was added. Enriched compost with nutrient content similar to that mentioned above is obtained with 40-60 days of composting.

Table 1. Chemical composition of N-enriched phosphocompost

Treatments	O.C (%)	T.N. (%)	C:N ratio	P_2O_5 (%)	Soluble P (ppm)	
					Water	Citrate
Crop residue (CR)	21.45	1.35	15.9	0.36	176.00	2750.00
CR + Rock P. (12.5%)	18.68	1.62	11.5	3.92	485.00	3840.00
CR + Rock P. (25%)	18.45	1.65	11.2	7.42	756.00	6780.00
CR + Rock P (12.5%) + Pyrite (5%) + N (0.5%)	17.86	1.87	9.6	4.21	696.00	4042.00
CR + Rock P (25%) + Pyrite (10%)+ N (1. 0%)	17.89	2.12	8.4	7.30	793.00	6720.00
Initial	50.43	1.24	40.66	0.29		

4.2 Field evaluation

Benefits of N-enriched phosphocompost in economizing fertilizer use were evaluated in maize and wheat crops grown in alfisol (pH 5.5). Data on yield of both the crops are given in table 2. It showed that N-enriched phosphocompost and phosphocompost not only substituted the use of single super phosphate but also economized nitrogen use by 25% without any reduction in crop yield. Use of ordinary phosphocompost prepared with addition of rock phosphate @ 12.5% (w/w) along with 75% N produced maize and wheat grains yields of 29.0 and 38.0 q ha^{-1} compared to 27.0 and 29.0 q ha^{-1} obtained on addition of 100% NPK through chemical fertilizers, respectively. Use of N-enriched phosphocompost prepared with the addition of pyrite (10%), and nitrogen along with 75% N produced grain yields of maize and wheat of 28.0 and 31.0 q ha^{-1} which were higher than the yields obtained with 100% NPK. Use of FYM (2.5 t ha^{-1}) along with 100% NPK however, produced maximum grain yields 31.0 q ha^{-1} of maize crop. In wheat, highest yield of 38.0 q ha^{-1} was obtained on use of phosphocompost prepared with 12.5% rock phosphate. It was further noticed that among the doses of rock phosphate use for the preparation of phosphocompost, lower dose of 12.5% produced greater crop response compared to higher dose of 25%.

5. Co-Composting of Agro-Industrial Wastes

Biodegradable farm wastes are usually utilized for compost preparation. Nutritional value of the compost so produced is very poor because of the low concentration of nutrient in crop wastes. On the other side, agro-industrial wastes contain nutrients in higher amounts but their disposal often leads to the pollution of air, soil and water. Co-composting of farm wastes with by-products of agro-industry result into production of nutrients rich compost of high quality. This approach is highly beneficial to both agriculture and agro-based industries.

Table 2. Effect of N-enriched phosphocompost on grain and straw yields of maize and wheat crops

Treatments	Yield (q ha^{-1})							
	Maize (GS-2)						Wheat (RR-21)	
	Grain			Straw			Grain	Straw
	1997	1998	Mean	1997	1998	Mean	1997-98	
N-Phosphocompost* + 75% N	23.66	25.00	24.33	55.65	55.00	55.33	26.33	32.59
N-Phosphocompost** + 75% N	24.00	29.00	26.50	56.98	66.66	61.82	29.33	37.00
N-Phosphocompost# + 75% N	27.16	29.66	28.41	70.37	59.66	65.02	31.33	40.06
N-Phosphocompost##+ 75% N	25.00	28.33	26.67	57.99	65.00	61.50	34.16	43.08
Phocphocompost+ + 75% N	22.00	24.33	23.17	49.13	55.65	52.40	35.00	44.45
Phocphocompost++ + 75% N	31.66	26.33	29.00	70.31	57.66	63.99	38.33	48.42
100% NPK	28.33	26.00	27.17	63.94	61.00	62.47	29.00	37.19
100% NPK + FYM @ 1.5 t ha^{-1}	25.83	32.33	28.08	60.21	70.33	65.27	35.60	45.13
100% NPK + FYM @ 2.5 t ha^{-1}	28.50	33.66	31.08	65.84	80.00	72.92	36.00	45.48
SEM ±	02.13	01.72	01.37	04.76	04.58	03.30	01.92	02.35
CD 5%	06.33	05.11	04.62	14.15	13.61	00.82	05.71	06.99
C.V. %	13.86	10.41	12.14	13.48	12.44	12.95	10.15	09.84

* N-phosphocompost prepared by addition of Rock phosphate, 25%; Pyrite, 5% and urea-N 1% (w/w)
** N-phosphocompost prepared by addition of Rock phosphate, 25%; Pyrite, 10% and urea-N 1% (w/w)
\# N-phosphocompost prepared by addition of Rock phosphate, 12.5%; Pyrite, 5% and urea-N 1% (w/w)
\## N-phosphocompost prepared by addition of Rock phosphate, 12.5%; Pyrite, 10% and urea-N 1% (w/w)
\+ N-phosphocompost prepared by addition of Rock phosphate, 25and urea-N 1% (w/w)
\++ N-phosphocompost prepared by addition of Rock phosphate, 12.5%; and urea-N 1% (w/w)

5.1 Poultry Wastes

Poultry wastes contain droppings of birds and bedding materials. Poultry wastes usually contain 2-4% N and 1-2% P. Significant losses ranging between 40-60% of initial N content have been reported during storage, handling and application of poultry wastes in the fields. Co-composting of poultry wastes with farm residues and mineral additives like rock phosphate and pyrite produces nutrient rich compost.

Poultry wastes mixed with rice straw (in the ratios: 1: 4 w/w) were composted with and without additions of rock phosphate (12.5%) and pyrite (10%). This mixture of poultry wastes and rice straw was mixed with cattle dung, mature compost and soil in the ratio of 8:1:0.5:0.5 before placement inside the pit. Moisture was adjusted between 60-75% WHC by addition of water. Material was mixed intermittently during composting at an interval of 15 days with moisture adjustment between 60-75%. Temperature builds up rapidly inside the pit. Cumulative loss of organic matter within 120 days period ranged between 65 to 77%. Composting of poultry waste alone with initial N content ranging between 1.98 and 2.31% resulted in maximum N losses of 67% of its initial content within 120 days. Mixing of poultry waste with rock- phosphate and pyrites (10%) lowered N losses from 67% to 43%. Mixing of poultry wastes with rice straw in the ratio of 1 :4 (w/w) also helped in conserving the nitrogen by reducing N losses. Mixing poultry wastes with rice straw (1:4 w/w) and addition of rock phosphate (12.5%) and pyrite (10%) was most beneficial in controlling N losses during composting. N losses decreased from 67% to 30% due to amendment with rice straw, pyrite and rock-phosphate. The composition of nutrient in the manure at the end of composting period showed that C: N ratio and N content of manure prepared after mixing rice straw (1:4 w/w), rock phosphate and pyrite were 15 and 2.0 compared to 17.0 and 1.85% in the compost made out of poultry wastes alone (Table 3).

Table 3. Chemical composition of enriched compost prepared from crop residues and poultry litter

Treatments	C (%)	N (%)	C/N ratio	Mineral N (ppm)
Poultry waste (PW)	31.5	1.85	17.03	1295
PW + Rock phosphate (12.5% w/w) + Pyrites (10% w/w)	32.5	2.46	13.21	1600
PW + Rice residues + Water hyacinth (1:2:2)	31.5	1.75	18.0	1180
PW + Rice residues + Water hyacinth (1:2:2)+ Rock phosphate (12.5% w/w) + Pyrites (10% w/w)	30.5	2.15	14.19	1250

5.2 Distillery wastes

Spent wash is a liquid waste produced during fermentation of molasses for alcohol production in distilleries. Spent wash is highly colored material, acidic in nature and contains very high BOD/COD load. It is characterized with high BOD load (45,000 to 75,000 $mg1^{-1}$), low pH, and high salt content. The pH is around 4.5 to 5.0 due to higher concentration of sulphate ions and organic acids. It contains 9-10 per cent solids of which 75% are organic compounds such as sugars, organic acids, glycerol, phenols etc. It contains sizeable amount of potassium with besides other macro and micronutrients, beneficial for plant growth.

Co-composting of spent wash with farm wastes produced nutrient enriched manures for use in crop production system. Most of the sugar industries and distilleries are adopting the process of composting of spent wash with press mud to prepare manure for use in agriculture.

Residues from paddy, mustard crops and other crops as well as press mud could be utilized for the preparation of enriched compost through co-composting with spent wash, rock phosphate and pyrite. Spent wash addition to straws increases nitrogen, phosphorus and potassium contents in the manure (Table 4).

Table 4. Co-composting of crop residues with spent wash

Treatments	Nutrient content (%)			C:N
	N	P_2O_5	K_2O	
Crop residue	0.94	0.31	0.56	22.8
Crop residue + spent wash	1.26	0.40	1.60	16.0
Crop residue + spent wash + R.P. + Pyrite	1.44	3.50	1.30	13.0

Nitrogen content increased from 1.0 to 1.4%, P_2O_5 from 0.3 to 3.5% and K_2O from 0.56 to 1.6% in the compost due to spent wash addition. Rock phosphate addition to the composting mixture was highly beneficial in improving phosphorus content as well as nitrogen content. Thus, C: N ratio of enriched compost prepared using spent wash and rock phosphate was below 20. Potassium content in the enriched compost was also increased. Thus, spent wash, an industrial waste material was highly beneficial in increasing the N, P and K content in the compost. Rock phosphate addition further improved the phosphorus content in the enriched manure resulting in the production of quality manure rich in all macronutrients.

6. Composting Methods

Composting methods usually involves simply stacking the materials in piles to decompose over a long period with little agitation, moisture maintenance and other management options essentially required for good compost production. Needless to mention that simple placement of manure in a pile does not satisfy the requirements for composting. This results into nutrient losses and low quality of compost containing weeds and pathogens. Without considerable *bedding* material, the *moisture content* of manure exceeds the optimum level, which makes pile anaerobic. Under these circumstances, the anaerobic microorganisms dominate the degradation with production of organic acids and other phytotoxic chemicals. All of the undesirable effects associated with anaerobic degradation occur including low temperatures, slow decomposition, and the release of malodorous compounds. **Indeed this is not compost as per definition of composting accepted world over for quality compost production technology.**

6.1 Indore Method

The traditional composting procedure was modified into a method of composting popularly known as the 'Indore method'. The NADEP method of composting is basically a slight modification of Indore method. The pits are made above ground with holes to allow the flow of air through convection and chimney action during thermophilic phase of composting (Fig. 3).

Fig. 3 A NADEP compost method

Raw materials

The raw materials used are mixed plant residues, animal dung and urine, earth, wood ash and water. All organic material wastes available on a farm such as weeds, stalks, stems, fallen leaves, pruning, chaff, fodder leftovers and so on, are collected and stacked in a pile. Hard woody material like cotton or pigeon pea stalks and stubble are cut into small pieces. Green materials, which are soft and succulent, are allowed to wilt for two to three days to remove excess moisture before stacking; they tend to pack closely if they are stacked in the fresh state. The mixture of different kinds of organic material residues ensures a more efficient decomposition.

6.2 Pit method

Filling the pit:

The material brought from the cattle shed is spread evenly in the pit in layers of 10-15 cm. On each layer is spread slurry made with 4.5 kg dung, 3.5 kg urine-earth and 4.5 kg of inoculum taken from a 15 day-old composting pit. Sufficient quantity of water is sprinkled over the material in the pit to wet it. The pit is filled in this way, layer by layer, and it should not take longer than one week to fill. Care should be taken to avoid compacting the material in any way.

Turning:

The material is turned three times during the whole period of composting; the first time 15 days after filling the pit, the second after another 15 days and the third after another month. At each turning, the material is mixed thoroughly, moistened with water and replaced in the pit.

6.3 Heap method

The heap is usually started with a 20 cm layer of carbonaceous material such as leaves, hay, straw, sawdust, wood chips and chopped corn stalks. This is then covered with 10 cm of nitrogenous material such as fresh grass, weeds or garden plant residues, fresh or dry manure or digested sewage sludge. The pattern of 20 cm carbonaceous material and 10 cm of nitrogenous material is followed until the pile is 1.5 m high and the material is normally wetted so that it may feel damp but not soggy (Fig. 4). The pile is sometimes covered with soil or hay to retain heat and is turned at six- and twelve-week intervals. When sufficient nitrogenous material is not available, a green manure or leguminous crop like sun hemp is grown on the fermenting heap by sowing seeds after the first turning. The green matter is then turned in at the time of the second mixing. The process complete in about four to six months to complete.

Fig. 4 Heap and Pit methods of composting

6.4 NADEP Method:

This method of composting is preferred in places where availability of crop residues and other biodegradable materials are limited. Water requirement is also very low (Fig.5).

Fig. 5 Filling of decomposable materials into the NADEP

The only difference in this method is the proportion of soil added to the decomposing materials. The ratio of the different materials to fill one pit of the size is given below.

No.	Material	Quantity (q)
1	Crop residues	12.0-15.0
2	Soil	1.0-1.5
3	Cattle dung	1.0-1.5
4	Mature compost	0.5-1.0
5	Rock-phosphate	1.0-1.25

7. Compost Quality Parameters

Compost quality parameters vary widely depending upon feedstock characteristics, process adopted for composting, and its end use. Normally compost stability, maturity, nutrient contents, presence of pathogens and weeds and other contaminants like heavy metals are some of the indicators used for deciding compost quality. In addition chemical analysis such as C:N ratio, concentration of plant macro-nutrient like N, P, K content and CEC are also utilized for overall assessment of compost quality. Compost is graded into different categories for use in nursery, crop production, horticulture, and other purposes such as diseases management or odor control through bio-filters.

In general, there are certain common quality parameters normally used by both compost producers and users. These are grouped into three classes,

- Physical characteristic
- Chemical characteristic
- Biological characteristic
- Phytotoix assessment

Physical characteristic

Free-flow-

The moisture content of well-decomposed mature compost shall not be more than 20-25 % (w/w).

Bulk density-

Bulk density is affected by moisture content, ash content, particle size distribution and the degree of decomposition. Bulk density usually increases with composting time, as ash content increases and as particle size is reduced by decomposition, turning and screening.

Odor

The decomposed organics are earthy odor where as undecomposed organics or partial decomposed organics under anaerobic conditions give order problem because of CH/S, H2S and other sulfur reducing compounds contents in compost, particularly in city garbage compost and poultry manure.

Color

Dark black color or deep brownish colors is the indicator of decomposed organics. While straw or light brown color indicates more time frame is required to decompose the composts. The light color is due to higher content of water-soluble carbon and carbohydrates in the immature materials compared to decomposed one.

Temperature

The stability of temperature during storage is one of the most important criteria to evaluate the maturity of compost. This temperature range is around 20-25 C after for stable compost.

Chemical properties

The C/N ratio, weight loss on ignition, ash content etc., are the indicator of compost stability. The C/N ratio of manure itself cannot be considered as a reliable indicator of compost maturity since the differences in lignin/cellulose ratio of raw material also influence upon compost quality.

Assessing Compost Stability and Maturity

It is difficult to determine the stability and maturity of compost by visual analysis. Opinions regarding the parameters of stability and maturity vary widely within the compost, agricultural, and horticultural industries. The term “stable” is often used to describe compost that is not undergoing rapid decomposition and whose nutrients are relatively available for release into the soil; unstable compost, in contrast, can tie up nitrogen from the soil. It is important to note that compost that is not fully stable can be useful in certain situations. Immature compost will contain more growth inhibiting compounds than mature compost. Compost that is immature may, for example, produce short-chain organic acids that are phytotoxic (toxic to plants), especially to seedlings. The following are sometimes used as indicators of compost stability and maturity.

7.1 Indicators of compost stability

Temperature of the Compost. In general, in moderate climates, if the temperature of the compost is more than (8 C) higher than the ambient air, the compost is still fairly unstable.

Respiration Rate. The rate of oxygen utilization represents the extent of biological activity. For horticultural applications, < 20 mg O_2 / Kg compost dry solids/hour is considered stable. For field applications, < 100 mg O_2 / Kg compost dry solids/hour is considered stable. Less than 5 mg CO_2 carbon/g compost carbon/day is considered stable and is usually suitable for seeds. Greater than 20 mg CO_2 carbon/g compost carbon/day may be fairly unstable. Composts that are cold, dry, or very salty may not respire even though they are not stable.

7.3 Indicators of compost maturity

Seed Germination. Growers may want to perform a germination test using the seeds they will be planting.

Maturity Index. Some labs will assign a maturity index to compost based upon both the germination rate, degree of humification and biodegradation index and the root tissue growth compared to a control.

Conclusion

Biodegradable wastes are important natural resources. There generation in large volumes as a result of processing the agricultural produces at a point results in accumulation of these resources and causing pollution of air, water and land. Often they are disposed rather than utilized in the agriculture production system. Technology for value addition to these resources and removal of their contaminants results into production of good quality compost with higher nutrient content. Their use helps in recycling the nutrients and improving the organic carbon content in soil. This improves soil fertility status and crop productivity on a sustainable basis.

Integrated Nutrient Management for sustainable management of Soil Fertility and Crop Productivity

S.S. Tomar[1] and AK Dwivedi[2]

[1]Director Research Services
[2]Principal Scientist
Directorate of Research Services
J N Kristi Vishwavidyalaya, Jabalpur – 482004 (M.P.)

Sustainable agricultural production incorporates the natural resources to generate increased productivity of crops without depleting the natural resource base In this connection. The basic concept of INM is to limit the unfavorable exploitation of soil fertility and plant nutrients. The maintenance and improvement of soil fertility and plant nutrition at an optimum level to sustain the desired crop productivity through optimization of the benefits from all possible sources of plant nutrients in an integrated manner is the main concern of IPNMS (Swarup and Rao, 1998). The combination of organic and inorganic fertilizer (Dwivedi etal, 2007) seems to be more practical than the use of organic fertilizer. The importance of INM is recognizes mainly because of the growing consumption of inorganic fertilizers and the unavailability of nutrients at low cost. Another reason is that, many researches revealed that neither inorganic fertilizers nor organic sources alone can achieve a sustainable productivity of soils as well as crops under highly intensive cropping systems alone (Liu et al., 2001) Among these agronomic measures, fertilization may be the most important way to maintain high crop productivity and soil quality (Sun, et al., 1997 and Tembhare et al, 1998;). Therefore, to produce more and more from an unit land area., the conservation and maintenance of soil fertility, as one of the most important tactical targets for sustaining productivity (Swarup and Wanjari,2000), hence, a judicious nutrient management strategic policy must be out lined to offset the undesirable trend and to tiger sustainable growth in crop production (Tomar and Dwivedi, 2007).

Concept: Soil fertility for sustaining crop productivity through optimizing all possible sources (organic, inorganic biological in an integrated manner appropriate to each farming situation is the basic concept of integrated plant nutrient system for the maintenance of inorganic, organic and biological resources so as to sustain improve or maintain the soil chemical and physical properties and provide crop nutrient packages which are technically sound economically attractive practically feasible and environmentally safe. The principal aim of the integrated approach is to utilize all the sources of plant nutrients in a judicious and efficient manner (Zang et al.,2002)

Goal of INM

Sustainable agricultural production incorporates the idea that natural resources should be used to generate increased output and incomes, especially for low-income groups, without depleting the natural resource base. In this context, INM maintains soils as storehouses of plant nutrients that are essential for vegetative growth. INM's goal is to integrate the use of all natural and man-made sources of plant nutrients, so that crop productivity increases in an efficient and environmentally benign manner, without sacrificing soil productivity of future generations. INM relies on a number of factors, including appropriate nutrient application and conservation and the transfer of knowledge about INM practices to farmers and researchers.

Components of the System

Balanced application of appropriate fertilizers is a major component of INM. Fertilizers need to be applied at the level required for optimal crop growth based on crop requirements and agro climatic considerations. At the same time, negative externalities should be minimized. Over application of fertilizers, while inexpensive for some farmers in developed countries, induces neither substantially greater crop nutrient uptake nor significantly higher yields (Smaling and Braun 1996). Rather, excessive nutrient applications are economically wasteful and can damage the environment. Under application ,on the other hand, can retard crop growth and lower yields in the short term, and in the long term jeopardize sustainability through soil mining and erosion. The system has four major components :

Soil Source : The nutrient supplying capacity of many soils declined steadily as to result of continuous and intensive cultivation practices.

Intensive cultivation also resulted in the deficiency of certain secondary and micronutrients in the souls. Therefore, it becomes necessary to reduce the nutrient losses through soul management practices, ameliorating problem soils in under to mobilize unavailable nutrients and to use appropriate crop verities natural practices and cropping system to maximum utilization of available nutrients.

Mineral Fertilizers : Mineral fertilizers play an important role in sustaining and increasing agricultural production. However, they are costly inputs and there is need to improve their use efficiency for efficient fertilizer management, the following 4 R constitute essential components:

1. Right type of fertilizer
2. Right dose of fertilizer
3. Right method of application
4. Right time of application

Besides, some other practices like making fertilizer recommendations based on soil test for a cropping system instead of a single crop in the system and eliminating limiting factors including secondary and micronutrients is also considered for optimizing fertiliser use.

Organic Sources : Organic sources are valuable by products of farming and allied industries derived from plant and animal matter. Organic source include farmyard manure, animal droppings crop wastes residues sewage and sludge and various industrial wastes. It has been estimated that the potential annual plant nutrients generated through organic sources are about 9.9 million tonnes of N, 2.7 of P_2O_5, and 4.4 of K_2O. Though organic sources contain nutrients in less amount most of the essential elements could be supplied by them on long-term basis.

Use of Organic Manures: Experience from Long-Term Fertiliser Experiments in 11 major agro- climatic regions of the country reveal that integrated use of farmyard manures (FYM) @ 15 t ha^{-1} $year^{-1}$ and 100 % NPK recommended dose of chemical fertilizers to each crop of an intensive crop rotation helps in maintaining higher productivity and in providing maximum stability in crop production. The impact of FYM on crop yields can be attributed largely to beneficial effect on soil physical property moisture retention and biological properties.

Crop Residues/ Organic Wastes: Organic wastes e.g. human and civic wastes crop residues are valuable commodities from agricultural point of view. It has been estimate that about 185 m.t. of crop residues (stubbles, roots, leaves etc.) from nine principal crops in India are available annually with nutrient content of 3.32 m.t. The availability of manure constituents from urban wastes alone accounts for 0.03 m.t. N, 0.021 m.t. P_2O_5 and 0.03 m.t. K_2O. Much attention has not been paid to the utilization of sewage water after its collection and purification.

Green Manuring : Green manuring of soils for the benefit of crops is an old practice and in the present content of integrated nutrient supply system. It needs adequate attention. The popular green manure crops are sun hemp, Dhancha, and Cowpea, are reported to fix about 100-150 and 85 kg N ha^{-1}) respectively. A Paddy yield was increased by one tones either through 112.4 kg fertiliser N or through 25.6 t green manure. Rice wheat rotation in western India no doubt is productive but it is a very exhaustive rotation. Experiments on rice-wheat rotation have shown that inclusion of cowpea as a green manure crop after harvesting wheat and before transplanting paddy saved nitrogen to the tune of 40-50 kg N ha^{-1} and also helped to maintain good soil physical conditions.

Biological Sources (Biofertilizers) : Microbial inoculants are popularly known as biofertilizers. It refers to cultures of bacteria microorganisms, which benefit the plants by providing nitrogen or phosphorus or bring about rapid mineralization of organic materials. Seeds or soils are treated with such cultures organisms with 3 objectives to increase their population in the rhizosphere so that microbial processes are substantially increased. This augments the availability of nutrients in a form, which can be easily assimilated by plants. There are various types of biofertilizers.

Effect of INM on Crop Productivity

Soybean

The findings of long term fertilizer experiment of soybean- wheat on a black soil at Jabalpur (table–1) revealed that increasing trend was recorded with the successive application of fertilizer over control, On the other hand, continuous cropping without supplementing with inorganic fertilizers invariably reduced the crop yields (Tembhare et al.1998). Hence, fertilizer responses to the successive levels is obvious (Dwiivedi, et al,2007).

Table1. Long term effect of fertilizer application on grain yield of Soybean and wheat at Jabalpur

Treatment	Mean yield (kgha^{-1}) of Soybean				
	1973-82	1983-92	1993-02	2003-05	Pooled
50%NPK	1795	2104	1421	1437	1661
100%NPK	2099	2389	1660	1678	1921
150%NPK	2303	2334	1706	1790	1978
100%NPK+HW	2075	2346	1541	1568	1877
100%NPK+Zn	2234	2338	1574	1531	1912
100%NP	1992	2225	1370	1578	1759
100%N	1376	1264	740	768	1064
100%NPK+FYM	2377	2593	1746	1862	2096
100%NPK-S	2022	2200	1539	1535	1789
Control	1032	1065	610	624	849
Treatment	**Mean yield (kgha^{-1}) of Wheat**				
	1973-82	**1983-92**	**1993-02**	**2003-05**	**Pooled**
50%NPK	2976	3289	3455	4257	3077
100%NPK	3743	4629	4686	5290	4088
150%NPK	4028	5037	4967	5831	4387
100%NPK+HW	3756	4392	4382	5093	3898
100%NPK+Zn	3864	4557	4645	5198	4053
100%NP	3608	4393	4267	4951	3829
100%N	1576	1482	1560	2590	1454
100%NPK+FYM	4171	5067	5121	5945	4504
100%NPK-S	3694	4263	4285	5063	3835
Control	1145	1135	1212	1630	1108

Continuous application of N alone though resulted in increased yield over control but the response went on decline with time due to limitation of P and K. From the inception of experiment a good response of P was recorded. Yield data of soybean further revealed that the crop did not show response to K in first 10 years (30 crops) and thereafter, the crop started showing response to applied K. The crop response to Zn was noticed only for 10 years and thereafter ceased due to build up of Zn in the soil maintained a higher yield level over the years. Absence of S in fertilizer schedule has shown reduction in soybean yield through out the period. Similar findings have been reported by Tembhare et al, 1998 and Tomar and Dwivedi, 2007. However, the soil sustained the productivity for twenty years and thereafter a drastic reduction in yield was noticed due to hidden hunger of nutrients at their suboptimal or deficient levels. Thus the results clearly demonstrate that K and S are essential for sustaining the yield (Tembhare et al, 1998; Dwivedi and Dikshit, 2002) It is interesting to note that the yield levels of wheat did not observed under continuous cropping of wheat without-fertilizer application Moreover, an increase in yield in last three years is observed. It seems that growing of soybean is responsible for sustaining the wheat yield at same level (Dwivedi et al, 2007).

The low response of soybean to K application in the beginning years to K could be attributed to the fact that these soils were initially rich in K and could maintain its supply by releasing K in appreciable amount, (Dwivedi and Dikshit,2002). The yield data revealed that continuous application of S free fertilizer in fertilizer schedule over the years may reduce the yields in long run. Thus to sustain the crop productivity on long term basis there is need for balanced fertilization (Tomar and Dwivedi, 2007)

Changes in soil physical properties

Soil physical conditions influence the growth of roots and soil microorganisms. Long-term use of fertilizers manure may results in change of soil biological conditions.

Soil Aggregation

Soil aggregation is one of properties of soil, which governs the root growth, and exchange of air into soil and also acts a storehouse of soil organic carbon. The data presented in Fig. revealed that in all the treatments except in 100% N and control

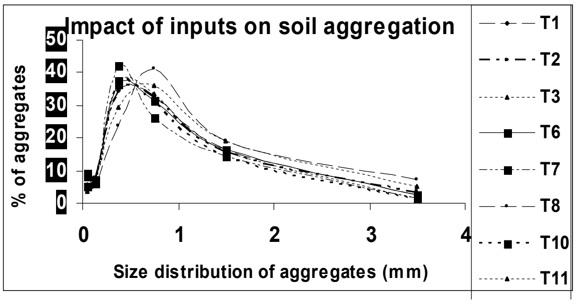
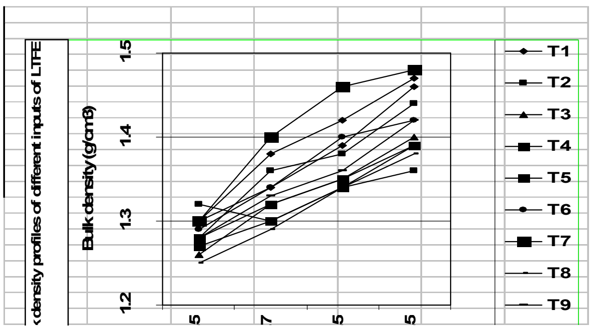


Fig Effect of different treatments in Long Term Fertilizer experiment on soil aggregation of surface soil

In general increase in proportion of bigger size aggregate was registered in all the treatments except NPK-S and 100% N at the expense of smaller size aggregates. The largest increase was noted in treatments with 100% NPK + FYM and 150% NPK. A similar effect of treatments on mean weight diameter was also noted by Singh et al, 2002. Thus from the data it can be concluded that balanced use of nutrients results in improvement in soil aggregation (Tiwari et al, 1998, and 2000).

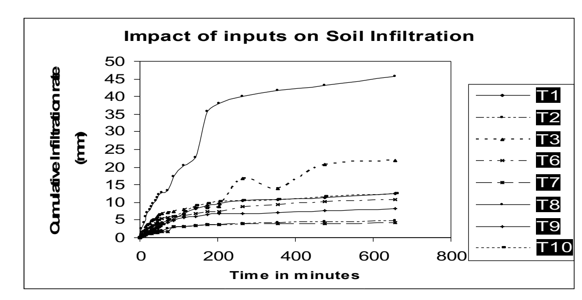
Bulk Density

Though there is no significant change in bulk density (BD) however, a slight decline a. was recorded in the plots that received balanced nutrition(Singh, etal, 2002). The maximum decline in BD was noted in NPK + FYM treatment as compared to control probably due to application additional amount of organic manure (Tiwari, et al,2002).



Initial (1972) bulk density of surface soil (0-15 cm) - 1.30 (Mg m^{-3})

Saturated hydraulic conductivity and Infiltration rate : Application of balanced fertilizer and manure improved the initial and cumulative infiltration rates with the highest value ranging between 8 to 10 mm hr^{-1} whereas application of unbalanced fertilizer had resulted in lower infiltration rate ranging between 2 to 6 mm hr^{-1} while the values were 2 mm hr^{-1} when the experiment was started in 1972 (Fig). Hydraulic conductivity behavior was also similar with values ranging between 6 to 12 mm hr^{-1} in balanced fertilizer and manure use where as they were around 4 mm hr^{-1} in treatments receiving unbalanced fertilizer (Singh,et al, 2002) . The initial hydraulic conductivity value in 1972 was 2.6 mm hr^{-1}.



Initial (1972) Constant infiltration rate - 20 (mm hr^{-1})

Changes in Soil Fertility

Soil Organic Carbon

Organic carbon plays an important role in maintaining soil health and governs the available of nutrients like N, P, S and micronutrients. Perusal of soil organic carbon data (Table8.2.1) revealed significant increase in SOC in all the treatment except control and 100% N alone. However, largest increase in SOC was recorded in 100% NPK + FYM followed by 100 %NPK. The increase in SOC was probably due to additional organic matter by soybean through leaf fall. It has been quantified that soybean sheds the leaves equals or little more then the seed yield in addition to root and nodule biomass (Tembhare, et al,1998). The larger increase in SOC in NPK + FYM is due addition of more amount of leaf biomass as a result of higher yield in addition to carbon added through FYM. The addition of organic matter through leaf fall is proportional to the seed yield of soybean and in this treatment gave high yield. Thus from the results it can be inferred that balanced use of nutrient either through chemical fertilizer or integrated use of fertilizer and manure would led to improvement in soil health (Tomar and Dwivedi, 2007 and 2008 b). The largest increase in organic carbon content i.e. 0.99 % in 100% NPK+ FYM treatment can be assigned to addition of more amount of carbon through leaf fall compared to other treatments in addition to continuous use of 15 tons FYM ha^{-1} during the period of experimentation.

Available Nitrogen

Soil analysis after 36 years of long term fertilizer trial at black soil of Jabalpur revealed that largest increase in available N was recorded in NPK + FYM followed by 150% NPK and 100% NPK through the differences among these are not significant but are significantly higher to other treatments. The increase in available N in other treatment was found to be superior over control but inferior to where balanced fertilizer was applied (Sun,et al,1999) . The increase in available N is due to increase in organic carbon content of the soil and almost follow similar trend to that of carbon added by soybean (Tembhare, et al,1998). Thus from the results it is concluded that inclusion of P and S in fertilizer schedule is helpful in improving the soil N.

8.2.3 Available Phosphorus

It is well-established fact that the crops use 25 to 30 per cent of applied phosphorus and the rest remains in soil in different forms. In this context, findings of Dwivedi etal, 2007 indicated that increasing level of P from 50% to 150 resulted successive increases the available P status from 7.6 mg kg^{-1} (control) to 18 mg kg^{-1} in 50%NPK, 29 mg kg^{-1} in 100%NPK and 44 mg kg^{-1} in 150%NPK treatment. It is interesting to note that increase in available P content was observed even in the treatments, which didn't receive P (Control and N alone). The increase in available P in treatments having P is obviously due to P application. Whereas increase in availability the treatments viz. control and N alone seems to be due to mobilization of native soil P on decomposition of soybean leaves added after each harvest. Thus from the results it is concluded that addition organic might help in maintaining the soil P even with less dose of P fertilizer in soybean-wheat systems (Tomar and Dwivedi,2007).

8.2.4 Available Potassium

In all the treatments an sharp decline in available K content was recorded after 20 cycles of soybean-wheat and maize fodder. Decline in available K is obvious as uptake of K is always higher than the applied K. From the results it can be concluded that present K recommendations are not sufficient and need revision otherwise an abrupt decline in production is expected (Tomar and Dwivedi, 2008a).

8.2.5 Available Sulphur

Continuous growing of soybean-wheat with application of S containing fertilizer resulted decline in available content of S from initial 16 kg ha^{-1} to 10 kg S ha^{-1} in control and 14 kg S ha^{-1} in N alone (Dwivedi et al,2007) . But an appreciable increase in available S content was found in the treatment receiving full dose of P through single super phosphate which contains 12% S in addition to P. The grain yield analysis revealed that soil supported the S supply in first 10 years and there after both the crop responded to S. Thus from the results it is concluded that for sustaining the productivity, S application is essential and continuous use or sulphur free fertilizer may decline in yield.

8.2.6 Available Micronutrient Status

One of the reasons for deterioration in productivity was found to be associated with micronutrient deficiencies specifically under intensive cropping system. The depletion pattern of DTPA extractable micronutrient Zn was higher in the soil treated with chemical fertilizers as compare to the plots treated with fertilizers in conjunction with organic manures. The data indicate (table 2) that the continuous addition of $ZnSO_4$ to wheat crop in alternate years resulted in increased Zn content in the soil and sustained higher yield levels. The incorporation of 100% NPK+FYM in a long run substantially increased the availability of zinc in the experimental soil.

Table 2. Soil test values after 35 cropping cycles (1972-2009)

Treatment	pH	EC (dSm^{-1})	OC (%)	Av. N	Av. P	Av. K	Av. S	Av. Zn
				kg ha^{-1}				mg kg^{-1}
50% NPK	7.6	0.12	0.57	220	18	236	16	0.50
100% NPK	7.5	0.15	0.84	293	29	266	23	0.46
150% NPK	7.5	0.12	0.94	311	41	269	33	0.54
100% NPK + HW	7.4	0.13	0.64	240	28	226	26	0.62
100% NPK + Zn	7.5	0.14	0.66	245	28	231	25	1.64
100% NP	7.5	0.13	0.69	258	26	234	24	0.85
100% N	7.6	0.12	0.50	200	13	191	14	0.46
100% NPK + FYM	7.3	0.13	0.99	318	39	307	33	0.82
100% NPK - S	7.6	0.11	0.73	264	27	212	13	0.48
Control	7.5	0.12	0.48	196	9	186	10	0.33
CD (P=0.05)	NS	NS	0.13	32.5	3.1	34.3	3.4	0.11
Initial (1972)	7.6	0.18	0.57	193	7.6	370	16.0	0.33

Source Ann. Report AICRP LTFE, 2008-09

Changes in Soil Biological Properties

Highest population of nitrosomonas, nitrobactor, azatobactor ,actinomycetes and fungi has been noticed in treatment where organic manure (FYM) has been used . The contribution of higher bio mass due to use of optimal and super optimal fertilizer use resulting from higher yields of crops in these treatments has resulted in improving microbial population (Fig.).

Benefits of Integrated Nutrient Management :

Agriculture sustainability refers to the ability of agricultural system to remain efficient enough to be productive. Quantitatively it implies trends in agricultural production of a system over a time , It means the ability of a system to maintain or enhance its performance , output, without damaging own long term production potential. Therefore, the challenge for agriculture over the coming decades will be to meet the world's increasing demand for food in a sustainable way. Declining soil fertility and mismanagement of plant nutrients have made this task more difficult. In their 2020,call for an Integrated Nutrient Management approach to the management of plant nutrients for maintaining and enhancing soil fertility, where both natural and manmade sources of plant nutrients are used. The key components of this approach are described, the roles and responsibilities of various factors, including farmers and institutions, are delineated; and recommendations for improving the management of plant nutrients and soil fertility are presented. The overall strategy for increasing and sustaining crop yields must include an integrated approach to the management of soil nutrients, along with other complementary measures. An integrated approach recognizes that soils are the storehouse of most of the plant nutrients essential for plant growth and that the way in which nutrients are manage will have a major impact on plant growth, soil fertility, and agricultural sustainability. Soil nutrient availability changes over time. The continuous recycling of nutrients into and out of the soil is known as the nutrient cycle (NRC 1993).The cycle involves complex biological and chemical interactions, some of which are not yet fully understood. Soils in many countries suffer from declining fertility. Their physical and chemical structure is deteriorating and the vital nutrients for plant growth are slowly being depleted. .

Future Need :

Under energy crisis and rapid depletion of non-renewable energy sources, declined the availability of natural fertilizer inputs causing excessive burden on use of chemical fertilizers. Such practice leads to wide gap in supply and demand of fertilizer. Hence, it was found difficult to small and marginal farmers to use mineral fertilizers. This warrants a look for other sources of plant nutrients, which are cheap as well as, readily available. At our farms there are number of sources of plant nutrients, which are complementary and supplementary to each other in one-way or the other. The major advantage with integrated approach is that it would be able to meet immediate as well as long-term needs of the crops without causing any danger to the ecosystem. This may prove as one of the important means for sustainable agriculture and in achieving the global food security

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Soil Resource Inventory for Land Use Planning

G.P. Gupta

Ex-Association Director Research
JN Krishi Vishwa Vidhyalaya, Jabalpur – 482004 (M.P.)

Soil, air and water are the basic natural resources that support all forms of life. Out of this, soil constitutes an important medium through which crops are grown, and food is produced. Aeration in sufficient quantity in proper proportion is a must to encourage metabolic processes. Water also please a significant role in soil plant growth relationship.

Present day soil studies have been generally a part of integrated land resource programme, the major aim of which is often to increase the crop production and also to improve proper land use. Soil surveys at one and locate the highly productive land with a description of the inherent soil properties and on the other they also define the so called unproductive lands and even indicate the appropriate technologies and cost for their reclamation.

Many fold problems of the land have increased due to increasing industrialization which have resulted in polluting the natural resource i.e. air, water and soil by way of enriching with various harmful components.

Considering the food demand of the future, Planning Commission of India in the year 1989 gave a major priority to inventorization of soil and water and reclamation of problematic areas for intensive food production.

Various approaches for land use planning

In order to develop a proper methodology a number of approaches have been made from time to time namely:

i) Interpretational approach (through simple soil surveys),

ii) Complex agro-pedological approach

iii) Integrated land evaluation approach.

1. Interpretational approach

In early sixties, interpretational approach was started through simple soil surveys considering soil mapping and interpretations. It was mainly based on a few individual profile characteristics like texture, drainage, soil depth and soil slope/erosion hazards and was called soil mapping unit (cl–d_5/A-e1). Soils were differentiated at high level between peodcals and pedalfers depending essentially on colour characteristics and on the eventual presence of free lime in the profile. Some times colour criteria was also linked with soil nutrient status. However, no systematic methodology with respect to any criteria was followed.

In cultivated areas, the soil appraisal was based on extrapolation and evaluation of crop yields obtained on similar well known soils. In virgin soils an expression of soil fertility status was based on the existence of native vegetation. Overall the relative approximations were mainly left to the personal interpretations of the soil scientist.

2. Complex agro-pedological approach

After the world war 2nd, it was felt necessary to develop more systematic approach towards soil inventorization and their application to agriculture. It was thought to replace the personalized way of interpretations through range of parameters and their ratings. Klingebiel and Montgomery (1961) developed land capability classification (LCC) in USA. They in 1966 listed a number of criteria/limitations for judging the capability of soils to produce crops which included soil depth, erosion, drainage, workability, stoniness/ rockiness, WHC, nutrient availability, salinity/alkalinity/climate. Based on these parameters, 8 capability classes were introduced indicating the potential to produce crops and pasture over a long period of time. Risk of soil limitations were progressively greater from class I to class VIII.

This capability classification system served the purpose for a longer period. Wherever letter on some of the following inconveniences were felt by the researchers and end users.

(i) Provided only general appraisal : The system led to a general appraisal but did not deal with the growth and production of specific crops each having particular requirements. This was very useful for broad planning purposes at regional/national level but lacked to answer accurately regarding specific agricultural uses.

(ii) Based on soil characteristics : Parameters considered for land capability groups, were based on soil properties and no attention was paid to climate growth requirements. Capability ratings did not provide productivity scale for crops.

(iii) Inaccurate criteria for grouping : Accurate definitions of the criteria especially ratings for drainage, soil depth or MHC were provided however, no proper definitions of climate and soil fertility existed for the purpose of grouping the soils. This approach also did not show link with agro-climatic conditions of the region.

3. Integrated land evaluation approach

Factors influencing crop growth have direct impact on the production. In this new approach, prime concern has been given to the plant and its specific growth requirements. The capability of a land to produce crops is determined by the combined effect of

(i) physical (climate, land form pattern, soil and moisture conditions

(ii) Human (availability of farmers and their ability and

(iii) Capital resource availability of funds resources.

Basic principles of this new approach include 5 fundamental assumptions.

(i) Specific kind of land use : Land suitability can only be properly evaluated for specific kind of use i.e. a preliminary decision has to be taken with respect to the required land use before the evaluation procedure is initiated.

(ii) Comparison of benefits: The evaluation requires a comparison of the benefits obtained and the inputs needed on different types of the land. Suitability for each use needs to be assessed by comparing the required inputs with the yields or other benefits. This indicates that highly productive land does not necessarily give highest benefits.

(iii) Physical, economical and social context of the area: This refers to the specific crop growth requirements on one hand and their marketing values on the other. For example higher produce achieved may not be economical due to main markets located for away from the place of produce. In other words, the evaluation of the land must be done considering these parameters.

(iv) Suitability assessment: The use of land must be assessed on a sustained basis. One should not think for short term profitability but on the contrary long term productivity should be maintained. Land degradation on the cost of getting high produce must not be appreciated.

(v) Comparison of more than one single kind of use : Evaluation is only reliable if the benefits and inputs from any given kind of use are comparable with one or several different alternatives for example comparison of different crops within one management type and vice-versa.

Phases for establishing Soil Site Suitability

The integrated land evaluation system is basically based on the crop growth requirements expressed in terms of climatic, soil and physiographic criteria followed by matching of those with the corresponding environmental parameters.

The step by step methodology as suggested by FAO (1976, 1984) Sys *et al*. (1981) and Verheye (1991). Is schematically represented in figure 1. It has 5 phases :

Phase 1. Identification of land use type: Type of crop or crop variety as well as the management type under which production will take place.

Phase 2. Definition of crop growth and production conditions: Plant growth requires a reasonable moisture and nutrient supply linked to a sufficient rooting depth. The nature of constraints can broadly be defined as :

- **No limitation** - optimal characteristics with no constraints.
- **Slight limitation** - Nearly optimal for given land and affects productivity by 20% only.
- **Moderate limitation**- Moderate influence on yield decrease which reaches upto 50%. Benefits however, can still be expected.
- **Severe limitation** - Marginal influence of productivity of the land where yield decrease reaches below to the profitability level.

Phase 3. Collection of environmental data which directly affect the crop production.

Phase 4. Key operation of the evaluation procedure : It deals with the matching of the environmental condition of the area with the specific crop and production criteria. This exercise leads to the evaluation for each individual soil and climatic unit of the nature and degree of limitations.

Phase 5. Criteria of suitability classification : based on the number and degree of limitations, a scale then be established and suitable and unsuitable lands can be demarcated.

Soil site suitability criteria

FAO (1976) three category system approach of the resent evaluation procedure was introduced since the mid of seventies. The order (kind of suitability) and class (degree of suitability) are given in table 1. Further the subclass that reflect the kinds of limitation are presented in table 2.

Table 1. Three category system approach for land evaluation FAO (1976)

Order (kind of suitability)	Class (degree of suitability)
S-suitable land	S_1-Highly suitable (Optimum conditions for plant growth)
	S_2-Moderately suitable (Affecting productivity by 20% or less)
	S_3-Marginally suitable (Severe limitations but correctable)
N-Non suitable land	N_1-Non suitable but potentially suitable (slightly correctable)
	N_2- Non suitable because potentially unsuitable (non correctable)

Table 2. Kind of limitations

Limitations	Symbol	Factors
Climate	c	RF (cr), Temp.(ct), Growing season (cg)
Topography	t	Slope (ts), Relief (tr), Erosion (te)
Wetness	w	Drainage (wd), Flooding (wf)
Physical soil properties	s	Depth (sd), Stoniness (ss), testure (st), lime (sl), gypsum (sg)
Natural fertility	f	OM (fo), CEC (fc), Base status (fb)
Salinity / alkalinity	a	EC (ac), GW (ag), ESP (ae)

The recent evaluation procedure was introduced since the mid seventies by FAO (1976) and lateron the same was modified by Sys *et al.* (1981). The classes and degree of limitations are presented in table 1 and 2, respectively.

a) Parametric approach of Sys (1976)

He proposed a parametric approach for evaluating soil suitability using capability index.

$$Ci = ABCDEFG$$

Table 3: Rating for various soil properties

Symbol	Rating for	Basis for calculation
A	Texture	Taken as 100 for loam and $\leq$ 50 for clay and sand
B	Soil depth	Taken as fraction of 1
C	$CaCO_3$ status	Taken as fraction of 1
D	Gypsum status	Taken as fraction of 1
E	Salinity / alkalinity	Taken as fraction of 1
F	Drainage condition	Taken as fraction of 1
G	Topography (slope)	Taken as fraction of 1

Hence,

Ci of soil = 100 x 1.0 x 0.9 x 0.8 x 0.9 x 1.0 x 1.0

= 64.8 or 65 % i.e. suitability

Table 4. Parametric approach using capability index (Ci) Sys *et al.* 1981

Capability index (Ci)*	Suitability	Limitations	Evaluation	Symbols used
$\geq$ 80	Excellent	No	Optimal for plant growth	0
60-80	Suitable	Slight	Nearly optimal (Productivity is affected by only 20%	1
45-60	Slightly suitable	Moderate	Decline of crop yield	2
30-45	Almost unsuitable	Severe	Use of soil not economical	3
< 30	Unsuitable	Very severe	Decrease of yield below profitable level	4

*Ci = ABCDEFG
A – Rating of soil texture, B – Soil depth, C – Calcium content status, D – Gypsum status,
E – Salinity alkalinity status, F – Drainage condition, G – Topography

Soil site suitability for wheat: A case study

In order to explain the above new land evaluation approach, a case study on wheat crop has been presented in table 5, 6 and 7.

Soil site suitability conditions for various arable and nonarable crops viz., soybean, rice, cotton, wheat, sorghum, maize, eucalytus, rubber etc. have been judged and defined by a number of scientists of the country.

Table 5. Kind and Degree of limitations for wheat crop

Kind of limitation		Land utilization type	Degree of limitations				
			0 (none)	1 (slight)	2 (moderate)	3 (severe)	4 (very severe)
Climate (c)	*RF(mm)	-	>750	500-750	250-500	<250	-
	*T(C)	-	15-18	18-22	>22	-	-
Topography (t)	*slope (%)	Plain (irri)	0-1	1-3	3-8	8-15	>15
		Hill (unirri)	0-3	3-8	8-15	15-30	>30
		Sprinkler	0-8	8-15	15-30	>30	-
Wetness (w)	*Drainage	-	Well	Mod Well	Impeded excess	Poor V. Excess	V.poor
	*Flooding	-	Nil	Slight	Mod.	Severe	V. severe
Physical soil property (s)	*Depth(cm)	-	>80	50-80	20-50	<20	-
	*Stoniness	<50 cm depth	0	0	1	2	2
		>50 cm depth	0	0	0	1	1
	*Texture	-	si sil sicl scl	sc cl	sic c ls	ls fs	cs
	*Lime	-	3-5	<3,15-25	25-50	50-75	<75
	*Gypsum		0.3-2.0	<0.3, 2-5	5-10	10-25	>25
Natural fertility (f)	*Org.M(%)	-	>1.5	1-1.5	<1-0	-	-
	*PSB	-	>80	50-80	35-50	<35	-
Salinity and alkalinity (a)	*ECe	-	<2	2-4	4-8	8-15	>15
	*GW(m)	-	>1.2	1.2-0.5	<0.5	-	-
	*ESP	-	<8	8-15	15-25	25-40	>40

Table 6 : Physico-chemical properties of soils on which wheat crop is to be grown

Soil series (Say)	pH	Ece (dSm^{-1})	Clay (%)	Gyp-sum (%)	Lime (%)	CEC	Org. M. (%)	Soil depth (cm)	GW Depth (m)
A	7.0-7.9	2-8	20-40	0.3-0.8	24-27	20-25	2.0	200	5
B	7.6-7.8	8-15	27-31	1-2	23-28	16-18	1.4	200	4
C	7.0-7.8	18-25	37-46	1-5	25-28	17-25	1.7	150	1.5
D	7.0-7.7	19-38	48-53	0.2-1	24-26	23-26	1.1	<20	-

Table 7 : Degree of limitation and soil site suitability for wheat crop

Soil series	Degree of limitations due to													Overall limitation	Soil site suitability evaluated
	c	t	w		s					f		a			
	Climate	Topography	Drainage	Flooding	Depth	Stoniness	Texture	Lime	Gypsum	Org.M.	Base saturation	ECe	GW (m)		
A	1	0	0	1	0	0	0	2	0	1	0	2	0	2	S2a
B	1	0	0	0	0	0	0	1	0	0	0	3	0	3	S3a
C	1	1	1	1	0	0	0	1	0	0	0	4	0	4	N1a
D	1	2	2	1	3	0	1	1	0	0	0	4	0	4	N1as

Conclusion

India, followed the USDA system of land capability classification till 1980 (Vadivelu, 1997) but lateron started adopting FAO guidelines (FAO, 1976) and their derivatives for assessing the suitability of land for growing various crops.

Further the country, developed the modified version of land evaluation guideline (Sehgal *et al*. 1989) of FAO (1976) and Sys's (1981) by refining the soil site suitability criteria for different crops. However, still the improvements in the land evaluation approach are being made NBSS & LUP, in India.

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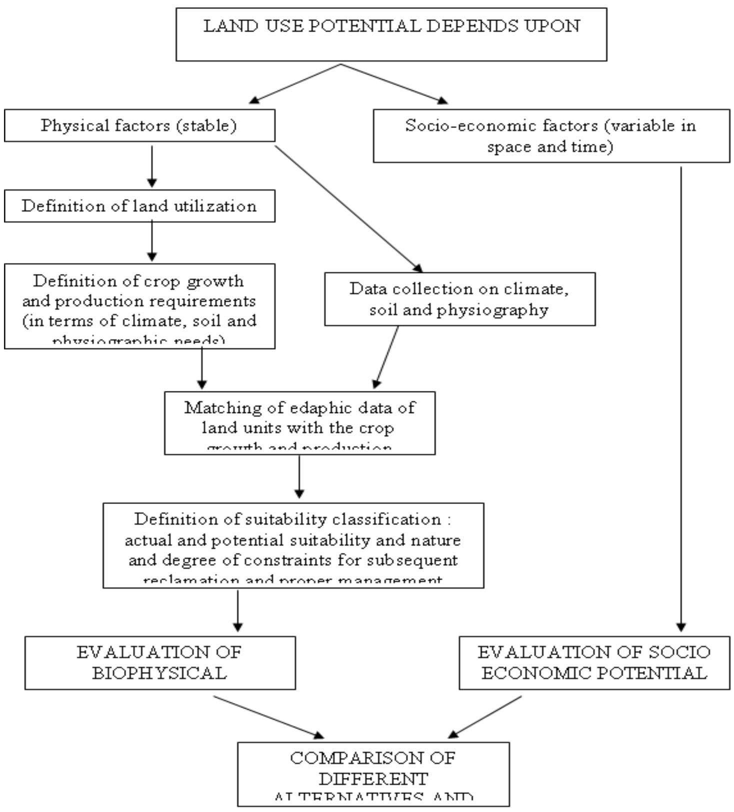

Fig. 1 : Step by step land evaluation approach (Verheye, 1991)

Biotic and Abiotic Resource Management for Eco-friendly and Sustainable Agriculture

R.D. Singh

Principal Scientist,
Division of Soil Science and Agricultural Chemistry
I.A.R.I., New Delhi-110012

Interrelationship between biotic and abiotic factors

High input agriculture coupled with cropping intensification has brought serious consequences of nutrient imbalance and deterioration of soil fertility. Most of the cultivated lands are so degraded that they become useless for any form of successful agricultural production and will remain so until land regeneration strategies are developed. Degradation of natural resources leads to loss of gene pools and biological diversity on one hand and on the other it slows down economic growth, increases the misery of people, siltation of rivers and urban migration. A disturbance is broadly defined as any event that causes a significant change from the normal pattern or functioning of ecosystem (Forman and Gordon 1986). Whether an event is considered to "cause a significant change from the normal pattern or functioning" depends on the temporal and spatial scale of interest.

Biotic and abiotic factors

Biotic, meaning of or related to life, are living factors and they can continue to reproduce their progeny. Abiotic, meaning not alive is nonliving factors that affect living organisms. They do not have capacity to reproduce and regenerate their population and non renewable. Biotic and abiotic factors combine to create a system or more precisely, an ecosystem. An ecosystem is a community of living and nonliving things considered as a unit. If a single factor is changed, perhaps by pollution or natural phenomenon, the whole system could be altered. For example, humans can alter environments through farming or irrigating. While we usually cannot see what we are doing to various ecosystems, the impact is being felt all over. For example, acid rain in certain regions has resulted in the decline of fish population. A variety of biotic factors such as pests, nematodes, diseases, etc. can reduce the net crop production. A pest causes damage to agriculture by feeding on crops. For example, boll weevil is a pest on cotton. It attacks the cotton crop, thereby reducing its yield. Weeds also reduce crop productivity by competing with the main crop for nutrients, light, and space. Abiotic factors such as salinity, temperature, etc. affect the net crop production. Some natural calamities such as droughts and floods are unpredictable. Their occurrence has a great impact on crops sometimes, destroying the entire crop.

Soil Organism

The soil is habitat for very diverse range of living organisms including fungi, bacteria and invertebrate animals. The food resource that supports these organisms is dead plant material (plant litters set by the vegetation). The soil organism utilizes this food by the source of process decomposition. The invertebrate community is very diverse with practically every major group of terrestrial invertebrates represented ranging in size from protozoa to earthworms. Certain termints, millipetes and earthworms feed directly on plant litters. Others including some protozoa and nematodes feed on bacteria. Many groups particularly some texa of collembolan and mites feed on fungi. Representatives of nearly all these groups also feed on particular organic matters. Organisms are subject to environmental pressures, but they are also modifiers of their habitats. The regulatory feedback between organisms and their environment can modify conditions over time and even after death, such as decaying logs or silica skeleton deposits from marine organisms. Ecosystem engineers are defined as organisms that directly or indirectly modulate the availability of resources to other species, by causing physical state changes in biotic or abiotic materials. In so doing they modify, maintain and create habitats. We have classified microorganisms based on their sources of energy and carbon. The cycling of carbon between carbon dioxide and organic compounds is of considerable ecological importance. In addition to eukaryotes (such as plants and algae), autotrophic bacteria (such as cyanobacteria) play an important role in the fixation of carbon dioxide into organic compounds. Consumers, in turn, use organic compounds and release carbon dioxide. Decomposition of plants and animals and their constituent organic compounds is carried out by a large number of bacteria and fungi.

Soil Organic matter

Soil organic matter is not a different requirement for plant growth. Rather, its amelioration of other direct constraints to plant performance provides an improved rooting environment. The direct soil-based constraints to plant performance include nutrient and water availability and plant toxicities. Soil organic matter dynamics and the interactions between plant constraints result from a series of plant, microbial and physicochemical processes. Decline in soil organic matter as a result of land management strategies, particularly excessive removal of crop residues and soil disturbance has an array of negative effects on plant productivity. Soil organic matter is an important regulator of numerous environmental constraints to crop productivity. Mineralization of decomposing residues is a major source of plant nutrients in highly weathered soils with little inherent mineral fertility (Sanchez *et al.*, 1989). The activities of microorganisms and soil fauna serve to promote soil aggregation (Oades, 1984), leading to reduced erosion (Lal, 1986) and greater moisture infiltration (Lavelle, 1988). Labile carbon compounds complex toxic aluminum and manganese specific characteristics of highly weathered tropical soils resulting in a more productive rooting environment (Hue *et al.*, 1986). Other important benefits resulting from the maintenance of soil organic matter in low input agro ecosystem include nutrient retention and storage (Woomer and Ingram, 1990), increased buffering capacity in low-activity clay soils and increase in their otherwise poor water-holding capacity (Lal, 1986). However, decrease in total soil organic matter as a result of land management and increase soil aeration is an almost universal event in both the temperate region (Post and Mann, 1990) and the tropics (Ayodele, 1986). Degradation of soil system through soil organic matter lost results from soil tillage (Follet and Schimel, 1989), and the clearing of natural vegetation. Even simple land perturbations such as soil mounding in low input systems are associated with a decline in soil organic matter. In many tropical cropping systems, little or no agricultural residues are returned to the soil. This leads to decline in soil organic matter (Woomer and Ingram, 1990) which results in lower crop yields (Lal, 1986).

The role of soil and climatic factors

The climatic component particularly temperature and rainfall have the greatest potential to influence the expression of many soil processes and soil properties. Soil temperature plays an important role in many processes, which take place in the soil such as chemical reactions and biological interactions. Soil temperature varies in response to exchange processes that take place primarily through the soil surface. These effects are propagated into the soil profile by transport processes and are influenced by such things as the specific heat capacity, thermal conductivity and thermal diffusivity. Similarly the rainfall its distribution and intensity has major role in influencing soil processes and crop productivity. Water is involved in most of the physical, chemical and biochemical process that operate within soils. Free draining soils in high rainfall environment provides a greater risk of loss of productivity because of the lack of synchrony than does soil with high water holding capacity in a semi arid environment. With mobile nutrients, the consequences of lack of synchrony may be negligible in low rainfall environment where the nutrients remain within the root zone. However, in a high rainfall environment, mobile nutrients may be rapidly leached below the root zone, with significant results.

Water and their role in crop production

Nutrient deficiency and toxicity's can affect WUE by altering yield, evaporation and transpiration. There are many reports that nutrient increases water use efficiency because of fertilizer application mostly increases yield, consequently increases in water use efficiency. Plant nutrients can also affect yield by influencing the flower initiation, flower fertilization and seed development.

Table 1. Grain yield of wheat under varying moisture regimes and nitrogen rates

Treatments	Nitrogen (kg/ha)			
Irrigation	0	50	100	150
RF	7.9	17.5	19.2	18.7
IW:CPE 0.40	11.7	19.8	25.0	28.1
IW:CPE 0.80	10.5	19.3	27.4	30.4
IW:CPE 1.20	9.4	21.5	26.7	31.0
CD at 5%	4.1			

The canopy temperature was measured with Infra-red thermometer and it did not vary much among nitrogen treatments. The maximum canopy temperature was noticed under rainfed treatment during course of crop growth. The canopy temperature remained lower under irrigated treatments probably due to better canopy development in turn more transpiration. The canopy temperature did not go beyond 30^{o}C in case of IW:CPE 1.20 and beyond 31^{o}C in case of IW:CPE 0.80. Due to N doses, it decreased with increase in N. Among irrigation treatments with N doses, it just ranged from 30.2^{o}C (100 kg N/ha) to 31.6^{o}C (control). In IW:CPE 1.20, it remained less than 30^{o}C mark from the first week of April. The grain yield and water use parameters of wheat are given in Table 1. The grain yield was affected significantly due to irrigation and nitrogen levels.

Characteristics of soils

The term normal, acidic, saline, saline alkali and alkali soils has been used to describe the soils under cultivation and otherwise also. These definitions are based on pH, ECe and ESP and the cation exchange capacity of the soil. The presence of excess salt impairs soil productivity. The direct effects of salts on plants growth are mainly physiological while the indirect effects are manifested through adverse salts lower the soil water potential, thus necessitating osmotic adjustment of cell sap on the part if it has to draw water from a saline soil. Certain essential and non-essential ions when taken up in excessive amount exert toxic effects on plant tissue through their effects on physiological functions of the plant. For example, excessive uptake of sodium, chloride or boron may be manifested in the necrosis of leaf margin or tips in the young plants. The indirect effects of excess salts on plants growth appear as deterioration in the supply of several essential nutrient elements and physical properties of the soil. Salt affected soils are very low in organic matter and salt affected may discourage build-up of sizable microbial population. The presence of exchangeable sodium beyond a certain limit, as determined by the amount and nature of clay minerals in the soil, disperses the soil aggregates. The dispersed clay clogs the soil pores to adversely alter the air and water relations of the soils. Water stagnation and poor soil aeration are major causes of retarded growth of many crops in alkali soils. The acidic soil has pH less than 7.0.

Table 2. Classification of salt affected soils

Soil Type	pHs	ECe (dS/m)	SAR	ESP
Normal	<8.5	<4	<13	<15
Saline	<8.5	>4	<13	<15
Saline-alkali	>8.5	>4	>13	>15
Alkali	>8.5	<4	>13	>15

Soil Resilience and Resistance

Soil resilience has been defined as the capacity of a soil to recover its functional and structural integrity after a disturbance. The functional and structural integrity are defined as a soil's capacity to perform vital soil functions such as those proposed by Karlen et al, (1997). The research approach for identifying and evaluating soil properties related to maintain essential ecological functions is based on dynamic interactions between disturbance regime, vegetation and relatively static and dynamic soil properties. Sustaining biological activity, diversity and productivity and regulating and partioning water and solute flow form core functions. The other functions like filtering, buffering, degrading, immobilizing, detoxifying organic and inorganic materials including industrial and municipal by-products and atmospheric deposition play key role. Structural integrity is linked to soil function and deals with the physical arrangements of primarily soil particles and their aggregation and affects soil physical property. Natural disturbances and causes of disturbance include fires, earthquakes, floods, landslides and high-intensity storms. Anthropogenic disturbance is nearly all human activities associated with land management and use can be classified as disturbances including logging, grazing, urban and industrial development, recreation and annual cropping. Agriculture itself is one of the greatest sources of stresses and disturbance to the environment (Brussaard 1994). Soil resistance, which is distinguished from soil resilience, has been defined as the capacity of a soil to continue to function without change throughout disturbance. The magnitude of decline in the capacity to function defines the degree of resistance to change. Land use practices are sustainable if they result in no net loss of capacity to generate products and services. Retention of this capacity depends on soil and ecosystem resistance. Most soil properties reflect current capacity. Some reflect resistance and, rarely, resilience. Consequently, we are losing production opportunities on land with low resistance but high resilience and taking unjustified risks on land with high resistance but low resilience. New properties must increasingly reflect soil processes. The properties must reflect ecosystem response to both chronic and episodic stressors, including extreme events. Resistance and resilience must be evaluated at multiple time scales

Case study of Himalaya

The Indian Himalayan region occupies a special place in the mountain ecosystems of the world. Assessing soil biodiversity which has a direct bearing on soil health is of paramount importance to develop potential strategies for improving agricultural sustainability. An investigation was undertaken to assess soil microbial groups and related biological and biochemical indicators in different land use systems, ranging from undisturbed natural (protected) forests dominating oak or deodar or pine trees (approx. age >100 years), orchards dominated by apple trees, and crop based systems (e.g., fodder, maize or soybean-wheat, organic farming) in the uplands and valleys

These land use systems are located from 800 m to 2500 m above the mean sea level. Results have clearly revealed the erosion of microbial biomass C from the highest of 1073 mg kg^{-1} in the undisturbed deodar forest (Chaubatia, Ranikhet) at the elevation of 1800 m to as low as 300 mg kg^{-1} in the apple plantation (Chaubatia, Ranikhet). Similarly, it varied with the dehydrogenase (3-15 mg TPF kg^{-1} h^{-1}) and acid (158 to 901 mg kg^{-1}) and alkaline phosphatase (58–233 mg kg^{-1}) activities. It was evident that bacterial population was 200-300% higher in forest ecosystems than cultivated crops. Soils under pine forests invariably showed very low microbial populations and their activities. Nitrification rates and population of nitrifying organisms were lower in forest ecosystems. Decrease in microbial abundance of individual group and diversity have been indicated from undisturbed forest to cultivated lands. At 15-30 cm depth these parameters reduced by 50 – 250%. In general undisturbed forests systems (Oak, Deodar, Pine) had almost 200-300% higher of these biological and biochemical parameters than that of cultivated systems.

Anthropogenic conversion of natural forest ecosystem to agro-ecosystems affects the soil biota and their resilience to sustain soil fertility. Interestingly, fungal population in the surface layer was recorded very low in soils under Pine and fodder crops. Population of *Actinomycetes* was highest in mixed forest followed by Oak, and Deodar. Like bacterial and fungal densities, pine, fodder and apple plantations showed lower population of *Actinomycetes.* Nitrification rates and population of nitrifying organisms (ammonia and nitrite oxidizing bacteria, AOB and NOB) were much higher in the surface layer in these systems. Deodar and organic farming showed higher densities of AOB than rest of the systems. However, a tendency of higher NOB was evident in cultivated systems. In general, there was a decrease in microbial abundance of individual group and diversity when undisturbed forest was converted to cultivated lands. The trend with the fungal population was similar, which was highest in mixed forest (53.6 x 10^5 g^{-1} soil), followed by Oak and Deodar.

Genomic DNA extracted from the soils and subsequent PCR of RISA of 16S-23S rRNA gene has revealed the distinct genetic finger prints of the bacterial communities under different land use systems. With regard to C and N sequestration, it has been noticed that Oak Deodar and mixed forest systems maintained highest level of organic C (2.5-3%). Whereas, pine forest and apple plantation recorded lower values of SOC. In agro-ecosystems SOC was highest in organic farming and upland rice systems may be because of regular application of FYM/compost. With regard to N cycling in the studied systems, soil under Deodar forest contained highest inorganic N (NH_4^+ + NO_3^-) and closely followed by mixed forest and Oak forest. Soils under pine forest and apple plantation had lower inorganic N. In case of cultivated soils, organic farming contained highest mineral N followed by rice and soybean-wheat systems. Potential nitrogen mineralization (PNM), which is also an indicator of quality of soil organic matter, varied narrowly in the range of 16-17 mg $kg^{-1}day^{-1}$ indicating close similarity of the quality of resident soil organic matter in the forest ecosystems in this study. Potential nitrate reductase activity, which is also an indicator of denitrification, was highest in mixed forest (16.8 mg NO_3^--N kg^{-1}) followed closely by Oak and Deodar. Soils under pine, apple plantation and cultivated crops showed more or less similar values, except upland rice which had comparatively higher NO_3^--N reductase than other systems in cultivated systems. Nitrification rates and population of nitrifying organisms (ammonia and nitrite oxidizing bacteria, AOB and NOB) were much higher in the surface layer in mixed forest, Oak and Deodar. AOB was invariably higher than the NOB. Deodar and organic farming showed higher densities of AOB than rest of the systems.

Conclusion

We have described the processes which maintain the natural integrity of natural ecosystems and mechanism buffering the extremes effects of climate and perturbations on soil. Traditional farming system continued over centuries have low external inputs including management practices based on their intuitive understanding farmers have developed around these principles. Intensification of these systems has frequently resulted in declining yield as a consequence of one or more component parameters. Conservation agriculture and improved regulation of soil biological processes through improved management strategies play and important role in reducing soil resource losses. The fertility of soil is central to the sustainability of both natural managed ecosystems because it is the medium from which terrestrial production emanates. It is recognized that the intervention of humans has resulted in the creation of many systems where there is substantial degree of asynchrony of nutrient release and demand.

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Micronutrients Management for Sustainable Crop Production

R.S. Khamparia

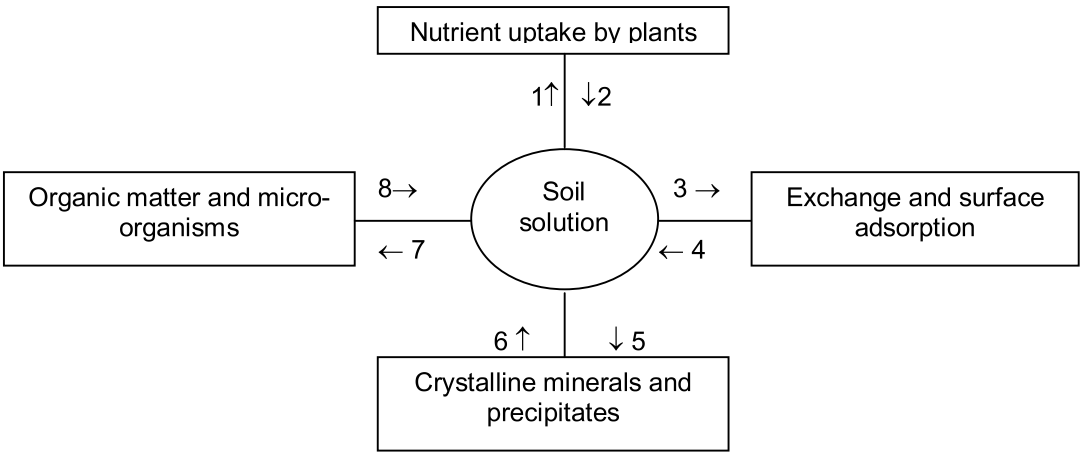
Ex. Dean and Professor
JN Krishi Vishwa Vidhyalaya, Jabalpur-482004 (MP)

In the era of exploitive agriculture intensive cropping is done using modern agricultural technology, high yielding varieties, irrigation and inorganic fertilizers. Application of NPK fertilizers have created the problem of micronutrients. Deficiencies of micro-nutrients especially of Zn and Fe have been reported widespread. In states like Punjab heavy use of inorganic fertilizers have imposed the problems of Mn, Cu and B deficiency. For sustaining the productivity it is essential to ameliorate the deficiency of micronutrients, and use balanced nutrition of crops.

Natural occurrence of the micronutrient elements

Zinc	Important ore minerals are sulphides - Sphalerite (ZnS) and less important smithsonite ($ZnCO_3$).
Copper	Important minerals are sulphides : Chalcopyrite ($Cu FeS_2$), digenite (Cu_9S_5) Chalcocite (Cu_2S), Bornite (Cu_5FeS_4), Enargite ($Cu_3 As S_4$) and Tetrahedrite ($Cu_{12} SB_4 S_{13}$)
Iron	Important ore minerals are oxides - hematite (Fe_2O_3) and magnetite (Fe_3O_4). Other minerals are goethite ($FeOOH$) Ferrihydrite [$Fe(OH)_3$], siderite ($FeCO_3$), Jarosite [$KFe_3(OH)_6 (SO_4)_4$], Ferromagnesian silicates.
Manganese	Important minerals are oxides - Pyrolusite (MnO_2) Psilomelane ($BaMn_9O_{18}.2H_2O$). Locally important are Rhodochrosite ($MnCO_3$) and Braunite ($Mn SiO_3$).
Molybdenum	Important ore is sulphide - Molybdenite (MoS_2).
Boron	Economic sources are borates eg Borax $Na_2 B_4 O_5 (OH)_4.8H_2O$, Tourmaline [$Na(Mg, Fe, Mn Li, Al)_3 Al_6 (Si_6O_{18}) (BO_3)_3 (OH, F)_4$ is a common accessory mineral.

Dynamic equilibrium in soils



Soils change constantly due to fluctuating temperature, moisture and biological activity Equilibrium is never attained.

Role of micronutrients in plant Nutrition

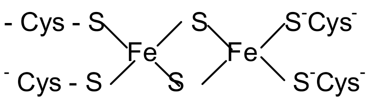
Iron (Fe)

Iron as a transition element is characterized by easy change of the oxidation state ($Fe^{III} \Leftrightarrow Fe^{II}$) and its ability to form octahedral complexes with various ligands. Main oxidation state in plants is Fe^{III}. Ferrous form and highly toxic free Fe^{2+} ions are normally below the detection limits.

There are two major groups of Fe containing proteins : heme proteins and Fe-S protein.

Heme proteins - Cytochromes-heme Fe-porphyrin complex as a prosthetic group cytochrome oxidase, catalase, peroxidase and leghemo globin which occur in root noduels of legumes.

Fe-S proteins - Fe is coordianted to the thiolgroup of cysteine or inorganic S as clusters or to both.



Most well known Fe-S protein is ferridoxin. Other Fe-S proteins have functions in metabolic processes, such as photosynthesis, SO_4 and SO_3 reduction respiration, tricarboxylic acid cycle and N_2 fixation. Fe activates a number of enzymes including aminolevulinic acid synthetase, coproporphyrinogen oxidase and plays a role in the synthesis of RNA.

The photosynthetic electron transport chain in the thylakoid membrans of chloroplast consists of various Fe containing heme groups and Fe-S clusters.

Therefore in case of Fe deficiency there is decrease in concentration of schlorophyll and other pigments like carotene and xanthophyll whereas respiration remains unaffected. Thus, chloroplast development is mainly affected. It decreases the chloroplast volume and protein content per chloroplast.

It is also involved in lipid metabolism due to suppression activity of lipoxygenase is affected.

Critical tissue concentration and deficiency symptoms

About 80% of Fe in leaves is localized in the chloropast. Critical deficiency concentration (CDC) of Fe in leaves range from 30 to 50 mg kg^{-1}. It is high in fast growing meristematic and expanding tissues upto 200 mg kg^{-1} (total Fe) and 60 to 80 mg kg^{-1} for HCl extractable Fe (active Fe). Critical toxicity concentration (CTC) for total Fe is quite high ranging from 400 to 1000 mg kg^{-1}.

First visible symptoms in shoots are chlorosis of young leaves though leaves expand normally. It is reversible due to Fe spray unless necrotic spots occur with severe deficiency. In case of acute deficiency cell division is inhibited thus leaf growth is impaired.

Manganese (Mn)

In plants Mn is present as Mn^{II} forming relatively weak bonds with organic ligands, in which it can be readily oxidized to Mn^{III}, Mn^{IV} and Mn^{VI}. Due to its relative ease in undergoing change in oxidation state, Mn plays an important role in redox processes such as electron transport in photosynthesis and detoxification of oxygen free radicals. Mn is involved in photosynthetic O_2 evolution (Hill reaction) in chloroplast. Electrons are liberated by the water splitting enzyme "S" which contain 4 Mn atoms. Due to its key role in water splitting reaction Mn deficiency primarily affect photosynthesis and O_2 evolution, the chloroplast structure and chlorophyll concentration may not be affected in case of mild deficiency however in case of severe deficiency their concentrations is also reduced. Resupplying of Mn improves O_2 evolution within 24 hours whereas ultra structure of chloroplasts and chlorophyll formation are more difficult to restore.

As with other super oxide dismutase (Cu-Zn-SOD) and (Fe-SOD) Mn-SOD also play an important role in protecting cells against deleterious effects of super oxide free radicals which are formed in various biochemical reactions in which O_2 is involved. The Mn-SOD is present in mitochondria, peroxisomes and glyoxysomes.

In carbohydrate metablism, Nicotinamide adinine dinucleotide (NAD) and phosphoenols pyruvate carboxy kinase have an absolute requirement of Mn which cannot be substituted by Mg. There is reduction in cell elongation (not cell division) due to Mn deficiency, inhibition in synthesis of lipids and gibberalic acid and isoprenoids. Lower concentration of phenolics, lignin and flavonoids in Mn deficient plants be partly responsible for a decrease in disease resistance of Mn deficient plants.

Critical tissue concentration and deficiency symptoms - CDC of Mn range from 10 to 15 mg kg^{-1} in mature leaves for shoot dry matter production and for seed production it is much higher 30 mg kg^{-1} than for photosynthesis (17 mg kg^{-1}).

CTC varies widely from 100 in beans to 650 in clovers and 5000 mg kg^{-1} in low land rice depending upon cultural practice, Si supply, temperature, moisture, pH and light intensity.

Deficiency symptoms - Cereals - Greenish gray spots, flecks and stripes on the more basal leaves (Grey speck).

Dicots - Interveinal chlorosis of younger and middle aged leaves.

In contrast to Fe chlorosis, the chlorosis induced by Mn deficiency is not uniformly distributed over the whole leaf blade and tissue may rapidly become necrotic. Preferential transport of Mn from roots to shoot apex may explain why the deficiency symptoms are often move sever on middle leaves than on the younger leaves. Seed disorders in Mn deficient legumes such as dark discolouration on cotyledons of pea and other legumes (Marsh spots) and cracks of the testa in lupin seeds (split seeds).

Copper

Cu forms stable chelates and easy electron transfer $Cu^{II} \Leftrightarrow Cu^{I}$ and thus had importance in physiological redox processes. In contrast to Fe, Cu containing enzymes can react directly with molecular O_2 and catalyse preferentially terminal oxidation processes.

Photosynthetic electron transport is influenced by Cu at various sites. Due to Cu deficiency the plastocyanin content is affected which result in a decreased photosynthetic electron transport.

Cu-Zn-SOD mainly localized in the slroma of chloroplast where the Cu atom is directly involved in the detoxification of super oxide radicals O_2^- generated during photosynthesis.

CO_2 fixation is decreased and the concentration of starch and soluble carbhydrates (sucrose) in plants causing low dry matter yield. Reduction of seed yield occur even with mild Cu deficiency, mainly as a result of male sterility.

Cu deficiency in legumes depresses nodulation and N_2 fixation rate leading to N deficiency symptoms as an indirect effect.

Cu containing enzymes - phenolase and laccase act as oxidases of phenols or tyrosin in biosynthetic pathway of quinones, alkaloids or lignin.

Inhibition in IAA oxidase activity due to Cu deficiency causes accumulation of IAA and delayed flowering and senescence. Cu deficiency depresses reproductive growth more than the vegetative growth.

Ascorbate oxidase activity is markedly reduced with Cu deficiency.

Critical tissue concentration and deficiency symptoms - The CDC of Cu in vegetative organs ranges from 1 to 3.5 mg kg^{-1} in youngest emerged leaf which is least affected by environmental factors.

For most crops CTC of Cu in leaves are 15 to 30 mg kg^{-1} and may be as high as 1000 mg kg^{-1} in Cu tolerant species.

Deficiency symptoms - Chlorosis (white tip, reclamation disease), necrosis, leaf distortion and dieback. Symptoms occur preferentially in young shoot tissues and are expression of poor redistribution of Cu in Cu deficient plants.

Enhanced formation of tillers (cereals) and auxillay shoots (dicots) are secondary symptoms caused by necrosis of apical meristems.

Reduced lignification due to Cu deficiency leads to other symptoms like wilting, shoot bending, lodging, mainly of cereals and reduced disease resistance. The most important symptoms are reduced seed or fruit yield caused by males sterility.

Molybdenum (Mo)

Transition element Mo exists in plants as an anion, primarily in its highest oxidized form Mo^{VI}, but also as Mo^{IV} and Mo^{V}. Its functions are related to electron transfer reactions. In higher plants Mo containing enzymes are NO_3 reductase and SO_3 oxidase. In legumes - nitrogenase and xanthine dehydrogenase.

Nitrate in cytoplasm is reduced to NO_2 by direct transfer of electrons from Mo^{VI} to NO_3 by nitrate reductase enzymes. There is direct relationship between Mo and RNA and growth. Compared with plants supplied with NO_3-N, plants with NH_4-N supply have a much lower requirement of Mo.

With Mo deficiency there is increase in concentration of soluble N compounds such as amides whereas protein concentration and alanine amino transferase activity decreases. The role of Mo in protein synthesis may be due to its effect on chlorophyll concentration, chloroplast structure and growth.

Biological N_2 fixation is catalysed by nitrogenase which contains two metalloproteins; Mo-Fe-S protein and Fe-S cluster protein, Mo of Mo-Fe-S protein directly transfer electron to N_2 whereas Fe acts as an electron transmitter. Thus Mo requirement for root nodules in legumes is quite high. In case of Mo deficiency the number of nodules may increase but the total dry weight of nodules per plant and N_2 fixation capacity are low and plant growth is inhibited.

As an effect on pollen formation, tasseling, anthesis, and development of anthers in corn are inhibited by Mo deficiency.

Critical tissue concentration and deficiency symptoms - Mo requirement by plants is lowest amongst the micronutrients and also depend on form of N supply. The **CDC** vary between 0.1 to 1.0 mg kg^{-1} in leaves. Legumes require higher Mo than other plant species. **CTC** vary widely from 200 to 1000 mg kg^{-1}.

Mo deficiency symptoms are not confined to the youngest leaves because Mo is readily translocated in the plants. Symptoms of N deficiency dominate in Mo deficient legumes. Most characteristic symptom is reduced and irregular leaf blade formation; known as whiptail. This malformation is caused by local necrosis in tissue and insufficient differentiation of vascular bundles in the early stages of development. Other symptoms are interveinal mottling and marginal chlorosis of the older leaves followed by necrotic spots at leaf tips and margins, which are closely related to high NO_3 concentration in the tissue.

Zinc (Zn)

In contrast to other micronutrients (Fe, Mn, Cu and Mo) Zn is not subject to valancy change and exist in plants only as Zn^{II}. Zn mainly functions as divalent cation by coupling enzymes with corresponding substrates and forming tetrahedral chelates with different organic compounds including poly peptides.

In higher plants Zn containing enzymes are Alchol dehydrogenase, Cu-Zn-SOD, carbonic anhydrase (CA) and RNA polymerase.

However, large number of enzymes are activated by Zn either by binding substrate enzymes or substrate and enzymes or effect on conformation of enzymes or both. In Zn deficient plants there is change in metabolism of carbohydrates, proteins and auxins and impaired membrane integrity. A key role of Zn in gene expression and regulation has been reported. Incase of extreme Zn deficiency net photosynthesis is inhibited due to disturbed chloroplast structure and inhibited photosynthetic electron transfer rather than due to reduction in CA activity.

Excretion of sugars at the leaf surface can be observed with severe Zn deficiency. Alcohol dehydrogenase (ADH) plays important role in anaerobic root respiration (e.g. in the root apex of flooded rice) catalyzing the reduction of acetaldehyede to ethanol, hence anaerobic root metabolism is impaired due to reduced activity of ADH under Zn deficiency.

Protein synthesis is inhibited under Zn deficiency due to marked decline of RNA; either by lower activity of the Zn containing RNA polymerase, by reduced structural integrity of ribosomes, or by enhanced RNA degradation.

The Zn containing isoenzyme SOD (Cu-Zn-SOD) plays an important role in the detoxification of super oxide radical (O_2^-) and, thus, in the protection of membrane lipids and proteins against oxidation. The activity of Cu-Zn-SOD is reduced with Zn deficiency but can be restored by addition of Zn.

There is impaired conversion of tryptophane to IAA under Zn deficiency resulting inhibition in protein synthesis. GA (Gibbrellic acid) metabolism is also impaired under Zn deficiency.

Due to preferential binding to SH groups, Zn plays a key role in stabilizing and structural orientation of membrane proteins. Loss in membrane integrity of Zn deficient plants increases susceptibility to fungal diseases and excessive P uptake by roots and transport to shoots may cause P toxicity.

Critical tissue concentrations and deficiency symptoms - CDC in leaves range from 15 to 30 mg kg^{-1} **CTC** or Zn in leaves of crop plants ranged from 200 to 500 mg kg^{-1}.

Most characteristic **visible symptom of Zn deficiency** in dicots are short internodes (rosetting) and decrease in leaf expansion (little leaf), stunted growth is often combined with clorosis of youngest leaves.

In monocots particularly in corn, chlorotic bands occur along the midribs of leaves combined with red, spot like discolouration. In rice brown spots on leaves (khera disease). Zinc deficiency symptoms on older leaves are mainly the results of P toxicity and are characterised by interveinal chlorosis and necrosis stunted growth and necrosis of older leaves in Zn deficient plants are intensified with high light intensity suggesting the involvement of super oxide radicals in symptom development.

Boron (B)

Only monomeric species of B i.e. B $(OH)_3$ and $B(OH)_4^-$ are usually present in aqueous solution.

Boron is neither an enzyme constituents nor does affect enzyme activity. Boric acid forms very stable complexes with organic compounds.

Most of the functions of B are related to cell wall formation, stabilization, lignification and xylem differentiation. B is said to be extra cellular nutrient.

Due to B deficiency there is change of the chemical composition of cell wall. As a result there is cell wall thickening in root apical meristems, increase in hemicellulose and pectin, disturb cell wall synthesis is also indicated by a decrease in elongation of cotton fibre suffering from B deficiency, phenol metabolism, impairment of plasma membrane restricted growth and elongation. Decreased growth may also be attributed by decrease in concentration of nucleic acid. Decrease in RNA levels precedes cessation in cell division.

The pollen germination and pollen tubes growth, viability of pollen grains are severely inhibited by B deficiency. For pollen tube growth, high B levels in the stigma and style are required for physiological inactivation of callose by formation of borate callose complexes at the pollen tube style interphase. On the basis of these functions of B in reproductive organs, seed and grain production is much more reduced than vegetative growth with low B supply.

Critical tissue concentration and deficiency symptoms

CDC in monocots	5 to 10 mg kg^{-1}
Dicots	20 to 70 mg kg^{-1}
Latex bearing plants	80 to 100 mg kg^{-1}

These differences are related to cell wall composition. In soybeans the CDC of B for young leaflets is about 3 to 4 times higher than the mature leaves, reflecting the main function of B in cell growth and differentiation.

The concentration range between B deficiency and toxicity is quite narrow, so special care is required when B fertilizers or municipal compost rich in B are applied or when irrigation water rich in B concentration is used. The **CTC** in leaves differ considerably among plant species and cultivars within a species e.g. 100 mg kg^{-1} in corn, 400 mg kg^{-1} in cucumber and 1000 mg kg^{-1} for squash and between 100 to 270 mg kg^{-1} in wheat genotypes.

Boron deficiency symptoms : Appear at the terminal buds and youngest leaves as retarded growth and necrosis. Internodes are shorter, leaf blades are misshaped and the diameter of stem and petioles are increased leading to stem crack in celery, water soaked areas tip burn and brown or black heart in heads of vegetable crops, such as lettuce. During storage roots of celery or sugar beet necrosis of meristmetic area leads to the typical heart rot. Boron deficiency induced increase in the drop of buds, flowers, and developing fruits. Reduction in or failure of seed and fruit set and the quality of fruit is affected by malformation (e.g. internal cork in apple or in citrus decrease in the pulp/peel ratio.

Chlorine (Cl)

Chlorine is abundant in lithosphere and atmosphere. It is highly mobile and easily taken up by plants. Average Cl concentration in plants ranges from 1 to 20 g kg^{-1} and thus is in range of macronutrients whereas requirement is much lower (150 to 300 mg kg^{-1}). Its functions are mainly as mobile anion Cl^- in processes such as osmoregulation (e.g. cell elongation, stomatal opening) and charge compensation in higher plants.

Chlorine acts as a cofactor to activate the Mn containing water splitting system, helps in stomatal opening, K metabolism. Depresses the diseases such as gray leaf spots in coconut palm, take all in wheat, stalk rot in corn and downy mildew in millet.

Critical tissue concentration and deficiency symptoms

The CDC for optimal growth varies between 70 mg kg^{-1} for tomato, and 1000 mg kg^{-1} for kiwi (Actinidia deliciosa). The CTC is about 3 to 5 g kg^{-1} and 20 to 40 g kg^{-1} for Cl sensitive and tolerant species, respectively.

Deficiency symptoms - Wilting of leaves curling of leaf lets, bronzing and chlorosis similar to those of Mn deficiency and inhibition of root growth

Factors affecting availability of micronutrients

A. Boron

Boron deficiency is higher under low top soil moisture conditions more in dry summer.

(i) **Temperature** : B uptake is largely a physical process involving the absorption of unionized H_3BO_3 and subsequent passive movement of B in the transpiration stream. Temperature correlated with B uptake by shoots.

(ii) **Soil water content** : Heart rot of sugar beet accentuated by drought stress. The disease was due to lack of B. Moisture stress in the surface soil accentuated B deficiency in alfalfa, apple and cotton. According to Batey (1971) turnip normally became B deficient on soils with < 0.3 mg kg^{-1} of extractable B. However, deficiency in a dry summer was observed in fields with extractable B levels of 0.5 to 0.6 mg kg^{-1}.

Boron toxicity is chiefly affected by the concentration of B in soil water. Tips and margins of older leaves are first affected. Increasing transpirations as a consequence of high temperatures and low humidity probably accentuates the occurrence of B toxicity in irrigated areas.

(iii) Light : High light intensity or long day conditions intensify B deficiency.

Critical limits of micronutrients

Nutrient	Extractant	Thresh hold value (mg kg^{-1})
Zn	DTPA (Lindsay and Norvell 1978)	0.5 to 0.7
Cu	---do----	0.2 to 0.5
Fe	----do----	2 to 4.5
Mn	-----do-----	1-2
Mo	Acid ammonium oxalate (pH 3.3)	0.05 to 0.1
B	Hot water soluble	0.1- 1.0 (0.5)

Approximate concentrations of micro-nutrients in mature leaves

Micro nutrient	Deficient	Sufficient or normal	Excessive or toxic
	--------------- mg kg^{-1} ---------------		
B	5-30	10-20	50-200
Cl	< 100	100-500	500-1000
Cu	2-5	5-30	20-100
Fe	< 50	100-500	> 500
Mn	15-25	20-300	300-500
Mo	0.03-0.15	0.1-2.0	> 100
Zn	10-20	20-100	100-400

Relative sensitivity of few crops to micronutrient deficiency

Crops	Sensitivity to micronutrient deficiency					
	B	Cu	Fe	Mn	Mo	Zn
Alfalfa	High	High	Medium	Medium	Medium	Low
Barley	Low	Medium	High	Medium	Low	Medium
Bean	Low	Low	High	High	Medium	High
Carrot	Medium	Medium	Medium	Medium	Medium	Medium
Cauliflower	High	Medium	High	Medium	High	Low
Clover	Medium	Medium	Medium	Medium	Medium	Low
Corn	Low	Medium	Medium	Medium	Low	High
Grasses	Low	Low	High	Medium	Low	Low
Lettuce	Medium	High	Medium	High	High	Medium
Oat	Low	High	Medium	High	Low	Low
Onion	Low	High	High	High	High	High
Pea	Low	Low	Medium	High	Medium	Low
Potato	Low	Low	Medium	High	Low	Medium
Radish	Medium	Medium	Medium	High	Medium	Medium
Sorghum	Low	Medium	High	High	Low	High
Soybean	Low	Low	High	High	Medium	Medium
Sudan grass	Low	High	High	High	Low	Medium
Tomato	Medium	Medium	High	Medium	Medium	Medium
Wheat	Low	High	Low	High	Low	Medium
Rice	Low	Medium	Medium	Medium	Low	High

Soil application of micronutrients

B	Legumes and root crops 2 to 4 kg B ha^{-1} other crops 1 kg B ha^{-1}. Generally broadcasted in soil. Foliar sprays in perennial crops @ 300 to 600 mg B L^{-1}. Residual effect - longer residual effect on high silt and clay soils than sandy soils. Lower solubility material have more residual effect. A broadcast of 2 kg B ha^{-1} as Borate on loam soils provided sufficient B for 2 years.
Cu	Basic Cu sulphate Cu $SO_4.5\ H_2O$ and synthetic chelates e.g. Cu EDTA and Cu HEEDTA are used to correct Cu deficiency cupric sulphate is most common fertilizers. Method - 3.3 to 14.5 kg Cu ha^{-1} as broadcast depending upon the soil and sensitivity of crops. Lower rates are required when applied as band placement as 1.1 kg Cu ha^{-1} for vegetables, and 6.6 kg Cu ha^{-1} for highly sensitive crops grown on organic soils. Foliar 0.25 to 0.5% Cu $SO_4.5H_2O$ spray is done on citrus trees. Residual effect of soil application lasts upto 5 to 8 years.
Fe	Deficiency occur mainly on alkaline and calcareous soils under high moisture conditions. Source of fertilizer - Most common ferrous sulphate containing 19% Fe ferrous ammonium sulphate 14% Fe Iron frits 20 to 40% Fe. Organic chelates NaFe EDTA — 5 to 14% Fe NaFe HEDTA — 5 to 9% Fe NaFe EDDHA — 6% Fe Iron ligno sulphonate — 5 to 8% Fe Iron methoxyphenyl-propane Fe MPP — 5% Fe

Fe application method and rates

Soil application of inorganic Fe sources are ineffective in controlling Fe chlorosis except when applied at very high rates.

Broadcast application of $FeSO_4$ is not recommended. The $Fe(NH_4)_2(SO_4)_2$ by product of P fertilizer industry was more effective than $FeSO_4$. In rice banding of 30 kg Fe ha^{-1} as $FeSO_4$ was found effective. Iron chlorosis in trees may also be controlled by the injection of $FeSO_4$ or $FeNH_4C_6H_4O_7$ solutions.

At most soil pH levels Fe EDDHA is effective whereas Fe EDTA is effective in acid soils. A soil application of 0.25 kg Fe ha^{-1} as Fe EDDHA $\equiv$ 50 kg Fe ha^{-1} as $FeSO_4$. Soil injection of Fe EDDHA was effective for correcting Fe chlorosis in trees. Same material can be applied in drip irrigation at low Fe rates.

Foliar application

Foliar repeated application of Fe are necessary as translocation of Fe is not sufficient. 2 to 3% $FeSO_4$ solution spray are recommended. Residual effect of soil application of Fe is very little.

Manganese

Deficiency occur in organic, alkaline and calcareous soils and poorly drained acidic soils with sandy texture.

Sources of fertilizers : Organic and inorganic compounds of Mn are used. Most common sources is $MnSO_4$. Other sources are MnO, $MnCl_2$ frits or oxysulphates.
$MnSO_4$ - 23-28% Mn, $MnCl_2$ 17% Mn, Mn frits 10 to 35% Mn, Mn -40% Mn manganese oxysulphate 28% Mn.

Organic compounds

Mn chelates Na_2 Mn EDTA	5 to 12% Mn
Mn ligno sulphonate	5% Mn
Mn polyflavonoid	5 to 7% Mn

Soil application : 5 to 22 kg Mn ha^{-1} as broadcast in soybean. Banding 3 kg Mn as $MnSO_4$ in soybean or 1 kg Mn ha^{-1} as Mn ligno sulphonate, Mn DTPA, Mn EDTA corrected Mn deficiency.

Foliar spray : Foliar application is effective in barley, corn, fruit trees, oat, safflower and soybeans. Rates from 0.3 to 5.4 kg in 31 to 230 L water ha^{-1} were used to correct Mn deficiency as $MnSO_4$. Multiple application of Mn was superior to single application of foliar spray. Other organic chelates may be also used in foliar sprays. No significant residual effect of soil application exist.

Molybdenum

Ammonium (54% Mo) and sodium molybdate (39% Mo) are common sources of Mo fertilizers besides Mo frits 2 to 3% Mo are also available.

Soil application : Rate of 0.1 to 0.5 kg Mo ha^{-1} correct Mo deficiency.

Seed treatment : 0.2 mg Mo kg^{-1}
Foliar spray : 100 g Mo ha^{-1}

Zinc

Source of Zn fertilizers

Zinc ammonia complex Zn NH_3	10% Zn
Zinc carbonate	52-56% Zn
Zinc chloride	48-50% Zn
Zinc frits	10-30% Zn
Zinc nitrate $Zn(NO_3)_2.6H_2O$	22% Zn
Zn O	50 to 80% Zn
Zinc oxysulphate	40 to 55 % Zn
Zinc sulphate heptahydrate	23% Zn
Basic zinc sulphate $ZnSO_4.4Zn(OH)_2$	55% Zn
organic compounds	
Zinc chelate Na_2Zn EDTA	14% Zn
Na Zn HEDTA	9% Zn
Na Zn NTA	9% Zn
Zinc ligno sulphonate	5 to 8% Zn
Zinc poly flavonoid	5 to 10% Zn

Application methods and rates

Soil application @ 5 to 10 kg Zn ha^{-1} depending upon the soil type and crops as broadcast is recommended. Foliar application of 0.5 to 1.0% $ZnSO_4$ may be done two to three times in standing crops to correct Zn deficiency. Lower rates of broadcast Zn as organic than as inorganic source can be used preferably.

Residual effect has been observed for 4 to 5 years however research conducted in M.P. reported for 6 succeeding crops.

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Enhancing Biotic Carbon Sequestration for Sustainable Agriculture

D.K. Benbi

ICAR National Professor
Department of Soil Science, Punjab Agricultural University, Ludhiana
Email: dkbenbi@gmail.com

The significance of soil organic matter (SOM) to soil fertility, crop productivity and terrestrial cycling of carbon (C), nitrogen (N) and sulfur (S) has long been recognized. Soil organic matter (SOM) is an essential reservoir of carbon, nutrients, and energy in the cycle of life. It plays several functions, the relative importance of which differs with soil type, climate, and land use. Though SOM constitutes only a small fraction of the total mass of mineral soils, it exerts a profound influence on physical, chemical and biological functions. It imparts desirable physical environment to soils by favorably affecting soil structure expressed through soil porosity, aggregation and bulk density, and soil water storage (Benbi *et al*. 1998; Benbi and Nieder 2003). It also exerts a significant influence on chemical properties of soils, nutrient availability (Benbi and Biswas, 1997), cation exchange capacity, and retention and mobilization of metals. Ion Exchange capacity and the retention of metals increase following addition of organic matter. Other soil chemical properties such as pH, electrical conductivity, and redox potential are determined greatly by the quality and content of SOM. One of the most fundamental functions of SOM is the provision of metabolic energy, which drives soil biological processes. Strong dependencies exist between the different groups of functions. For example, the ability of organic matter to chelate multivalent cations can affect its potential to stabilize soil structure as well as its biodegradability. The effects of organic matter on soil properties often involve interactions with the soil mineral fraction with the consequence that variations in soil properties across different soils may be a consequence of both variations in the SOM quality and quantity and in the mineral soil components.

Soil organic component represents the living and dead organic matter in the soil. The living organic matter is represented by plant roots, soil animals and microbial biomass and the dead organic matter is formed by chemical and biological decomposition of organic residues. The dead organic matter may be differentiated into unaltered material (in which morphology of the original material still exists) and the altered or the transformed products (also called humus). Generally, soil humus is defined as a mixture of dark, colloidal polydispersed organic compounds with high molecular weights and relatively resistant to decomposition. The final products of organic matter decomposition in soil accumulate as humus (termed soil organic carbon) and disappear as CO_2. Practices and conditions that favor higher and faster evolution of CO_2 oppose build-up or maintenance of organic carbon (also known as C sequestration) in soils. The importance of C transfer from soils to the atmosphere lies not only on the global C cycle but also on the potential of soils to produce food, fiber, and fuel. As of today, more terrestrial organic matter has been lost in the form of CO_2 than it has been sequestered in soils. This is evidenced by 28% increase (change from 280 ppm to 365 ppm) in CO_2 load of earth's atmosphere over the last 60 years. During the 19^{th} century until the 1940s, changes in C emissions from terrestrial ecosystems were dominated by the expansion of agriculture in the middle and high latitudes. Since the 1950s, emissions from the tropics have increased due to changes in land use. These losses from soils that are already of low fertility are clearly of concern in relation to future productivity.

Carbon Pool Sizes

The global pool of SOM is estimated to contain about 1500 Pg C (Batjes, 1996). This compares with estimates of 600-700 Pg C in above-ground biomass, 800 Pg C in atmosphere, and about 40,000 Pg C in the oceans. The geologic C pool comprises 5,000 Pg with 4,000 Pg C as coal, 500 Pg C as gas and 500 Pg C as oil. Majority of soil organic carbon (SOC) is associated with organic matter, although charcoal may be an important constituent in ecosystems subject to frequent fires. Reserves of inorganic carbon (as carbonate) stored in soils have been estimated to be about 720 Pg C.

Climate and vegetation are important factors controlling SOC levels. Among forest ecosystems, mean values for soil C increase from the lowland tropics to the boreal region. Lowland tropical forests are not greatly different from temperate forest soils in terms of SOC content. High rates of SOM production in the tropics are accompanied by high rates of decomposition. Although plant production is lower at high elevations, larger SOM accumulations occur in mountain tropical forests because decomposition is inhibited. Low temperatures retard decomposition in Tundra and Boreal areas. Soils of these regions worldwide contain the largest SOM accumulations. It is estimated that forests occupy about 3.7 billion hectares globally and the forest soils store about 582 Pg of SOC (excluding litter, estimated to be between 20-30 Pg) and 210 Pg of inorganic carbon (SIC). About 40% of the SOC of global soils is stored in forest ecosystems. Around 50% of the SOC of global forests is in the tundra region followed by 28% in tropical forests. According to earlier literature, SOM and its accumulation was of minor importance with respect to soil formation in permafrost soils (Cryosols). However, recent studies (Blume *et al.*, 1997; Beyer *et al.*, 1998) show that the SOM contents in mineral top-soils of the ice-free coastal Antarctic region is much greater than the one expected from the earlier literature.

The agricultural soils in India are low in organic carbon, which may be attributed to excessive tillage, imbalanced fertilizer use, little or no crop residue recycling, and severe soil degradation. Total organic carbon pool in soils of India is estimated at 21 Gt to 0.3 m depth and 63 Gt to 1.5 m depth (Velayutham et al., 2000), which represents ~3% of the world pool and 10 to 12% of the total C stocks in the tropical regions. There has been a decrease of 30 to 60% in SOC concentration of cultivated soils by 1960. Total soil inorganic carbon (SIC) pool in soils of India is estimated at 196 Gt to a depth of 1 m (Pal et al., 2000) as compared to 722 Gt in world soils (Batjes, 1996). Therefore, the SIC pool in soils of India comprises about 27% of the world's total SIC. The SIC pool is generally high in calcareous soils that cover 54% of the geographical area of the country. The accumulation of organic carbon in soils is related to climatic conditions, (temperature and precipitation). In the Indo-Gangetic Plains (IGP) of India covering 43.7 m ha area, total organic and inorganic C stocks to a depth of 1m are estimated to be 1.56 and 1.96 Gt, respectively (Bhattacharyya et al., 2004). The carbon stocks are higher in the surface soils of hot semi-arid and hot subhumid moist agro-ecological regions (AERs 4 and 13) followed by hot arid, dry and hot sub-humid (AERs 2, 9 and 15). The contribution of SOC stock in the overall total carbon stock decreases with depth and SIC stock increases. The conducive conditions favouring accumulation of SOC in soils of the IGP are humid to per-humid climate with a cool winter for 2-3 months.

Processes and Practices Influencing SOC

There are several factors and processes that affect SOC pool and its depletion. Decline in soil quality, soil's productivity and environment moderating capacity (Lal 1997; Johnson et al., 1997) exacerbates SOC depletion. Several agricultural activities lead to the emission of greenhouse gases from agricultural ecosystems to the atmosphere. Emission of CO_2 from soil to the atmosphere is influenced by the mineralization of C in SOM through microbial processes that use it as a source of energy, combine C with O_2 leading to release of CO_2 and H_2O. The CO_2 emission from soil is accentuated by plowing and mixing crop residue and other biomass in the soil surface. Biomass burning is another source of CO_2. In the tropics, cultivation of rice paddies leads to emission of CH_4. Land misuse and soil mismanagement exacerbate the emission of greenhouse gases from soil to the atmosphere through onset of soil degradation or decline in soil quality.

The SOC level depends on the input and output of biomass C into the soil (Table 1). Sources of C input include the amount of above ground and below ground biomass returned to the soil, and any other biosolids applied (e.g. manure, compost, sludge etc.). Other management practices for higher C include i) intensification of agriculture ii) increasing area under forests, and iii) agro-forestry. Agricultural intensification implies adoption of recommended management practices on prime agricultural soils while restoring degraded and marginal soils to productive land uses. Some management practices for C sequestration are conservation tillage and residue management, cover crops and crop rotation, nutrient management including fertilizer and manure, and water management (Table 1). Two principal strategies of C sequestration include:

1. Reducing losses of C from soil: losses of soil C pool are caused by accelerated soil erosion, mineralization and decomposition. Some effective erosion control measures include conservation tillage, mulch farming, cover crops etc. Improving soil structure and enhancing aggregate stability, and providing balanced soil nutrient pool (N, P, S) are important to decreasing mineralization, and
2. Increasing C sequestration in soil by returning large quantities of biomass to the soil, and improving water and nutrient use efficiencies.

Technological options that have been found to be efficient for soil C sequestration in Indian agro-ecosystems include integrated nutrient management and manuring, crop residue incorporation, mulch farming and/conservation agriculture, agro-forestry systems, grazing management, choice of cropping system and intensification of agriculture. Integrated nutrient management involving addition of organic manures/composts along with inorganic fertilizers results in improved soil aggregation (Benbi et al.,

1998) and greater carbon sequestration especially in macroaggregates (Benbi and Senapati, 2010; Sodhi et al, 2009). Incorporation of organic manures induces decomposition of organic matter where roots, hyphae and polysaccharides bind mineral particles into microaggregates and then these microaggregates bind to form C rich macroaggregates. This type of C is physically protected within macroaggregates. The free primary particles are cemented together into microaggregates by persistent binding agents characterized by humification of organic matter and stimulate accumulation of C in aggregates.

Table 1. **Strategies for C sequestration in agricultural soils**

Increase input	Decrease output
Increasing crop productivity	Erosion control
Diversified crop rotations	Reduced or no tillage
Higher return of crop residues	Mulch farming
Increasing use of organic manures	Reduced bare fallow
Green manuring	Input of low quality organic material
Intensive cropping	
Elimination of fallow	
Agroforestry systems	
Improved irrigation	
Greater root biomass	
Depth placement of carbon	
Switching from annual crops to perennial vegetation	

Intensive agriculture with improved nutrient and water management results in enhanced C sequestration due to higher crop productivity and greater return of crop residues, root biomass and root exudates to soil. Results of a 25-year study from the north Indian state of Punjab showed that intensive agriculture resulted in improved SOC status by 38% (Benbi and Brar, 2009). Enhanced C sequestration was related to increased productivity of rice and wheat; one tonne increase in crop productivity resulted in a C sequestration of 0.85 t ha^{-1} (Fig. 1). Results of several studies have shown that C sequestration is higher under submerged rice soils as compared to aerobic soils due to incomplete decomposition of organic materials, and decreased humification of organic matter under flooded conditions. Soils under adequately fertilized rice-wheat system have been found to sequester 70% more SOC as compared to maize-wheat system (Kukal et al., 2009). Higher rate of C sequestration in rice–wheat is due to the soils being under flooded moisture regime for 3–4 months resulting in slower rate of organic matter decomposition and secondly due to higher biomass production in rice as compared to maize. Though several management strategies lead to C sequestration, the most appropriate practices to increase soil C reserves are site specific. Available best management practices will require evaluation and adaptation with reference to soil type and land use system, social acceptability and economic feasibility.

Optimum contents of C in soils are within a relatively narrow range. Above the optimum ranges, environmental pollution occurs, below the ranges, yields are insufficient. In order to uphold the optimum SOM conditions, it is necessary to adopt management practices that sequester C. Best management practices to sequester C in the soil, basically are those that increase the input of organic matter to the soil, and/or decrease the rate of soil organic matter decomposition. The most appropriate management practices to increase soil C reserves are site specific. Available best management practices will require evaluation and adaptation with reference to soil type and land use system. The exploratory scenarios show that from 14±7 Pg C may be sequestered over the next 25 years if the world's degraded and stable agricultural lands are restored and submitted to appropriate management. In India, more than 100 million hectares are classified as degraded and greatly depleted in SOM; 35% of this area is classified as salt-affected wasteland. Especially saline soils could store significant quantities of C. It has been suggested that only by reclamation of salt-affected wasteland in India, up to 2 Pg C could be sequestered.

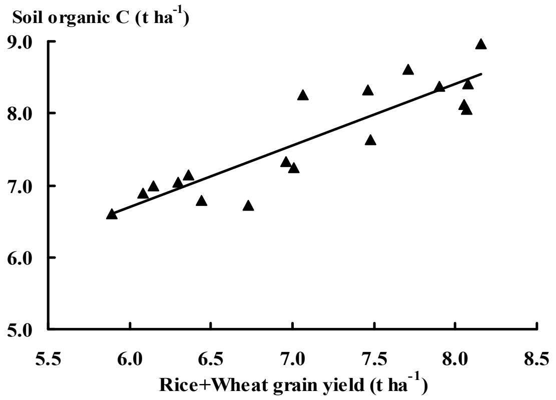

Fig. 1. Relationship between soil organic carbon and total rice and wheat grain yield in Indian Punjab

Soil organic carbon and yield sustainability

A number of ancillary benefits can be associated with practices primarily aimed at enhancing organic matter storage in soil. These co-benefits include restoring soil fertility, enhanced crop productivity, reduced erosion and associated loss of nutrients such as N and P and greater biodiversity. There is a strong relationship between crop yields and the amount of SOC in the root zone. Several studies in India have documented a positive relationship between SOC concentration in the root zone and yield of a number of crops including wheat, rice, and maize. For example, in alluvial soils of northern India, wheat grain yield without fertilizer application increased from 1.4 Mg ha^{-1} at an SOC concentration of 0.2% to 3.5 Mg ha^{-1} in soils with an SOC concentration of 0.9% (Fig. 2). With the application of chemical fertilizers the effect of SOC concentration on wheat productivity was small indicating an interaction between SOC and fertilizer use. The wheat productivity per ton of organic carbon declined from 33 to 15 kg ha^{-1} t^{-1} C as the SOC concentration increased from 0.2 to 0.9% (Benbi and Chand, 2007). The change in crop productivity with SOC concentration suggests that it will be more beneficial to sequester C in soils with low SOC than with relatively greater SOC concentration. In situations where the availability of organic resources for recycling is limited, their application may be preferred in soils with low SOC concentration.

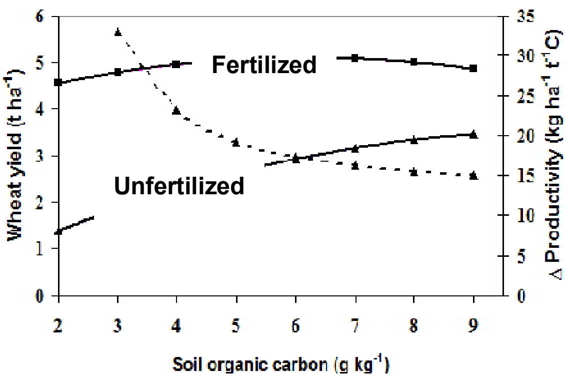

Fig. 2. Influence of soil organic carbon (SOC) concentration on wheat yield (solid lines) and productivity (dashed line) per ton organic carbon in the 15-cm plough layer

Modelling C Dynamics

Much experimental work has been undertaken in the last few years in attempts to quantify C fluxes and to identify the key factors which govern them. However, fluxes vary greatly between ecosystems, and are often subject to great variations, both spatial and temporal, within ecosystems. Consequently, there is an essential role for modelling, to scale up observations made on relatively small areas to larger regions and ultimately to global level, and also to be able to predict the effects of environmental changes and changes in land use and management on C dynamics. Models, such as Century, Roth-C, and DNDC have been developed and calibrated under different soil, plant and management systems.

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Fertilization for Sustainable Agriculture and Food Security

A.P. Singh

Professor
Department of Soil Science and Agricultural Chemistry
Institute of Agricultural Sciences
Banaras Hindu University

Fertilization has played a vital role in bringing about green revolution in India along with high yielding dwarf cereal varieties and remarkable enhancement in irrigated area during 1960-90. However, a number of reports have now started pointing out towards the ill effects of use of chemical fertilizers. Many organizations have even advocated a complete shift to organic farming. It becomes therefore pertinent to review the current status of use of chemical fertilizers in India vis-à-vis their use in other parts of globe, the requirement of food grains in India and world, the projections about addition and removal of nutrient elements and the results of long term field experiments being carried out to assess the impact of chemical fertilization on soil health.

It is a well known fact that population of India which was mere 0.36 billion in 1950 is estimated to touch 1.5 billion mark in 2025 and 1.80 billion in 2050. Thus, it is likely to register a five fold increase in hundred years as compared to less than two fold increase in developed countries. This alarming increase in population will require an equally fast enhancement in our food grain production from continuously shrinking agricultural land. If we see our resources and liabilities, the pressure on agricultural land is bound to go up. With only 4% (1/25) of world's fresh water resources and 2.3% (1/44) of land, India has to support 17% (1/6) of world's human population and 11% (1/9) of world's livestock. Though, we have achieved so far 4.5 times increase in food production, 6 times increase in horticultural crops, 9 times increase in fish production and 27 times increase in egg production, the challenges ahead are even bigger. The country will require more than 400 tons of food grains in 2050 and with the present growth rate we would be no where near to that. We are stagnating near 210 M tons since last about 10 years. Further, non agricultural use of land which was 16.48 M ha in 1970 has already risen to 24.72 M ha in 2004 and it is likely to increase dramatically in years to come. India unfortunately has no possibility to enhance area of cultivation. Thus, the only option is to increase productivity by using modern technologies including soil test based fertilizer application.

Use of chemical fertilizers has contributed to the tune of 40-60% in production of food grains from different cropping sequences. However, the imbalanced use of fertilizers may also lead to decline in crop yield and soil health.

The major issues of soil health that need to be addressed are:

1. Physical degradation caused by compaction, crusting etc., by excessive cultivation or puddling, soil erosion
2. Chemical degradation caused by:
   - Wide nutrient gap between nutrient demand and supply
   - High nutrient turn over in soil-plant system coupled with low and imbalanced fertilizer use
   - Emerging deficiencies of secondary and micro nutrients
   - Poor nutrient use efficiency
   - Insufficient input of organic sources because of other competitive uses
   - Acidification and aluminum toxicity in acid soils
   - Salinity and alkalinity in soils
   - Irrigation induced water-logging
3. Biological degradation due to organic matter depletion and loss of soil fauna and flora
4. Soil pollution from industrial wastes, excessive use of pesticides and heavy metal contamination

An estimate points out that about 75% of total soil degradation (220.61 Mha) in India is caused by soil erosion. Therefore, in spite of the large scale efforts of Govt. of India to check soil erosion, it continues to be our prime concern. Erosion causes an annual soil loss of 6000 Mt in the country. Thus, one ha of eroded land may loose on an average 163 tons of precious top soil per year. This results in nutrient loss of 5.6-8.4 Mt and loss in food production may be around 30-40 Mt per year. The nation thus suffers a loss in food production of about 11560 crore and loss in nutrients due to erosion may amount to 6250 crore.

All the above mentioned factors have collectively caused multi nutrient deficiencies in India. The table given below shows the extent of deficiencies of nutrients in India:

N	Low in 228, medium in 118, high in 18 districts
P	Low in 170, medium in 184, high in 17 districts
K	Low in 47, medium in 192, high in 122 districts
S	Deficiency scattered in 100-120 districts
Mg	Kerala, other southern states, very acid soils
Zn	50% of 150,000 soil samples analyzed were found deficient
Fe	Deficiency in upland calcareous soil for rice, groundnut, sugarcane
B	Parts of Bihar, Orissa, W.B., N.E., Karnataka

The nutrient consumption in India compared to some other countries clearly points out that there is lot of scope to encourage use of higher doses of fertilizers in the country. However, the current ratio of use of NPK fertilizers is not as per the recommended norms.

Continent Country	$N+P_2O_5+K_2O$ = Total (per hectare)	$N : P_2O_5 : K_2O$	Average yield of cereals (t/ha)
Asia			
China	184+73+44=301	4.2 : 1.7 : 1	5.23
India	75+31+14=120	5.3 : 2.2 : 1	2.49
Europe			
France	112+30+37=179	3.0 : 0.8 : 1	7.00
Germany	147+23+35=205	4.2 : 0.6 : 1	6.72
Netherlands	407+55+204=466	2.0 : 0.3 : 1	8.28
U.K.	185+42+60=287	3.1 : 0.7 : 1	7.20
N. America			
Canada	34+13+6=53	5.4 : 2.1 : 1	3.20
U.S.A.	88+36+37=161	2.4 : 1.0 : 1	6.48
Africa			
Egypt	544+73+7=624	77.7 : 10.4 : 1	7.56
Oceania			
Australia	19+23+5=4.7	3.5 : 4.2 : 1	2.00
New Zealand	124+139+46=309	2.7 : 3.0 : 1	6.67
World Average	63+26+20=109	32 : 1.3 : 1	3.35

The crop response to applied NPK fertilizers (kg of food grains/kg of nutrients) which used to be about 12 in sixties, has been dropping gradually over the years, and has reached a low of about 5 at present. The projected plant nutrient (NPK) addition and removal in India shows that there will be a gap of about 7.86 Mt in 2020. This could only be met by using all possible organic sources in conjunction with chemical fertilizers. Therefore, the only option in future will be extensive use of integrated nutrient management. The benefits of INM in enhancing productivity and enriching soil health are well known. The following table clearly shows that when FYM was added along with recommended doses of NPK, there was greater build up of soil organic carbon. This will also result in higher fertilizer use efficiency which at present is only 40-45% in irrigated areas and less than 35% in rain fed areas.

Integrated approach for build up of SOC

Cropping system, location, soil	Initial SOC (%)	SOC (%)		
		Control	NPK	NPK+ FYM
Rice-rice, Bhubneshwar, Inceptisol	0.27	0.41	0.59	0.76
Rice-wheat, Pantnagar, Mollisol	1.48	0.50	0.95	1.51
Rice-wheat, Faizabad, Inceptisol	0.37	0.19	0.40	0.50
Rice-wheat-jute, Barrackpore, Inceptisol	0.71	0.42	0.45	0.52
Rice-wheat-cowpea, Pantnagar, Mollisol	1.48	0.60	0.90	1.44
Maize-wheat Palampur, Alfisol	0.79	0.62	0.83	1.20
Fallow-rice-wheat, Karnal, Alkali Soil, Inceptisol	0.23	0.30	0.32	0.35
Cotton-cotton, Nagpur, Vertisol	0.41	-	-	0.55
Cassava, Trivendrum, Ultisol	0.70	0.26	0.60	0.98

The low fertilizer use efficiency is a matter of great concern. It is therefore advisable to promote among the farmers the soil test based balanced fertilizer use in conjunction with organics, residue management and reduced tillage. The following points may be kept in mind while planning strategies for fertilization:

Nitrogen

- Rate of application matched with crop needs
- Method of application to reduce nutrient losses

- Time of application matched to crop nutrient uptake pattern
- Source of nitrogen-modified urea materials
- Fertilizer amendments-nitrification and urease inhibitors, coatings

Phosphorus & Potassium

- Placement of P and K fertilizers is key to their efficient utilization
- P and K fertilization should be done keeping in view the requirement of entire cropping system
- Use of VAM and phosphobacterium

Sulphur and Micronutrients

- Application of appropriate quantities of S and deficient micronutrients is essential to exploit yield potential and maintain soil quality

In order to enhance the efficiency of fertilization in rain-fed ecosystems, it becomes vital to revive the farm/village ponds and to create small farm reservoirs to provide irrigations at critical stages. The other measures for in situ conservation of rain fall such as fallow ploughing, field leveling, and bunding are very effective in reducing run-off.

Nutrient Management: I. A Key to Productivity and Long-Term Sustainability

Muneshwar Singh

Project Coordinator
All India Coordinated Research Project on Long-Term Fertilizer Experiments
Indian Institute of Soil Science, Bhopal (M.P.)

The ever increasing population of the country is forcing the planner to produce more and more with shrinking natural resources. To meet the challenges high yielding verities and intensification of agriculture played an important role and brought the green revolution in the country. The external supply of nutrient and water helped in sustaining the green revolution over the time. However, the use of high analysis fertilizer accelerated the mining of micro and secondary nutrients which resulted in hidden hunger of these nutrients and brought down the productivity cropping systems at several places in the country.

Indian soils are running with negative nutrient balance to the tune of 12-14 m ton yr^{-1} and this negative balance will continue to be present even after using the full potential of fertilizer industry. Under this situation, it is really very hard to maintain soil health and productivity. Nutrient management in long term study may explain the nutrient behavior, soil health and sustainability. In this paper attempts are made to have an over view of nutrient management and crop productivity and sustainability of various cropping systems in long term fertilizer experiments in progress at different locations of the country.

1. Nutrient Management and Productivity

Enhancing the productivity is a prime objective and priority of Indian agriculture to feed the ever growing population from shrinking natural resources. Long term study in India and elsewhere in the world documented that it is impossible to attain the potential yield of crops with out external supply of nutrient. However, the indiscriminate or misuse of nutrient had adverse effect on productivity. In the following section nutrient management and productivity in different soils is reviewed with special reference to long term experiment.

1.1 Rice-Wheat: Rice-wheat is most predominant cropping system of the country and contributes major portion of food basket. The yield data (Table 1) of Pantnagar (Mollisols), Barrackpore (Inceptisols) and Raipur (Vertisols) indicated that integration of nutrients resulted increase in productivity of the system at all the three places and incorporation FYM further enhanced the productivity. At Pantnagar application of 100% N alone for 37 years, average yields of rice and wheat recorded were 4658 and 3588 kg ha^{-1}. Integration of P with N and K with NP resulted in increase in yield of rice to 4828 and 5008 kg ha^{-1} and of wheat to 3756 and 3767kg ha^{-1} respectively. Incorporation of FYM with NPK further increased productivity of rice and wheat to 5716 and 4490 kg ha^{-1} respectively. The similar trend in yield on integration of nutrient was also noted at other two locations. Difference in the level of magnitude in productivity is because of climatic condition. Increase in yield on incorporation of FYM is not only due to additional supply of major nutrients but also ruled out the hidden hunger of Zn and secondary nutrient at many places. Moreover, organic manure also helped in turnover process of nutrients in soil which is responsible for nutrient transformation in soil.

Table 1. Effect of integrated nutrient management on average productivity of rice- wheat (kg ha^{-1}) cropping system under LTFE at different locations

Treatments	Pantnagar		Barrackpore*		Raipur	
	1972 to 2006-09		1972 to 2006-09		1999-2006-09	
Crop	Rice	Wheat	Rice	Wheat	Rice	Wheat
Control	2816	1432	1432	755	2337	1002
100 % N	4658	3588	2981	1955	3614	1459
100 % NP	4828	3756	3311	2181	5055	2140
100 % NPK	5008	3767	3442	2287	5124	2141
NPK + FYM	5716	4490	3647	2326	5447	2388
100% NPK + GM	-	-	-	-	4480	1754
50% NPK + BGA	-	-	-	-	4225	1640
CD 5%	611	448	265	316	328	346

*Saha et al., (2008)

To evaluate the INM practice on productivity of rice and wheat number of trials were conducted throughout the country under AICRP Agronomy. The data summarized in table 2 indicated that combined use of fertilizer and organic manure (FYM) resulted in increase in larger productivity of the system with residual effect on subsequent wheat crop (Singh and Singh 1998). Eight years study on integrated nutrient management in rice-wheat in Vertisols (Singh et al.,2001) at Jabalpur revealed that conjunctive use of 5 t FYM and 6t green manure (Parthenium) with 90 kg N not only sustained the productivity but also saved nearly 90-100 kg ha^{-1} fertilizer N annually. In addition to saving of nitrogen, integrated nutrient management practices also improved the SOC and nutrient status of soil (Table 3) and available status of nutrient.

Table 2. Effect of combined use of organic and inorganic fertilizer average crop yields (t ha^{-1}) in rice-wheat at different location

Treatment		Location					
		Bhagalpur (87 trails)		Manipur (96 trails)		Ludhiana (5 years)	
Rice	Wheat	Rice	Wheat	Rice	Wheat	Rice	Wheat
FoN_{60}	FoN_{60}	4.21	2.75	441	1.04	5.6	2.8
$^{a}F_{12}N_{60}$	$F_{12}N_{60}$	4.14	2.95	5.44	1.33	5.7	3.9

At Ludhiana a= N_{80} to rice and N_{90} to wheat Singh and Singh (1998)

Table 3: Integrated Nutrient management in rice wheat for 7 years and average productivity of rice-wheat (tha^{-1}) and nutrient status in Vertisol at Jabalpur

Treatment	Rice	Wheat[$]	Nutrient Status after 7 years (mg kg)		
			OC%	P**	K*
N90	4.42	4.19	0.58	21.1	138
N180	5.08	4.70	0.71	18.7	125
N90 + FYM	4.95	4.49	0.74	40.1	230
N90 + GM	4.58	5.07	0.72	39.1	240
Initial	-		0.60	19.5	195

[$]Singh *et al.,* 2001, *Singh *et al.,* 2002 & **Singh *et al.,* 2007.

1.2 Soybean Wheat: Soybean-wheat is predominant cropping system of MP and extended into in Rajasthan and Maharastra. Thirty seven years data summarized in table 4 clearly indicated that integration of N, P and K sustained the yield at a higher level compared to application of N and NP. However, the maximum average productivity is recorded on conjunctive use of NPK and FYM.. In Alfisols at Ranchi, continuous application of N alone has adverse effect on productivity. Integration of P and PK with N increased yield of soybean from 293 Kg ha^{-1} (100% N alone) to 870 and 1496 Kg ha^{-1} respectively and the corresponding yields of wheat recorded were 386(100% N) 2449 kg ha^{-1} and 2795 Kg ha^{-1} (Table 4). It is interesting to note that integration of NPK with FYM further increased the yield of both soybean and wheat. At Ranchi use of lime as a component of INM also improved the productivity significantly.

Table 4. Effect of integrated nutrient management on average productivity of soybean/ maize-wheat system under LTFE at different locations

Treatments	Ranchi[b]		Jabalpur[a]		Palampur[c]	
	1972 to 2006-09		1972 to 2006-09		1999-2006-09	
Crop	Soybean	Wheat	Soybean	Wheat	Maize	Wheat
Control	605	692	814	1238	287	381
100 % N	293	386	1024	1668	422	367[$]
100 % NP	870	2449	1652	4071	2004	1635
100 % NPK	1496	2795	1818	4419	3237	2294
NPK + FYM	1867	3327	2004	4850	4660	3102
NPK + Lime	1795	3170	-	-	4112	2854
CD 5%	212	390	282	441	706	502

$ at present yields are zero. [a]Dwivedi *et al.,* (2007), [b]Mahapatra *et al.,* (2007), [c]Sharma *et al.,* (2005).

Seven years study on soybean-wheat at IISS farm also demonstrated that integration of nutrient (FYM and fertilizer) sustained the yield at higher level compared to sole application of either organic or fertilizer (Rao et. al. 1998). Similarly, trials conducted at farmers' field in Sehore and Bhopal districts for three years (Table 5) further confirmed that integrated nutrient management is the best option as far as productivity and profit of the farmers are concerned (Singh et. al. 2008).

Table 5. Effect of INM on productivity of soybean wheat (t ha^{-1}) and economics

Treatment	Soybean	Wheat	Total output cost*
FYM	1.81	3.87	45631
PM	1.90	3.69	46390
IPNS	1.97	4.32	50392
Conventional	1.74	3.98	45617
CD (5%)	NS	0.39	-

*The cost of output was calculated on the basis of price prevailed during that period.

1.3 Maize-Wheat: Maize-wheat is another important cropping system of North-West India. The yield data of 36 years old maize-wheat cropping system at Ludhiana and 10 years old experiment at Udaipur and Delhi indicated that integration of P and K with N enhanced the productivity of the cropping system. Integration of P with N increased the yield of maize from 1771 Kg ha^{-1} (N alone) to 2209 and wheat from 2932 Kg ha^{-1} to 4108 Kg ha^{-1} At Ludhiana. Addition K and incorporation of FYM further enhanced the productivity (Table 6). At Palampur (Alfisols) continuous application N resulted in decline in yield with time and at present there were zero yields in this particular plot. However integration of PK along with FYM/lime sustained the productivity of the system over last 36 years. (Table 4)

Table 6. Effect of integrated nutrient management on average productivity (kg/ha^{-1}) maize-wheat system and LTFE

Treatments	Ludhiana		New Delhi		Udaipur	
	1972 to 2006-09		1995-96 to 2006-09		1997-98-2006-09	
Crop	Maize	Wheat	Maize	Wheat	Maize	Wheat
Control	899	1206	1221	2381	1900	1907
100 % N	1891	2999	1552	4076	2458	3112
100 % NP	2376	4123	1781	4524	2837	3610
100 % NPK	3117	4769	2185	4524	3042	3879
NPK + FYM	3805	4987	2421	4867	3410	4374
CD 5%	234	251	184	271	181	207

1.4 Finger millet-Maize: Finger millet-maize covers large area in southern India. The yield data of both finger millet and maize indicate that integration of all the three major nutrients (NPK) always had the larger productivity compared to application of N and NP. Integration of FYM with NPK further boosted the productivity of the system (Table 7).

Table 7. Effect of integrated nutrient management on average productivity (kg ha^{-1}) of finger-millet and rice-rice system under LTFE

Treatments	Bangalore*		Coimbatore		Pattambi	
	1987-2007		1971-2007		1998-2007	
Crop	F. Millet	Maize	F. Millet	Maize	Rice	Rice
Control	568	291	1067	1037	1595	2196
100 % N	726	383	1322	1322	2200	3073
100 % NP	940	649	2698	2871	2097	3010
100 % NPK	4145	2213	2784	3134	2263	3158
NPK + FYM	4803	2642	3294	3628	2770	3629
NPK + Lime	4755	2597	-	-	2634	3536
CD 5%	126	566	385	301	385	285

*Sudhir et al., (2004)

1.5 Rice-rice: Rice-rice is quite common cropping pattern in some parts of southern and eastern states of the country. The 10 year average yield data (Table 7) indicated that integrated nutrient management is the only option to sustain productivity of rice-rice Alfisols of Pattambi (Kerala). At Pattambi green manure and liming are essential components of INM for sustaining the productivity at higher level.

Thus, data generated under long-term study in the country clearly demonstrated that balanced and integrated nutrient management are the only options to sustain the productivity. Application of FYM ensures the sustainability at higher level by taking care of the hidden hunger of micro and secondary nutrients which other wise could have been limiting factor in sustaining the productivity. Applications of FYM in addition to supply of nutrient also act as conditioner for physical condition of soil like infiltration and bulk density which improves aeration and water movement in soil, required for better root and plant growth. In Alfisols of Ranchi, Bangalore and Palampur application N alone had adverse effect on productivity. Decline in productivity in Alfisols is due to non availability of P and K due to reduction in soil pH on application of N alone. Whereas at Jabalpur P and K were not limiting nutrient for quite some which made possible to sustain the yield.

3.2 Sustainability Yield Index (SYI): Sustainability yield index is other way to assess the soil health and sustainability of the system. The sustainability index worked out for different cropping system indicates that as we complementing the nutrients SYI increases. For instances (Table 8) at Barrackpore SYI value observed in control plot was 0.17 which increased to 0.37, 0.44, 0.45 and 0.51 on application of N, NP, NPK and NPK+FYM, respectively. Increase in SYI on application of N and NP indicates that soils are inadequate to supply N and P. Whereas no improvement on application of NPK over NP indicate that soil is sufficient to supply K. A similar behavior of nutrient management was recorded in Vertisols of Coimbatore. The increase in SYI on application of 150% NPK suggest that the amounts of nutrients applied as 100% NPK are not sufficient to get the potential yield of the crop.Of course increase in SYI on application FYM over and above NPK indicate that other than nutrient physical properties and biological condition of soils are also important to sustain the productivity. Application of FYM improved the physical properties of soil which helped in improving the biological condition of soil.

Unlike Inceptisols and Vertisols, application of N in Alfisols resulted decline in SYI compared to control. This suggests that application of N alone had adverse effect on crop growth and soil health. Perusal of data on yield and soil properties revealed that continuous application of N alone resulted decline in soil pH to the extent which has adverse effect on availability of P and K and due to this crop is not able to take nutrient from soil and crop growth is badly affected. The increase in SYI in Alfisols of Ranchi and Palampur on application of P (NP) and K (NPK) indicates that these soils are suffering from P and K as well. Application of both lime and FYM at both the places (Ranchi and Palampur) maximized SYI, suggested that to sustain the productivity of these soils regular use of FYM and lime is mandatory. Better SYI on application of FYM compared to lime indicate that FYM is superior soil amendments to manage the acid soils.

Table 8. Sustainability yield index (SYI) for various treatments

Site	Crop	Control	N	NP	100% NPK	150% NPK	NPK+ FYM	NPK+Lime
Barrackpore	Rice	0.17	0.37	0.44	0.45	0.53	0.51	-
	Wheat	0.14	0.41	0.48	0.52	0.64	0.54	-
Coimbatore	F.millet	0.05	0.12	0.48	0.47	0.51	0.55	-
	Maize	0.05	0.07	0.40	0.43	0.45	0.50	-
Ranchi	Soybean	0.14	0.01	0.21	0.47	0.45	0.62	0.61
	Wheat	0.05	0.01	0.21	0.41	0.41	0.57	0.55
Jabalpur	Soybean	0.18	0.20	0.38	0.44	0.38	0.57	-
	Wheat	0.13	0.13	0.49	0.53	0.54	0.57	-
Palampur	Maize	0.01	-0.07	0.13	0.33	-	0.51	0.45
	Wheat	0.03	-0.03	0.15	0.38	-	0.58	0.58

On the basis of the results discussed in the paper it is concluded that irrespective of soil type and cropping systems balanced and integrated use of nutrient sustained the productivity over the years. On contrary to imbalance or indiscriminate use of nutrient stagnated the productivity in Vertisols and Inceptisols but in Alfisols deteriorated the crop productivity to extent of zero level. Thus balance use of nutrient is the only key for sustaining the productivity.

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Nutrient Management: II. A Key to Soil Health and Quality

Muneshwar Singh

Project Coordinator
All India Coordinated Research Project on Long-Term Fertilizer Experiments
Indian Institute of Soil Science, Bhopal (M.P.)

It is well documented that our soils are working under stress due to disproportionate human and live stock population. From 2.3 percent geographical area, India support 15 per cent livestock and 18 per cent human population. Thus under this situation it has become more relevant that we must ensure that quality of our natural resource should be maintained. To sustain productivity for long period of time it is essential to maintain soil health. It is also our moral responsibility to pass on a healthy and good quality soil to next generation.. In this paper attempt has been made to assess health of different soils and quality under different nutrient management practice.

Nutrient Management and Soil Health

2.1 Chemical Properties

2.1.1 Impact on Soil pH: Soil pH is an important intrinsic property of soil which usually does not change easily. However, long term use of fertilizer indicated that continuous use of nitrogenous fertilizer or use of ammonium sulphate as a source of nitrogen resulted decline in pH which had adverse effect on productivity of crops in Alfisols. Continuous use of urea alone resulted decline in soil pH but the effect of fertilizer is more serious in Alfisols because of poor buffering capacity (Table 8)

Table 8. Effect of nutrient management on soil pH at Palampur and Ranchi

Treatment	Alfisols		Vertisols	
	Ranchi	Palampur	Jabalpur	Akola
Initial	5.5	5.8	7.6	8.1
100% N	4.4	4.4	7.6	7.8
100% NP	4.8	5.0	7.5	7.8
100% NPK	4.6	5.1	7.4	7.8
100% NPK+FYM	4.7	5.2	7.4	7.8
100% NPK+ lime	5.7	6.4	-	-

Singh and Wanjari 2006-2007

2.1.2 Soil Organic Carbon: Data depicted in table 9 on soil organic carbon (SOC) revealed that continuous balanced nutrients application maintained SOC whereas incorporation of FYM resulted in build-up in SOC in Alfisols of Bangalore and Palampur. At Ranchi, only NPK+FYM could maintain SOC whereas in all other treatments decline in SOC is recorded. Thus, results indicate that under high rainfall incorporation of FYM is essential to sustain soil productivity.

Organic carbon data of Inceptisol of Ludhiana and Vertisol of Jabalpur and Alfisol of Bangalore revealed that balanced application of fertilizer maintained the soil organic carbon and the yields (Table 4 & 5) are also sustained. (Table 9).

2.1.3 Available Nitrogen: Available N is an oxidizable and is considered to be available to plant during the course of growth. Perusal of data (Table 10) revealed that application of nutrient in balanced and integrated form resulted in improvement available N at Ludhiana, Raipur, Bagalore, Jabalpur and Akola whereas decline in available N was noted at Pantnagar, Udaipur, Palampur with respect its initial.

Table 9. Soil organic status in long term fertilizer experiments

Locations	Initial	NP	NPK	NPK+FYM
Ludhiana	2.2	3.3	3.6	5.2
New Delhi	4.4	3.9	4.4	5.5
Udaipur	6.9	7.1	7.8	9.9
Jagtial	7.9	1.0	1.0	1.1
Jabalpur	5.7	6.5	7.4	9.6
Akola	4.6	4.9	5.1	6.8
Coimbatore	3.0	6.7	7.0	9.8
Palampur	7.8	9.4	9.7	1.3
Bangalore	4.6	4.7	4.9	5.7
Pantnagar	1.5	8.5	8.7	1.6
Barrackpore	7.0	4.7	4.6	6.8
Ranchi	4.5	3.8	3.9	4.5
Raipur	6.2	6.0	6.1	7.0

Table 10. Effect of nutrient management on available N (kg ha^{-1}) at different sites of LTFE

Centre	Initial	N	NP	NPK	NPK + Lime	NPK + FYM
Ludhiana	87	118	123	126	-	132
Udaipur	360	277	280	293	-	319
Pantnagar	392	240	241	242	-	328
Raipur	236	236	241	241	-	246
Ranchi	295	250	243	239	225	244
Banglore	257	315	309	308	296	316
Palampur	736	306	287	317	322	335
Jabalpur	193	193	255	263	-	315
Akola	120	242	258	273	-	309
Coimbatore	199	174	179	177	-	195

2.1.4 Available Phosphorus: Data (Table 11) revealed that irrespective of soil and cropping system absence of P in fertilizer schedule resulted decline in available P status in soil whereas continuous application of P resulted increase P status. The largest increase in P status was noted in NPK+ FYM. Increase in P status is due uptake of P less than applied.

2.1.5 Available Potassium: Available K status (table 12) revealed that in general decline in available K was noted. However, at some locations like Ludhiana, IARI, Pantnagar increase in available K was noted. Decline in available K status is due to uptake of K in quantity larger than applied. But increase in K status is due to K content of irrigation water or due to mining of K from lower layer and accumulated in surface layer, on decomposition of roots and stubble. At Ludhiana during late Kharif, irrigation is applied through canal water and contained lot of silt and adds K to soil. It is interesting to note that soils of Bangalore are low in K but here also improvement in K content in NPK+FYM treatment. Incorporation of FYM not only adds K but also mobilizes non exchangeable K to exchangeable.

Table 11: Effect of nutrient management on available P (kg ha^{-1}) at different sites of LTFE

Centre	Initial	N	NP	NPK	NPK + Lime	NPK + FYM
Ludhiana	9	7.6		86	-	99
IARI	16	18	34	35	-	41
Udaipur	22	16	23	25	-	25
Pantnagar	18	9	19	19	-	35
Raipur	16	9	24	25	-	28
Ranchi	13	8	126	118	64	227
Banglore	34	8	178	113	111	195
Palampur	12	19	152	103	104	194
Jabalpur	7.6	3.1	26	29	-	39
Akola	8	4.7	28	29	-	36
Coimbatore	12	11	18	18	-	27

Table 12. Effect of nutrient management on available K (kg ha^{-1}) at different sites of LTFE

Centre	Initial	N	NP	NPK	NPK + Lime	NPK + FYM
Ludhiana	88	82	85	99		114
IARI	155	252	206	287		316
Udaipur	671	527	497	564		620
Pantnagar	125	87	98	140		154
Raipur	474	425	397	428		450
Ranchi	158	94	61	90	84	115
Banglore	123	76	66	169	173	206
Palampur	194	141	121	156	158	215
Jabalpur	370	188	239	266		313
Akola	358	259	278	386		456
Coimbatore	907	477	492	594		639

2.2 Physical Properties: Good physical properties of soil facilitate to microbial activity, root proliferation and water transmission characteristics of soil which together all help in regulating the supply of nutrient and ultimately plant growth.

2.2.1 Bulk density: Bulk density of soil indicates compactness of the soil. The data recorded(Table 13) on bulk density after practicing a specific nutrient management practice for several years indicates that application of nutrient resulted decrease in bulk density. The effect of nutrient was more conspicuous on application NPK and NPK+FYM. This may be due to incorporation root biomass in larger quantity as a result of good crop growth. This is also evident from SOC of under these treatments.

Table 13. Effect of nutrient management on Bulk density (Mg m^{-3}) at different sites of LTFE

Centre	Bulk density (Mg m^{-3})				
	N	NP	NPK	NPK + Lime	NPK + FYM
Ludhiana	1.54	1.53	1.53		1.49
IARI	1.48	1.48	1.48		1.41
Udaipur	1.47	1.47	1.45		1.36
Pantnagar	1.38	1.3	1.35		1.2
Ranchi	1.44	1.40	1.40	1.40	1.40
Banglore	1.57	1.56	1.52	1.53	1.45
Palampur	1.36	1.22	1.17	1.21	1.13
Jabalpur	1.3	1.29	1.28		1.25
Coimbatore	1.28	1.33	1.27		1.22

2.2.2 Mean weight diameter: Mean weight diameter (MWD) is again a property which indicates size of aggregate and decide the pore space in soil. Data (Table 14) indicate that as we move from single to multiple nutrients, improvement in MWD was recorded irrespective of soils. Increase in MWD on application of nutrient is again due to increase in SOC. The larger increases in MWD on application of NPK+FYM confirm the hypotheses.

Table 14. Effect of nutrient management on Mean weight diameter (mm) at different sites of LTFE

Centre	Mean weight diameter (mm)				
	N	NP	NPK	NPK + Lime	NPK + FYM
Ludhiana	0.34	0.38	0.41		0.52
IARI	0.36	0.38	0.45		0.5
Pantnagar	0.68	0.71	0.72		1.04
Banglore	1.45	1.28	1.49	1.75	1.82
Palampur	0.89	1.57	1.68	2.18	2.70
Jabalpur	0.93	1.03	1.05		1.17

2.2.3 Hydraulic conductivity: Hydraulic conductivity is a function of bulk density and pore space which is governed by size of aggregate. Data presented in Table (15) clearly demonstrated that application of fertilizer nutrient resulted increase in hydraulic conductivity. The effects of nutrients were more pronounced on application of NPK and NPK+FYM. Increase in hydraulic conductivity is due decrease in bulk density and increase in pore space as a result of increase in MWD.

Table 15: Effect of nutrient management on Hydraulic conductivity (cm hr^{-1}) at different sites of LTFE

Centre	Hydraulic conductivity(cm hr^{-1})				
	N	NP	NPK	NPK + Lime	NPK + FYM
IARI	0.54	0.56	0.69		0.76
Udaipur	0.28	0.29	0.28		0.32
Pantnagar	0.72	0.76	0.74		0.8
Ranchi	4.10	4.39	4.30	4.50	4.79
Banglore	1.01	0.67	0.96	0.88	0.59
Jabalpur	0.4	0.6	0.5		1.4
Coimbatore	2.08	1.95	2.09		2.84

2.3 Biological Properties: The availability of nutrient in soil to plant is mediated by soil microbes. Microbial population is indirect indicator of soil health. Good soil health means move activities of microbes.

2.3.1 Microbial population: Perusal of data on microbial population presented in table 16, 17 &18 revealed application of nutrient had significant positive effect on population of Bacteria, fungi and actinomyclis at Bangalore. Which indicates application of fertilizer nutrient population of microbes also increases which means there has been improvement in biological health of soil. A similar effect of nutrient application was also recorded at Palampur. However, at Palampur little decline fungi was noted compared to control which may not be significant statistically whereas as Barrackpore, decline in bacterial and fungal population was recorded in the plot received only N, may be because of non availability of P for growth of organism also P is needed.

Table 16. Effect of nutrient management on Microbial Population at Bangalore

Treatment	Bacteria X 10^6 g soil	Fungi X 10^3 g soil	Actinomyclis X 10^4 g soil
Control	10.00	3.70	1.30
100% N	13.70	4.00	1.70
100% NP	15.30	6.70	2.30
100% NPK	16.70	9.00	3.00
100% NPK+FYM	24.00	15.00	4.30
100% NPK+Lime	17.70	7.30	4.00
CD(0.05)	4.04	2.79	1.29

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Table 17. Effect of nutrient management on Microbial Population at Palampur

Treatment	Bacteria X 10^5 g soil	Fungi X 10^4 g soil	Actinomyclis X 10^4 g soil
Control	9.53	4.45	11.97
100% N	4.55	6.98	4.63
100% NP	7.66	5.13	2.43
100% NPK	11.49	7.83	20.3
100% NPK+FYM	28.0	2.78	7.32
100% NPK+Lime	18.08	0.45	8.78

Table 18. Effect of nutrient management on Microbial Population at Barrackpore

Treatment	Bacteria X 10^7 g soil	Fungi X 10^5 g soil	Actinomyclis X 10^4 g soil
Control	10.93	9.03	Na
100% N	1.96	1.96	Na
100% NP	4.80	13.44	Na
100% NPK	36.74	2.33	Na
100% NPK+FYM	39.42	53.2	Na

Na- Not determined

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2.3.2 Microbial Biomass Nutrient: As stated earlier that availability of nutrient to plant is mediated by soil microbes and microbial biomass nutrients are most easily available to plant. The data on microbial biomass carbon and N presented in table 19 and 20 indicate that as we go complementing the nutrient, improvement in microbial biomass C & N was noted. Though the magnitude of biomass C. & N differ with place, which depends on climatic factors and crop growth later provide substrate for the growth of microbes.

Table 19. Effect of nutrient management on Microbial biomass carbon (mg kg^{-3}) at different sites of LTFE

Centre	N	NP	NPK	NPK + Lime	NPK + FYM
Ludhiana	167.2	185.7	210.1		210.1
Udaipur	177.2	186.7	208.5		289.2
Raipur	366.5	393	426.2		486.5
Ranchi	129.4	153.4	189.6	213	231.3
Banglore	184.0	189.0	212.0	208.0	265.0
Palampur	163.1	188.3	828.3	871.4	980.7
Akola	202	244	262		365
Coimbatore	227.3	258.8	280.8		385.0

Table 20. Effect of nutrient management on Microbial biomass nitrogen (mg $kg^{-3)}$ at different sites of LTFE

Centre	N	NP	NPK	NPK + Lime	NPK + FYM
Ludhiana	8.6	10.9	14.5		16.6
Udaipur	29	27.5	34.2		41.2
Ranchi	10.1	13.8	18.5	21.8	24
Banglore	21.6	22.1	24.7	24.3	30.9
Palampur	11.4	12.2	15.8	18.2	20.5
Coimbatore	32.4	30.1	37.9		48.2

Thus data generated on biological condition of soil clearly indicate that application of nutrient helped increasing microbial population in biomass nutrient in soil. In other terms balanced application nutrients improved the biological heath of soil.

3. Soil Qualities

Unlike air and water we don't have definite soil parameters and their limits to define soil quality. The definition of soil quality also depends upon the user.

Land Manager: Capacity of soil to sustain higher yield maintaining the soil resources quality
Conservationist: Sustaining soil resources and protecting the environment
Consumer: Production of healthy and inexpensive food product.
Environmentalist: Maintain soil biodiversity, water quality and nutrient cycling.

Definition of soil quality (Larson and Pierce 1991) :

The capacity of soil to function within ecosystem boundaries to sustain biological productivity, maintain environment quality and promote plant and animal health.

To assess soil quality, soil indicators (Soil properties), are usually linked to soil function. These soil indicators are sensitive to management. Improved soil quality often is indicated by increase in infiltration, aeration, aggregate size, soil organic matter and decrease in bulk density. To identify soil indicators minimum data set is defined covering the physical, chemical and biological properties of soil. On the basis of data generated through long term fertilizer experiment soil indicators were identified. The Fig.1,2 &3 reveled that at different location different soil indicators are responsible for soil quality and therefore indicators are site specific. For instance at Ranchi Ca, Mg pH, HWSB, SMBN were identified as soil indicators whereas at Bangalore B.D. was found to be among the soil indicators. In Vertisols, MWD and hydraulic conductivity in addition to available K, pH were main soil indicators. Whereas in Vertisols of Coimbatore, soil organic carbon along and available nutrients were found to be masters indicators. Thus soil indicators are site specific. Once the soil indicators are identified then soil quality can be worked out using the following relationship. Larger the value better is soil

3.1 Soil Quality Index (SQI)

To evaluate the soil quality index is calculated by using the following equation

$$SQI = \sum_{i=1} wisi$$

Where *S* is the score for the subscripted variable and wi weighted factor derived from PCA. Higher is the score better in the soil quality.

SQI is relative numerical figure which indicate the condition of soil at that point of time under a particular management and how it has affected by your management practice. More is the SQI better is the soil quality. By using this concept, soil indicators were identified through principal component analysis (PCA) and using their relative contribution in productivity. SQI was calculated for some of the sites of long term fertilizer experiment.

The data in figure I indicated that at Palampur pH, DHA, SHC, MBC&N and PAWC were main soil indicators. Data revealed that continuous use of N alone resulted decline in soil quality whereas balanced use of nutrient resulted increase in soil quality. The SQI calculated were found to be more or less same in NPK, NPK+ Lime but grater than control which suggest that balanced application of nutrient improved soil quality. however incorporation of organic manure further improved the soil quality. In these treatments yields are also sustained at higher levels which suggest that balanced use of nutrient not only sustained the yield but also improved the soil quality. Similar trend was also observed at Bangalore and Coimbatore. However SQI values were relatively larger at Coimbatore because of higher reference (control).

Fig.1 Soil Quality Index under different nutrient management option

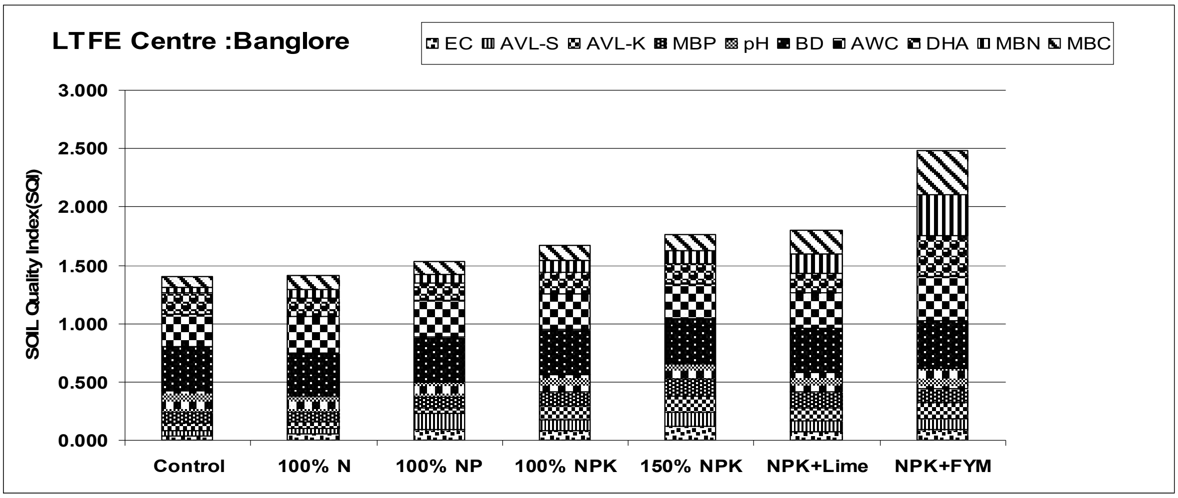


Fig.2 Soil Quality Index under different nutrient management option

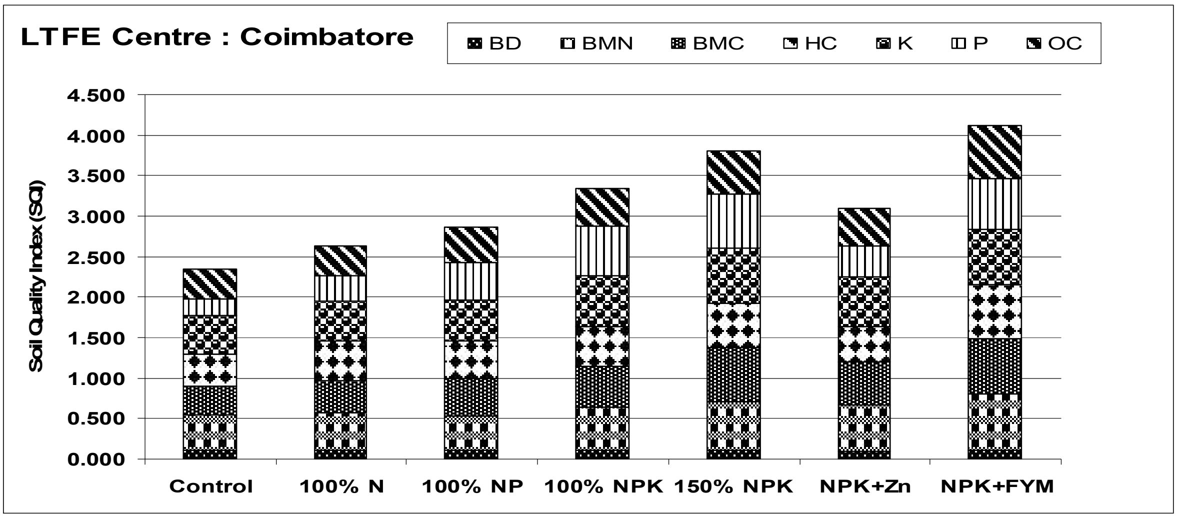
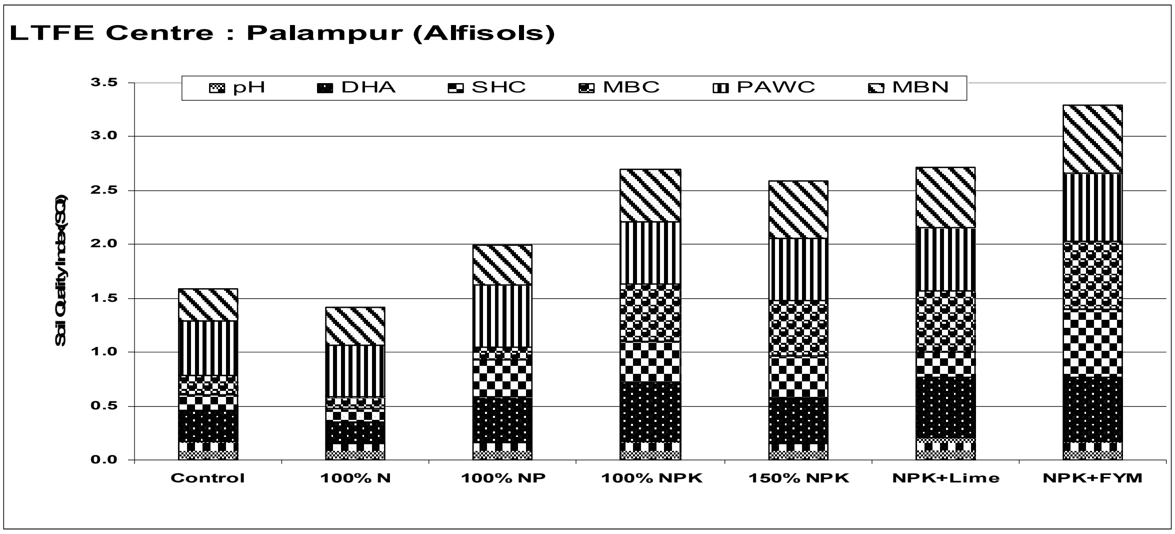


Fig.3 Soil Quality Index under different nutrient management option



Conclusion :

On the basis of data reported it can be concluded that external supply of nutrient is essential to sustain soil health. Nutrient management in appropriate manner not only sustained the productivity but also improved soil properties (Chemical, Physical and Biological). Further analysis of data indicated that nutrient management in an appropriate way also enhanced the soil quality. Thus nutrient management is the only key for sustaining soil health and improving soil quality.

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Relationship of Soil Nutrients with Plant Pathogens and Diseases Caused by them

M.N. Khare

Ex-Dean and Professor Emeritus Plant Pathology,
JN Krishi Vishwa Vidhyalaya, Jabalpur-482004 (MP)

Efforts are being made to increase agricultural production per unit area and per unit expenditure to feed the population in the country which has crossed one billion. The total area under crop production in the country is about 180 m ha and the production has crossed 200 mt. It is not possible to further increase the areas, hence vertical approach is essential to raise the production by increasing the productivity. Production technology has been worked out for crops and several inputs have been recommended which are to be applied in proper quantity at most suitable time to get the maximum return. Nutrition in the form of fertilizers is a must. The relationship of a crop and the pathogen is affected by the nutrients both required at macro and micro level.

The crops face both biotic and abiotic stresses. The reaction given by the plant is exhibited by development of certain abnormalities which are termed symptoms. Non-availability or excess of water, lack of proper aeration, high and low temperatures, light problem, lightning, wind, hail, deficiency or excess of essential elements, high or low pH are all abiotic factors which influence the crop growth, yield and quality of the produce. Injudicious use of agro-chemicals results in diseases called 'iatrogenic plant diseases'.

Agriculture is the most important source of renewable wealth and development of an integrated plant nutrient supply system involving an appropriate mix of organics, biological nitrogen fixation, phosphorus solubilizing microbes and need based chemical fertilizers would be crucial for the sustainability of production and soil as the resource base for it. The nutrients are depleted due to continuous cropping, erosion, leaching etc. Intensive cropping systems can remove annually 500-900 kg N + P_2O_5 + K_2O per ha per year along with substantial quantities of micronutrients. A paddy-potato-wheat rotation has been shown to remove Fe 4640 g, Mn 1243 g, Zn 615 g, Cu 325 g, B 305 g and Mo 17.5 g per hectare (Singh, 1996). High yielding varieties remove the essential nutrients very fast.

Crops are attacked by various pathogens and insect pests which deteriorate the quality and quantity of the produce. Attempts have been made and continuous efforts are there to evolve varieties of crops resistant to such harmful agencies. The resistance of a crop variety is determined by its ability to limit the penetration, development and/or reproduction of invading pathogens. The resistance varies with genotype of the host and the pathogen, host age and environment. Race specific resistance is controlled by one or more major genes and nonspecific resistance is usually polygenic. The nonspecific resistance is influenced by several factors like environment and is degraded by deficiency of specific micronutrient in the host. In some cases host exhibited tolerance to certain level. The tolerance to pathogens is not a response specific to the pathogen but is a normal homeostatic response of the host that has been evolved to counter a wide range of environmental strains, mostly abiotic. Thus a genetically controlled ability to tolerate nutritional stress would also confer tolerance to a root rotting pathogen in a host growing in such soils, since the pathogen has the effect of reducing the nutrient absorbing surface (Graham and Webb, 1991).

Resistance and tolerance are relatively independent factors in a host pathogen relationship. The application of essential elements contributes to disease tolerance wherever the soil is deficient in that element, by increasing the vigour of the host plant. Last (1962) reported increased grain yield in cereal crop infected with powdery mildew grown in N deficient soil when N was supplied to the soil. The resistance of the host was lowered under N deficiency which improved on removal of the deficiency (Gour *et al.*, 2002).

The essential elements are classified into macronutrients like nitrogen, phosphorus, potassium, calcium, manganese, zinc, copper, molybdenum and chlorine. The nutrients are derived by the crop plants from the medium on which they grow through the root system. The availability of nutrients depends upon such factors like minerological composition of soil, pH and several other physico-chemical factors and the physiological activities in plants. Nutrients are essential for plant growth and required functions. Carbon, hydrogen and oxygen are the constituents of most of the organic compounds and are obtained by plants through air and water (Colhoun, 1973).

Macronutrients : NPK are considered as primary, and S, Ca, Mg secondary macronutrients.

Nitrogen : It is the component of proteins, amino-acids, chlorophyll, purines, pyrimidines and coenzymes. It increases plant growth, vigour and number of roots. Nitrogen decreases or increases disease intensity depending on other factors. It is mobile. Nitrogen deficiency leads to chlorosis, stunted plant growth, delayed flowering, sterility, no fruit formation and elongation of roots. Yellow berry of wheat is due to nitrogen deficiency. Gummosis and die back in citrus and stone fruits and firing or burning of leaves occurs due to excess nitrogen.

The forms of nitrogen influence the disease severity differently. The ammonium nitrogen increases cortical and root diseases due to the species of *Fusarium, Rhizoctonia, Aphanomyces, Cercosporella* and *Ophiobolus*, cereal rusts, mildews etc., however nitrate nitrogen has reversed affect (Huber and Watson, 1974; Filho and Dhingra, 1980; Basuchaudhary and Gupta, 1988).

At higher doses of nitrogen host tissues develop larger thin walled cells which remain loose with larger intercellular spaces, the stomata remain wide open. Due to these factors susceptibility in host plants gets increased to many diseases like wilts, root rots, Alternaria leaf spots, bacterial blights, rusts, powdery mildew, paddy blast (Palti, 1981). In certain cases high dose of nitrogen reduces the disease incidence caused by *Pseudomonas syringae* and *Drechslera turcicum* in maize and *Fusarium moniliforme* in rice (Sunder and Satyavir, 1997). Heavy application of urea reduced tobacco wilt (*Pseudomonas sclanacearum*).

Phosphorus : It is constituent of nucleoproteins, phospholipids – NADP, ADP, ATP etc. Phosphorus plays a vital role in energy transfer, respiration, photosynthesis, phosphorelation, starch hydrolysis, transamination and absorption of other nutrients. It is mobile.

Phosphorus deficiency causes accumulation of soluble N compounds as in tomato, soybean etc. It results in purple pigmentation, stunted growth, less lateral shoots, retarded flowering and fruiting, premature death of buds, imperfect pollination.

Single foliar spray of phosphorus induced a systemic protection against powdery mildew in cucumber (*Sphaerotheca fuliginea*) and rust in maize (*Puccinia sorghi*) (Reuveni and Reuveni, 1998). Increased dose of P at 30, 60 kg ha^{-1} level decreased soybean rust (*Phakopsora pachyrhizi*) (Sharma *et al*., 1996), collar rot of lentil (*S. rolfsii*) (Khare, 1980), root rot of chickpea due to *Fusarium solani* (Gaur and Vaidya, 1982). However, higher dose of phosphorus increased root rot of cotton (*S. rolfsii*) (Jordan and Nelson, 1939) and wilt of sweet potato (Ngeve and Roncadori, 1984).

Potassium : The role of potassium in plants is to activate enzymes like pyruvic acid kinase. It affects mechanism of stomata, photosynthesis, starch synthesis, adenine synthesis, metabolic activities of chloroplasts and mitochondria, transpiration, water translocation and indirectly affects cell wall thickness. It is mobile, K makes the plant resistant to pathogens.

Under K deficiency loss of cell turgor occurs which facilitates penetration by fungi, Glutamine is high under K deficiency which stimulates spore germination as in *Pyricularia oryzae* on rice leaves (Suryanarayan, 1958). Leaf scorch of apple, potash hunger in potato, browning of leaves with necrosis giving rust like appearance in cotton. Seed often fails to mature and remains small.

K in split application, one at the basal stage and the other at maximum tillering in NPK combination of 40:20:20 kg ha^{-1} significantly reduced the incidence of sheath blight of rice (*R. solani*) and increased yield (Baruah, 1995). Application of K decreased black spot disease in rape (Sharma and Kolte, 1994). Ascochyta blight of chickpea (Singh and Chand, 1996), rice blast (Fillipi and Prabhu, 1998), Rhizocotonia disease of potato (Das and Western, 1959), root rots of sunnhemp caused by *R. solani* and *S. rolfsii* (Pal and Baschaudhary, 1980), root and collar rot of lentil due to *R. solani* and *S. rolfsii* (Prasad and Basuchaudhary, 1984), cotton wilt (Miles, 1936). Powdery mildew of wheat was less when PK were applied (Yurina *et al*., 1997).

Magnesium : Chlorophyll contains Mg and it plays an important part in enzymatic activity in carbohydrate metabolism. Mg ions are essential for oxidative phosphorelation. It is mobile.

Mg deficiency results in interveinal chlorosis, Anthocyanin pigment develops resulting in spots. Sand drown symptoms develop in tobacco leaf. Soybean is also affected.

Calcium : Calcium plays an important role in the integrity of membranes and cell walls as calcium pectate is a constituent of middle lamella. Calcium promotes meristematic growth and also auxin action. It is immobile. It also plays a role in lipid synthesis.

The deficiency of calcium results in killing of growing points, roots are poorly developed. In potato, tuber and shoot formation is severely affected. Blossom end rot occurs in tomato, Die back symptoms appear in apple. In broad bean pods are deformed, wilted and blackened and seeds fail to develop. Application of gypsum, super-phosphate to Ruscus plants effectively reduced susceptibility of out branches to infection by *Botrytis cinerea* (Elad and Kirshner, 1992) pod rot due to *R. solani* and *Pythium myriotylum* in groundnut (Hallock and Garren, 1968). Calcium deficiency occurs most commonly in strongly acid soils.

Sulphur : It is a constituent of S-containing aimino-acids, tripeptides, proteins, vitamins, glutathione, lipoic acid, coanzyme A. glycosides and thiols. A portion of total S in plants is mobile and the movement is through phloem.

The deficiency of sulphur affects N metabolism, leaves become small, chlorotic, brittle and rolled.

Micronutrients: The micronutrients are Mn, Cu, Zn, B, Fe, Mo, Cl, Ni and Si which play a definite role in plant metabolism.

Manganese: Mn deficiency affects photosynthesis and O_2 evolution. It is an important contributor in the development of resistance in plants to both root and foliar diseases caused by fungi. Host plants require more quantity of Mn than fungi and bacteria. The effect of Mn is both in the deficiency range as well as in the sufficiency range. The Mn requirement of the host plant for disease resistance is higher than for yield and it somehow lowers the inoculum potential in case of soil borne pathogens. As the Mn concentration in host tissues decreases incidence of diseases increase. The root pathogen reduce the absorptive surface of the root which results in lesser absorption of Mn. The fungus also mobilizes Mn in the rhizosphere by oxidation, thereby decreasing the availability of Mn in soil. Mn gets concentrated around infection sites. Certain soil factors also affect the availability of soil Mn. Higher pH, addition of lime, nitrate forms of N, cold wet soils decrease whereas, ammonical forms of N, Cl fertilizers, green manures and irrigation increase the soil Mn availability. Several pathogenic diseases have been successfully controlled by Mn fertilizers like powdery mildew of cereals, downy mildew of sorghum, take all disease of wheat, common scab of potato. Mn deficiency develops marsh spot in pea.

As regards the mechanism of action of Mn in disease resistance, it plays a role in lignin synthesis which is a basis of resistance to powdery mildew and take all disease in wheat. The lignin response in roots has been reported greater than in shoots. Phenols are responsible for resistance to diseases. Mn is involved in biosynthesis pathway to phenol, its deficiency leads to a decrease in soluble phenols influencing resistance. Amino-peptidase is a host enzyme activated by a pathogen to supply essential amino acids for fungal growth. The induction of this enzyme is inhibited by Mn. Mn also inhibits pactinmethylesterase which is a fungal coenzyme for degrading host cell walls. The deficiency of Mn severely inhibits photosynthesis which influences root exudation and ultimately rhizoflora is affected influencing the pathogen. The root exudations increase Mn in soil making it toxic to the pathogen. Cotton cultivars tolerant to Mn toxicity are preferred as the high soil Mn concentrations controlled the inoculum density of *Verticillium alboatrum* by inhibiting secretical production which is necessary to saprophytic survival of the pathogen. The Mn deficiency results in greenish grey spots, flecks and strips in leaves of cereals and interveinal chlorosis of the younger and middle aged leaves in dicots. The tissues become necrotic.

Copper : Cu deficiency depresses reproductive growth, seed and fruit formation more than vegetative growth. It causes chlorosis leaf distation, and die back. Copper is used for the control of foliar pathogens by topical application in the form of salts. It is essential for plants. The fungi and bacteria need it in minute quantity and is toxic at higher concentrations which are tolerated by host plants. The foliar and root diseases are controlled by providing more Cu 10 to 100 times greater than those normally needed (0.1-0.2 kg ha^{-1}) to curve Cu deficiency. When Cu is applied to soil, the disease control is observed both in roots and leaves.

Copper fertilizer controlled powdery mildew of wheat (Graham, 1980). Wheat plant takes about six weeks to exhibit deficiency of Cu, consequently it affects disease resistance of more mature plants, when wheat normally acquires greater resistance called adult plant resistance. Several foliar diseases have been controlled with soil application of Cu as wheat powdery mildew, *Alternaria* of sunflower, brown rust of wheat, ergot of rye and barley, paddy blast and *Septoria* on wheat. Cu supplementation has suppressed many soil borne diseases like *Verticillium* wilt of tomato and cotton, potato scab, take all of wheat (Graham, 1983).

The mode of action of Cu in developing host resistance and reducing disease severity is based on direct toxicity. It denatures proteins, indirectly it helps as Cu plays a vital role in lignin synthesis. Lignin acts as a partial barrier in penetration of many pathogens. Cu is also involved in the synthesis of soluble phenols and in their oxidation to more toxic quinones which not only kill the invading microorganisms but also the surrounding cells of the host and give rise to a local lesion, an important auto-amino response which checks infections by obligate parasites like rust and powdery mildew.

Zinc : Zinc increases the resistance to pathogens in host plants. It directly affects the pathogen as well through plant's metabolism. In *in vitro* tests Zn has checked the growth of the microorganisms. Zoosporangium and zoospore formation was inhibited by *Phytophthora megasperma* and growth of several other fungi. In high concentrations Zn checks several diseases. Pre-treatment of soil with $ZnSO_4$ decreased *Fusarium* wilt of cotton. Dipping of potato tubers in 0.05% $ZnSO_4$ plus 1% acetic acid for 15 minutes before planting checked black surf due to *R. solani*. Application of $ZnSO_4$ in soil also checked *Fusarium* root rot of chickpea, *R. bataticola* rot of groundnut Zn also plays a role in controlling fungal growth within the plant.

Zn is important in the stability of biological membranes and it helps in preventing root membranes from leaking. The Zn deficient roots leaked more carbo-hydrate and amino acids attracting more zoospores by chemotaxis which allow more successful invasion. In soybean collar rot caused by *S. rolfsii* high rates of $ZnSO_4$ (0.5%) decreased infection, it also increased the population of potential antagonistic microorganisms. The Zn efficiency is the factor responsible for tolerance to diseases. Zn checked blast in rice (Fillipi and Prabhu, 1998) and downy mildew of bajra.

Boron : It has beneficial effects in reducing diseases like club root of crucifers, *R. solani* in green gram, pea, cowpea, *R. bataticola* in groundnut, *F. solani* in bean etc. B is involved in many physiological and biochemical functions.

Boron is involved in phenolic and lignin metabolism. It has been shown to decrease pathogens which do not involve vascular tissue like potato wart caused by *Synchytrium endobioticum* and club root of crucifers. In both the cases tumor or gall is formed. Pathogens invading vascular tissues like species of *Fusarium* and *Verticillium* enter the xylem vessels through invastion just behind the root cap where lignification is the least. B deficiency weakens the lignification of other parts of the root system where from invasion occurs later. B deficiency leads to hollow heart in groundnut resulting in discolouration and rotting of seeds. Premature fruit/seed drop also occurs.

Iron : The deficiency causes chlorosis of young leaves and cell division is inhibited. At high concentrations Fe checks rust infection on wheat leaves, wheat smut and banana anthracnose. Foliar sprays of Fe increased resistance in apple and pear to *Sphaeropsis malorum* and tolerance of cabbage to *Olpidium brassicae*.

Fe plays key role in oxidative phosphorylation and is involved in plant synthesis directly or indirectly. High Fe reuirement is there for phytoalexin synthesis. Production of antibiotics by several soil bacteria is highly promoted by Fe.

Molybdenum : Deficiency caused poor and delayed flowering, reduced pollen viability. Application of Mo to tomato roots reduced *Verticillium* wilt. Mo had a direct effect by reducing the production of *Roridin E.*, a toxin produced by *Myrothecium roridum*. Soil application of Mo decreased nematode populations. Interveinal mottle, scald, interveinal and marginal necrosis of leaves occurs in phaseolus bean.

Chlorine : It is involved in O_2 production during photosynthesis. Cl exists in soil plant system as the stable Cl anion. Chloride fertilizers as micronutrient have partially controlled several diseases like stalk rot of corn, stripe rust of wheat, take all of wheat, downy mildew of pearl millet, *Septoria* in wheat. Cl deficiency causes chlorosis of younger leaves in overall wilting due to possible effect of transpiration.

Nickel : $Ni(NO_3)_2$ at 70 mg/l as spray decreased leaf rust on wheat 77 to 0.1 pustule per leaf and entirely prevented stem rust infection. Ni has eradicative and protective action within a few minutes of its application. The efficacy of conventional organic fungicides has been improved by combining them with Ni salts.

The relatively low concentrations, short contact time and the protective effect of Ni suggest physiological mechanisms in the host leading to resistance. When Ni was supplied via roots in low concentrations the rust pustules were highly reduced in cowpea which suggests no direct toxic effect to the pathogens, it is involved in some biochemical pathway that leads to resistance.

Ni is an essential ultra micronutrient as it plays a vital role in the N metabolism of plants. The resistance pathway may have a higher requirement for Ni than growth itself.

Silicon : It is essential to biochemical pathways leading to resistance to certain pathogens. Silicates provided protection against rice blast fungus and brown spot. In certain soils low in silica, the application of silicate can suppress these pathogens, decreasing the disease and increasing the yield.

Other trace elements : Among other trace elements, Lithium and Cadmium through their marked suppressive effects on powdery mildews, are the most noteworthy. Li is supposed to catalyze a metabolic pathway which functions normally in defense.

It is evident from the above account that the addition of nutrients decreases the incidence of diseases in crop plants. The host plant tolerance and resistance to pathogens is most important. The response is more over the deficiency range for the element concerned. In any integrated crop protection programme adequate emphasis should be given to micronutrients as at a very minor quantity they reduce the disease to an acceptable level, or at least to a level at which further control by other cultural practices or biocides becomes possible. It may be further controlled with least expenditure successfully. While recommending inorganic fertilizers, micronutrients may also be recommended after proper analysis. The objective has to be to get maximum yields of a crop.

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Edaphic Resource Management through Agroforestry - An Eco-friendly Approach

S.D. Upadhyaya

Professor,
Department of Forestry
JN Krishi Vishwa Vidhyalaya, Jabalpur-482004 (MP)

Agroforestry as the term is used for growing of woody perennials in close association with agricultural crops. It is a land use system that involves trees, arable crops and/or livestock seeking positive synergism on the same land unit in space or time. Active agroforestry research has been going on for the last two decades (Nair, 1993) wherein the purposeful growing of trees and crops and/or animals in interacting combination for a variety of objectives have been studied. In fact the inductive research on agroforestry is now leading to deductive status, which is shortly going to culminate into technological innovations. Concepts and potentials of different agroforestry systems and practices has already been worked out during mid 70's and now itis practically proved that agroforestry can manage the edaphic resources and increase the productivity of agricultural land besides meeting the needs of food, fodder and fuel, especially in third world countries.

Agroforestry best for third world:

The food, fodder and fuel production in developing countries will have to be increased by 60% in the next 25 years to meet the needs of the growing population. The FAO study says that about 80 million hectares of culturable wastelands would have to be brought under cultivation/plantation in the next 25 years. The study also stressed that the trend of stripping forest cover to meet food/fodder and fuel need must be controlled and efforts be made to increase productivity of agricultural land by advocating agroforestry as one of the most practical way of meeting the needs for food, fodder and fuel.

Coming to recent times, the increasing pressure on land as well as on forests, rising demand for fuel and fodder and finally the requirement of timber for multifarious purpose have reinforced, as never before, the absolute and inseparable nexus between agriculture and forestry. In fact, the distinction sought to be made between agriculture as related to food, fiber and oilseed crops and forestry embracing tree culture in a general sense is, to a great extent, artificial and not well founded. For his survival, man has to ensure optimum use of Agriculture, Grasslands, Forests and aquatic bodies, including oceans. Of these, the combination of first three systems Agrisilviculture, silvopastoral are covered under Agroforestry.

Although the term sustainable land use is at present widely used, the precise interpretation of this concept remains problematic. We consider ecological sustainability as one component of sustainable land use. Ecological sustainability refers to the need to maintain the long-term production potential of the land. Other components of sustainable land use refer to social, cultural and economical aspects, such as the ability of land managers to adopt proper management systems and the equitable distribution of inputs and outputs of production. In assessing whether specific agroforestry systems are indeed sustainable, each of these components should be evaluated rather than one component only.

In order to be ecologically sustaibable, agricultural land-use should maintain an equilibrium between outputs and inputs of natural resources (e.g. in order to avoid soil depletion) and should maintain ecosystem flexibility and biodiversity. An important prerequisite is, therefore that the exploitation rate of natural resources, by human land use, should not exceed the carrying capacity. The carrying capacity is defined as "the level of exploitation of renewable resource, which imposes limits on a specific type of land-use, that can be sustained without causing land degradation within a given area". One difficulty is that ecological sustainability may be expressed at various scales of time and space.

Agroforestry systems are often claimed to be superior to agricultural systems without a woody component, because of their ability to contribute to sustained production of crops, livestock and wood especially on fragile land and in areas with prevalent low external input agriculture. The woody plants are assumed to contribute to both protective functions (enhancing ecological sustainability) and productive functions (taking the place of chemical fertilizers). It is also commonly expected that agroforestry can contribute to land rehabilitation and increased production on degraded lands.

Understanding of the ecological potential of agroforestry systems under different environmental conditions has increased tremendously during the last twenty five years.

The greatest ecological potential of agroforestry seems to be in buffering and in maintaining the production capacity of agricultural systems rather than in increasing crop production. The buffering capacities have greatest potential in high potential areas where opportunities for niche differentiation between woody plants and herbs are plentiful. Hoever, an increase in agricultural production can, in most cases, be achieved best by the use of external inputs both organic and inorganic. This does not mean that because trees do not easily contribute to increasing agricultural production, there is no potential for the combination of agricultural cropping and forestry. Properly managed woody plants on crop lands where such external resources are used contribute to prevent resource losses (referring to their buffering functions). A crucial management component in such agroforestry systems is the limitation of resource losses by other means than through crop harvesting. On degraded land the reintroduction of woody plants may assist in restarting the original production potential of the land, but this will normally make many years during which exploitation of the vegetation should be limited. Even ;if trees exert a negative effect on crops (e.g. through shade or root competition), it may still make economic sense for a farmer to practice agroforestry.

All agroforestry (AF) systems consist of at least two of the three major groups of AF components i.e. trees and shrubs (perennial), agricultural corps (annual or biennial) and pasture/livestock, trees and shrubs being present in all the AF systems. There may be other components also, such as fish, honeybees, silk worms etc. Depending on the nature and type of components involved, AF systems can be classified as:

- Agrisilviculture (trees + crops)
- Boundary Plantation (trees on boundary + crops)
- Block Plantation (tree + crops)
- Energy Plantation (tree + crops during initial stage)
- Alley cropping (hedges + crops)
- Agrihorticulture (fruit tree + crops)
- Agrisilvihorticulture (tree + fruit trees + crops)
- Agrisilvipasture (tree + crops + pasture / animals)
- Hortipasture (fruit trees + pasture / animals)
- Silvipasture (trees + pasture / aminals)
- Forage forestry (forage trees + pasture)
- Shelter belts (tree + crops)
- Wind breaks (tree + crops)
- Live fence (shrub under trees on boundary)
- Homestead (multiple combinations of trees, fruit trees, vegetable etc.)
- Entomoforestry (tree + sriculture)
- Aquaforestry (trees + fishes)

An AF system consist of one or more AF practices that are practiced extensively in a given locality or area, the system is usually described according to its biological composition and arrangement, level of technical management or socio-economic features. An AF practice denotes a specific land - management operation on a farm or other management unit, and consists of arrangements of AF components in space and / or time

Soil productivity aspects of Agroforestry:

The incorporations of compatible and desirable species of woody perennials on formland can result in a marked improvement in soil fertility such as:

- An increase in the organic matter content of the soil through litterfall.
- More efficient utilization of nutrients
- Biological nitrogen fixation
- Solubilization of relatively unavailable nutrients (for example phosphate, through active mycorrhizas)
- More efficient sharing of nutrient resources among the components
- Enhanced nutrient economy
- Increased activity of favourable microorganism in the root zone
- Improvement of the soils physical conditions i.e. permiablity, water-holding capacity, agrregate stability, soil temperature etc.
- Soil conservation and erosion control.

Nutrient budget and woody perennials

Process by which woody plants are assumed to increase nutrient availability are mainly nitrogen fixation and uptake of nutrients from sub-soil (young 1989 Nair et al, 1999). Both processes have their limitations. Nitrogen fixation depends on the presence of:

(a) Leguminous plants with the ability to nodulate and
(b) Sufficient available phosphorus and sufficient moisture for rhizobia to survive and produce.

The uptake of nutrients from the sub-soil depends on the presence of:

(a) Deep roots,
(b) A penetrable and deep soil profile, and
(c) Nutrients in the sub-soil

Nutrient Budgets
Gains:

- Atmosphere: rain and dust
- Fertilizer
- Organic additions (compost, manure, etc.)
- Non-symbiotic fixation (nitrogen)
- Symbiotic fixation (nitrogen)
- Deep capture (uptake by roots of trees from below the rooting depth of crops)
- Rock weathering (excluding)

Loses:

- Erosion
- Leaching
- Harvest (including for fodder)
- Removals not treated as harvest
- Gaseous losses: denitrification and volatilization (nitrogen) Burning (nitrogen, sulphur)
- Net fixation on to clay minerals (phosphorus)

Internal flows: Uptake:

- Uptake by plants from soil
- Return: Mineralization of litter and humification of litter
- Throughfall and stemflow: Ash from burning

Tree - crop interaction

- Rainfall is intercepted by the canopy
- Soil infiltration is higher under the canopy
- Radiation is reduced 30-60% under canopy
- Soil temperature under canopy reduced by 6 - 8 %
- Soil under canopy is drier during rainy season but wetter during dry season
- Aerial biomass of the plant is increased by some 25% under the canopy
- The root biomass of plant does not seem to influenced by the canopy
- The root / shoot ratio of the plant is higher in open
- P and Ca in the soil decrease along a transect from the tree to open, but only for a very short distance (2 m) from the tree
- N mineralization is double under the canopy
- Microbial biomass is higher under the canopy
- Nematode density is influenced by the canopy
- A large proportion of the extra nutrients accumulated under the canopy originates from bird's nests in the trees
- The stomatal activity of various graminea is influenced by the shade of the canopy

Agroforestry helps to improve the soil ecosystem

The inclusion of leguminous trees on fragile soil ecosystem facilitates the soil productivity improvement through:

- Addition of soil organic matter through leaf litter and organic debris
- Nutrient cycling efficiency underneath the trees
- Efficiency in biological nitrogen fixation, nitrogen fixing trees can add the nitrogen ranging from 100-500 kg N / ha / yr
- Little loss of nutrient from the system, trees can withhold the nutrients that can otherwise be lossed by leaching
- Little erosion runoff, because the woody perennial component of agroforestry has the capacity to maintain soil cover.
- Trees take-up nutrients from deeper layers of soil and deposited it on surface layer via litter.
- Nutrients also added in the soil by root decay.
- Viable counts of beneficial microorganisms also added to the soil ecosystem favourabley.
- Soil physical conditions like water holding capacity, aggregate stability, soil temperature and moisture regimes, permeability, drainage also improves favourably due to deliberate incorporation of trees with arable crops.
- Activation of mycorrhiza which can facilitate solubilization of unavailable nutrients, and
- Also help in mutual sharing of nutrients among agroforestry components.
- Improvement in soil physical conditions such as water holding capacity, aggregate stability, soil temperature regimes, permeability, drainage etc. by
  - Adding shoot / root biomass, about 3000 kg dry matter / hectare / year.
  - Nitrogen supplement from Nitrogen Fixing Tree species (NFTs)

In a nutshell Agroforestry facilitates ....

.....Increases additions to the soil

- Maintenance or increase of soil organic matter
- Nitrogen Fixation
- Nutrient uptake
- Atmospheric inputs
- Increased water infiltration

.......reduces losses form the soil

- Protection from erosion
- Nutrient retrieval and recycling through reducing leaching
- Reduction in the rate of organic matter decomposition
- Reduction of water loss from evapotranspiration
- Increased water storage capacity

.......affect soil physical conditions

- Maintenance or improvement of soil physical properties
- Penetration of compact or indurated layers by roots
- Modification of extremes of soil temperature

.......affect soil chemical condition

- Reduction of acidity
- Reduction of salinity and sodicity
- Reduction of soil toxicities caused by pollution
- Accelerate soil biological processes
- Improvement in the activity of soil fauna

- Improvement of nitrogen mineralization through the effects of shade
- Root nodulation
- Exudation of growth promoting substances by the rhizosphere of trees

Agroforestry Suitable for Rainfed Areas:

It is known that about 70 per cent of our cultivated land is rainfed, naturally, majority of our farmers are directly connected with the progress of rainfed farming. The poor productivity of these lands is attributed broadly to low moisture, eriatic rainfall with uneven distribution and unpredictable seasonal variations due to climate change. Incorporation of trees in such areas will certainly bring "Brown Revolution" which is the future of Indian Agriculture. Trees are the important components of this land use system which when combined with crops, yield certain environmental benefits in rainfed areas i.e. (a) conserving the natural forest for precipetation, (b) efficient recycling of nutrients, (c) reduction in nutrient leaching and soil erosion, (d) conserving soil water and checking evoporation from soil surface through mulching, and (e) ;improving the microclimate. In other words, agroforestry promotes the biomass production as well as rehabilitate the land. Traditionally, several agroforestry systems were practiced in our country (Tejwani, 1994). Among others the rainfed farming include.

- Acacia-babul in rice growing areas
- Khejri in arid arable fields
- Ziziphus in both arable and grasslands of arid ecosystem
- Fruit trees like mango, guava, citrus in semi-arid ecosystems
- NFT and fodder trees in grasslands as silvipastoral,
- Improved fallows/biomass transfer as trees on culturable wastelands, etc.

Summary :

Agroforestry has generated rather high levels of enthusiasm in recent years concern with rainfed land use and sustainable resource management system (Singh, 1999). It is a resource rich farming system having the productive role with the conservation farming techniques. It is a device of integrating production of trees with the production of agricultural crops in a sustainable manner. It has the most apprearent potential in rainfed areas and in resource limiting small holding farming systems where monocultural agriculture may not be the most feasible or desirable, based on the principles of self maintenance. The National Research Centre for Agroforestry (NRCAF) significantly contribute research on various aspects of agrisilviculture, agrihorticulture and silvipastoral including MPTs evaluation suitable for different agroclimatic zones of India (Solanki et al., 1999, Dhyani, 2009). Studies conducted under AICRP in Agroforestry also revealed that incorporation of trees and / or animals in rainfed farming systems improves the overall productivity of the system in a sustainable manner, without deteriorating the natural resources.

Hence, agroforestry can be seen as phases in the development of productive agroecosystem. Within this ecological framework, farmers can manipulate and manage their trees to take advantage of the benefits or the processes in ecosystem services or products. Therefore, the agroforestry should be reconsidered as a dynamic, ecologically based natural resource management system that can sustains small holder production through the intergration of trees in farm and / or in rangelands for increased social, economical and environmental benefits.

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Nematodes and Soil Ecosystem

S.P. Tiwari

Professor
Department of Plant Pathology
JN Krishi Vishwa Vidhyalaya, Jabalpur-482004 (MP)

Most of the soil organisms perform beneficial roles in soil ecosystems. Nematodes are also a part of a complex soil ecosystem. A small fraction of soil fauna depends upon primary producers, feeding on plant roots and their exudates. Soil nematodes are relatively abundant ($6x10^4$ to $9x10^6$ per m^2), small (300 µm to 4 mm)in size with short generation (days to a few weeks) respond to change in food supply (Wasilewska, 1979). Nematodes occupy various trophic roles and perform important functions within the soil web. Nematodes are convenient indicators of similar functions performed by other organisms in the soil web and documented indicators of ecosystem condition. Generally vermiform nematode characters are used in their description; facilitate assessment of body volume and weight. Prescribed coefficients allow calculation of their carbon metabolism. Their production of body structure and eggs can be standardized for life course duration. Nematodes metabolic activity levels, attributable to the abundance of nematodes performing various functional roles, can be calculated from existing and accessible morphometric data. Metabolic footprints of nematode assemblages provide measurement of ecosystem services per formed by each functional guild.

Nematodes affect food web structure and function :
1) channelling resources derived through feeding on roots
2) predation on other organisms
3) serving as prey for higher-level predators
4) redistributing organisms in the soil matrix
5) sequestering minerals, C and energy
6) converting organic molecules to mineral forms available for uptake by plants and microbes
7) regulating opportunistic species.

Organic matter Decomposition:

Bacterial-feeding nematodes-

When farmers add organic matters to the soil, organic residues usually decomposed to release nutrients for plant to uptake. In decomposition pathways where bacteria are the primary decomposers.

Bacteria and fungi are primary decomposers of organic matter and soil food webs. Bacterial-feeding nematodes affect organic matter decomposition directly by feeding microbes and indirectly by dispensing microbes (Bouwman *et al.,* 1994). Decomposition of organic matter in a soil could be divided into two channels, a faster bacterial channel and a slower fungal-based channel. Soil ecosystem types and Carbon to Nitrogen ratios (C: N ratios) determine the predominant decomposition channels (Ingham et al., 1983). Although bacteria and fungi are the primary decomposers in the soil food web. these microbes also could immobilize inorganic nutrients in the soil (Ingham et al., 1983), making nutrients unavailable for plants to uptake. Decomposition of organic matter performed by bacterivorous and fungivorous nematodes while graze on such microbes and produce CO_2 and NH4+ and other nitrogenous compounds, affecting C and N mineralization directly (Ingham et al., 1983). Indirectly, nematodes can disseminate microbial propagules throughout the soil, which advances the colonization of substrates and mineralization of nutrients. Nematode metabolites may also stimulate specific bacterial growth by releasing growth-limiting nutrients (N and vitamins).

However, overgrazing of bacterial or fungal populations by nematodes can result in a reduction of the overall activity of these decomposers. Fortunately, in the hierarchy of the soil food web, generalist predators (such as the omnivorous and predatory nematodes) prey on these bacterivorous and fungivorous nematodes.Thus improving nutrient cycling and allowing more nutrients to be released (Yeates and Wardle, 1996). Therefore, free-living nematodes play important roles in soil nutrient cycling.

Nematode excretion contribute up to 19% of soluble N in soil (Neher, 2001). In nematodes a lower N content than the bacteria (C:N ratio of 3-4). (Wasilewska and Bienkowski, 1985). The growth efficiency of nematodes are smaller (< 25%) than those of the bacteria (> 30%) (Hunt et al., 1987). Nematodes excretes assimilated C and N which is consumed by the bacteria. Bacteria, on the other hand, usually respire most of the assimilated C, but immobilized most of the assimilated N. Availability of N to plants usually contributed by nematodes to N mineralization which is relatively high than bacteria in soil ecosystems. Besides contributing to N mineralization, many bacterivorous, omnivorous, and predatory nematodes correlate with concentrations of many other soil nutrients (Wang et al., 2004). Adding organic amendments to the soil, growing cover crops as green manure, covering soil with organic mulch, and practicing conservation tillage are various methods to enhance population densities of beneficial free-living nematodes in the soil.

Bacterivorous nematodes affect organic matter decomposition directly by feeding on microbes and indirectly by dispersing microbes (Bouwman *et al.,* 1994; Griffiths, 1994). The nematodes are attracted to bacterial food sources via CO_2 or exuded metabolites and possibly temperature gradients (Freckman, 1988). Nematodes are primary consumers of bacteria in the rhizosphere; protozoa are equally prevalent in rhizosphere and bulk soil (Griffiths and Caul, 1993). C-to-N ratios of bacterial-feeding nematodes have been estimated as around 1O:l by Anderson *et al.,* (1981) and as 4.6: 1 by Persson (1983). The estimates of Anderson *et al.,* (1981) are based on measurements of the N content of a fungal-feeding nematode, *Ditylenchus trtformis* by Myers and Krusberg (1965), and on estimated C content. The excess N is excreted mainly as ammonia which freely permeates the nematode cuticle (Rogers, 1969; Wright and Newall, 1976; Lee and Atkinson, 1977). Considerable mineralization of N is associated with nematode metabolic activity.

Nematodes can serve as a model subsystem that provides a holistic measure of the biotic and functional status of soils (Neher, 2001). The development of the maturity index (MI) (Bongers, 1990) represented a significant advance in interpreting the relationship between the ecology of nematode communities and soil function, and thus, facilitated bio-assessment studies using nematodes as indicators. Positive relations between plant species diversity and the abundance or diversity of soil organisms were explained by increased substrate diversity, increased substrate quantity or increased diversity of soil microhabitats (Spehn *et al.,* 2000, Stephan *et al.,* 2000). Effects of plant species diversity in the soil food web and ecosystem processes are explained by Porazinska *et al.*(2003) Primary consumers, microbes and plant feeders often appeared to be more responsive than secondary microbe-feeders and tertiary consumers (predators) to plant (Korthals *et al.,* 2001, Porazinska *et al.,* 2003 and Wardle *et al.,* 2003).

Indices of ecosystem condition

The soil nematode assemblage has basal, enrichment and structural components. Trophic group prevalence indicates C and energy flow through herbivory, and through fungus- and bacteriamediated decomposition channels. Functional guilds are based on feeding habits and cp. Structure (SI), Basal (BI), and Channel (CI) indices are calculated from weighted faunal components (b, e, s) of the nematode assemblage: b (Ba2 þ Fu2)) w2; e (Ba1) w1) þ (Fu2) w2); s (Ban) wn þ Fun) wn þ Prn) wn), where the abundance of bacterial-and fungal-feeding nematodes is indicated by Ba and Fu, and that of higher predators.

The production component

Nematode biomass is calculated by the Andrássy. Nematodes, in general, have elongate cylindrical bodies tapering towards both ends with the anterior bluntly rounded and the posterior more acute. That simple shape provides conveniently for calculation of volume and biomass of nematode. The formulae of de Man have been the standard morphometric descriptors for nematode taxa for over 50 years. Among the standard parameters are L, the body length, and a, the ratio of length to maximum body diameter. Thus, from information available in the taxonomic descriptions of nematode species, the formula for nematode volume is restated as V (L3/a2)/1.7. To calculate the weight of nematodes, Andrássy determined specific gravity of nematodes.

Soil health

Soil health is the capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality and promote plant and animal health (Doran *et al.,* 1996). A healthy soil have ability to support life processes through nutrient supply, retention of optimal water and soil properties, support soil food webs, recycle nutrients, maintenance of microbial diversity, remediate pollutants, and sequester heavy metals. Plant pathologists assert that disease suppression seems to be a function of soil health. Plant parasitic nematodes, fungi, bacteria, phytoplasma, protozoa and viruses are soil-borne organisms which affect a plant productivity. Plant parasitic nematodes develop non-specific symptoms on infection. Nematode lives out of sight of the growers and plant protection workers due to microscopic size. Root-knot nematodes are an exception which develops distinctive as root galls, galls also referred to as 'root elephantiasis'. Interactions between nematodes and other soil pathogens results recognition of the problem and assessment of the damage. Nematodes are attracted to bacterial food sources via CO_2 or exuded metabolism and temperature gradients (Nicholas 1984). Enhanced nutrient cycling in both the rhizosphrer and bulk soil depends on consumption of bacteria by nematodes to mineralize immobilized N (Clarholm,1985). Nematodes appear to be the primary consumers of bacteria in rhizosphere

(Griffith *et al.,* 1991). The abundance of bacterial-feeding nematodes may be useful indicator of bacterial productivity in the soil (Freckman, 1988).

High population of beneficial free-living nematodes and comprehensive nematode faunal analysis in soil ecosystem management strategies for the protection of damage caused by plant-parasitic nematodes ultimately leads to improvements in plant health. Biological diversity, community stability, ability to maintain the integrity of nutrient cycling and energy flow, suppression of multiple pests and pathogens, and improved plant health includes soil health improvement.

Nematodes as soil health bio-indicators

Nematodes inhabit virtually in all the environments of the world. Nematodes feed on bacteria, fungi, algae, other nematodes, soil fauna other parasites of plants and animals. Millions of these organisms may live in 1 square meter of soil, and only about 3% of them have been studied and described so for. Nematodes are important participants in the cycling of minerals and nutrients for the biological activity in diverse ecosystems. They play major roles in decomposing organic wastes, biodegradation of toxic compounds by regulating primary decomposer populations hence can be used as bio-indicators of soil health due to ubiquitous and diverse feeding behaviors and life strategies. Few of them also survive better even under harsh, polluted, or disturbed environments whereas some have short life cycles and respond rapid changes to environment. Morphology of nematodes reflects feeding behavior allowing easy functional classification. These nematode faunal analysis characteristics provides insight into soil food web conditions, although there ambiguities in feeding they are classified into eight feeding groups out of these five feeding groups with distinct buccal cavities are bacterivore, fungivore, herbivore, omnivore and predator.

Nutrient cycling

Nematodes are also important in mineralizing, or releasing, nutrients in plant-available forms like protozoa. When nematodes eat bacteria or fungi, ammonium ($NH4^+$) is released because bacteria and fungi contain much more nitrogen than the nematodes require.

Role of Nematodes in Soil Nutrient Cycling

Organic matter, plant debris and organic residues are an important components of soil and release nutrients for plant uptake after decomposition results improvement of soil's biological, physical, chemical properties and soil function. Increasing nutrient availability, providing a favorable physical condition for plant growth, increasing soil buffering capacity and biological diversity, stimulating root development and facilitating a number of carbon and nitrogen cycles (Magdoff, 1992). Bacterial (*Escherichia coli*) feeder nematodes viz., *Caenorhabditis elegans,Bursilla labiata,cruznema tripatium, Panagrolaimus detritophagus, Acrobeloides bodenheimeri, Cephalobus persegnis* and *Rhabditis cucumeris* showed C to N ratio were variable and ranged from 4.87 to 6.99. Faster bacterial and a slower fungal-based energy channel decompose organic matter in a soil food web.

Soil Ecosystem Management from Nematodes

Both, maintaining soil nutrient availability and plant-parasitic nematode suppression are most important issues in nematode management for soil health. Plant-parasitic nematodes cause damage to plant roots, resulting in root systems which are less able to take up nutrients and water. Enhancing soil nutrient availability for plant uptake also provides materials required to grow functional roots, increasing the plant tolerance against nematode damage. Fungal egg-parasites, nematode-trapping and endoparasitic fungi, plant-health promoting rhizobacteria, obligate bacterial parasites, mites, collembola, tardigrades, predatory nematodes, turbellarians, and protozoans are resource for suppressing plant-parasitic nematodes in soil ecosystems.

Thus developing soil ecosystem nematode management systems constituent are

(a) The enhancement of free-living nematodes which significantly involved in soil nutrient cycling; Bacterivorous nematodes have efficiency in nutrient mineralization act as strong bio-indicators of N mineralization enhanced soil nutrient cycle.

(b) The suppression of multiple nematode pests through crop rotations or inundative biological control practices for single nematode pest. In soil ecosystem *Crotalaria juncea* a cover crop is a poor host for suppressing root-knot as well as reniform nematodes.

(c) The enhancement of natural enemies of plant-parasitic nematodes like free-living nematodes, nematophagous fungi produce adhesive networks, constricting rings and adhesive knobs *Hirsutella rhossiliensis* an endoparasitic fungus, a trapping fungus forming adhesive knobs as *Monacrosporium ellipsosporum* , a trapping fungus forming constricting rings by *A. dactyloides, A. oligospora* and a trapping fungus forming adhesive three-dimensional networks due to *M. cionopagum*

(d) The improvement of plant health by organic matter stimulated bacteria providing a food base for free-living nematodes at the time of soil amendments enhance soil suppressiveness against plant-parasitic nematodes.

Soil ecosystems stability

Both, structural and functional diversity are more important for soil health. Functional diversity refers to a reserve pool of quiescent organisms or a community with vast inter-specific overlaps and trait plasticity allows an ecosystem to maintain long-term stability of soil function.

Succession on nematode communities

Organic matter decomposition enriched-opportunist bacterivorous nematodes with C:N ratios. Fungivorous nematodes increased higher C:N ratio gradually, such residues became more abundant for omnivores and predators *Fusarium solani* f. sp. *phaseoli*, *R. solani*, *Pythium ultimum* and *T. basicola* and lesion nematode *Pratylenchus* spp.are of common.

Conclusion:

Nematodes play a key role in soil health ecosystem. Organic matter decomposition products are assimilated by the nematodes which ultimately reach to plant as a source of nutrient.

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Integrated Nutrient Management : A Key for Sustainable Crop Production

P.S. Kulhare

Principal Scientist
Department of Soil Science and Agricultural Chemistry
JN Krishi Vishwa Vidhyalaya, Jabalpur-482004 (MP)

For feeding a increasing population of 1.4 billian by 2025, India will need to produce 301 M t food grain in addition to other commodities . To achieve the production about 45 M t plant nutrient would be needed with the demand of chemical fertilizers nutrient 35 M t and about 10 M t should be came from organic sources.

Reason of low crop production –

(1) Inadequate imbalance use of chemical fertilizer created a 8-10 M t negative nutrient balance

(2) Only use of organic manure system can not sustained the crop production due to less availability.

(3) Deteriorating soil health / quality resulting multi nutrient deficiencies.

(4) Decreasing nutrient response.

Integrated Nutrient management (INM)

INM is an integrated approach of effective and efficient utilization of all nutrient resources, organic including microbial as well as inorganic which are locally available economically viable, socially acceptable and ecofriendly for sustaining and increasing crop production. INM technology envisaging conjuctive use of inorganic , organic sources , hold great promise in maintenance of soil quality , enhancing nutrient use efficiency and realizing optimum and sustainable yield of crops.

Advantages of INM

(1) Combined use of organic and inorganic have been well established.

(2) INM is helpful in arresting the nutrients deficiencies and favorably optimizing physical, chemical and biological environment of soil and bringing economy and efficiency of fertilizer.

(3) INM concept is economically favorable, environmental friendly and sustaining productivity and enhancing quality of soil.

Components of INM.

1. Chemical fertilizers-

With the use of high yielding variety and increase of total irrigated area, chemical fertilizers played the most significant role in increasing the production of crop.

2. **Organic sources**

Organic manure induce improvements in soil quality and sustainable crop production. The integrated nutrient supply including use of chemical fertilizers with FYM, compost green manure, biofertilizers etc helps not only is bridging the existing wide gap between the nutrient removal and also in ensuring balance nutrient proportion , in enhancing nutrient response, efficiency and maximizing crop productivity of desired quality.

The inclusion of legumes as an inter crop or otherwise in the cropping sequence contribute considerable N through biological N – fixation and having residual effect on succeeding cereal crops. Long term fertilizer experiments in different agro ecological zone of India clealy demonstrated that over full application of recommended doses of NPK fails to sustain the soil quality and crop productivity, but combined use of chemical fertilizers and FYM could obtain higher crop yield beside improvement of soil fertility (Swarup,1998). The positive influence of regular additions of organic manures on soil quality was envident in improvements in values of different physical , chemical and biological attributes of soil OC, mean weight diameter, water retention , infiltration , microbial biomass- C and microbial count increased and bulk density and exchange acidity decreased with the application of recommended NPK+FYM compared to NPK alone in long term experiments (Table- 1 and 5, Chhibba, 2010).

The integrated nutrient supply has to be based on need based application of fertilizer nutrient and other amendments which may required for correcting any fertilizer induced imbalance in soil environment and health (Gos wami and Rattan, 2000).

Table 1. Effect of organic materials on soil physical properties of soil under Rice-wheat production system

Treatment	Post wheat harvest soil properties		
	Bulk density (Mg m^{-3})	Infiltration rate (x 10-2 cm min^{-1})	Mean weight diameter
Urea to rice	1.72	2.30	0.35
GM (Sesbania) + urea to rice	1.68	3.00	0.40
FYM + urea to rice	1.70	2.75	0.41
FYM+GM to rice	1.64	4.64	0.49
Wheat straw + GM	1.67	4.19	0.44
Wheat straw + GM + urea	1.62	3.92	0.52
Wheat straw + urea + RS	1.65	3.45	0.46
Wheat straw + GM+ urea + RS	1.58	7.30	0.56
LSD (P =0.05)	0.03	-	0.03

FYM- Farmyard manure; GM – Sesbania green manure; RS- Rice straw

Table 2. Effect of rice straw management on soil properties.

Straw management	Post - rice harvest soil properties			
	Bulk density (mg m-3)	Infiltration rate (cm h-1)	Mean weight diameter (mm)	Aggregate stability (%)
Removal	1.69	0.34	0.26	8.0
Burning	1.67	0.34	0.32	10.0
Incorporation	1.59	0.41	0.37	15.0
LSD (P=0.05)	0.03	-	0.067	2.4

Table 3: Effect of green manuring on crop yield and soil nutrient status.

Sequence	Yield (t ha^{-1})		Change over initial			Apparent nutrient balance		
	Rice	Wheat	O.C. (%)	P (kg ha^{-1})	K (kg ha^{-1})	N	P	K
Rice wheat	5.73	5.65	+1.1	+15.5	-7.8	+141	+28	-63
Rice – wheat-green gram GM	6.80	5.71	+19.1	+32.2	+2.1	+210	+76	-04
Rice-wheat-Sesbania GM	6.58	5.69	+14.6	+36.8	+2.5	+166	+70	-10

Table 4: Crop residue management and soil biological fertility

Parameter	Residue management		
	Removal	Burning	Incorporation
Bacteria (x 10^6)	15.3	2.8	30.7
Fungi (x 10^3)	60	10	109
Phosphatase activity (mg p-NP $g^{-1}h^{-1}$)	125	135	175
Dehydrogenase activity (mg TPFg^{-1} 24 h^{-1})	36	33	52

Table 5: Effect of burning and incorporation of straw on soil nutrient status .

Treatment	Sandy loam			Silt loam		
	O.C. (g kg-1)	Available P (kg $acre^{-1}$)	Available K (kg $acre^{-1}$)	O.C. (g kg-1)	Available P (kg $acre^{-1}$)	Available K (kg $acre^{-1}$)
Burning	0.35	3.7	30	0.59	9.4	68
Incorporation	0.42	4.6	33	0.66	10.4	73

Source: (Chhibba, 2010)

3. **Biofertilizers**

Biofertilizers are the products containing living cells of different types as micro organisms that have an ability to mobilize nutrients from non usable to usable form through biological process. These broadly include N fixers, P solubulizer capable of mobilizing nonlabile nutrients and transporting metals to and across the plant roots. On global basis biological fixed N potential has been estimated at 139 M t/ha/ yr as against 70 M t N fixed chemically (Brady and Weil, 1998). In India, BNF potential is 20 mt/ annum for 1997-97 against 10.08 mt fertilize N produced (Fertilizer statistics 1997-98). Conjoint application of biofertilizers, chemical fertilizers and organic manures, in addition to include of legumes in cropping system and incorporation of on and off farm generated crop residues constitutes are efficient nutrient management strategy.

4. **Legumes as green manuring.**

Usefulness of legumes as soil fertility building practice in multiples cropping systems is well established. Symbiotic association of the legumes with different species of Rhizobium has proved useful in sequestering significant amounts of atmospheric N in the soil plant system to the extent of 25-50% of the chemical fixed N requirement of the succeeding cereal crop can be met by atmospheric N fixed by legume (Table-6).

5. Urban waste

Large quantity of city and urban waste is available that can be used as source of plant nutrients after proper treatment. Urban sludge improve soil structure contain secondary and micro nutrients as well a NPK.

Table 6: contribution of green manure for N fixation

		Biomass (t ha^{-1})	N harvest (kg ha^{-1})
Dhaincha	Sesbania Aculeta	22.5	125
Dhaincha	Sesbania rostrata	20.06	146
Sunhemp	Crotolaria Juncea	18.4	113
Green gram	Vigna radiata	6.5	60.2
Black gram	Vigna mungo	5.1	51.0
Cowpea	Vigna unguiculata	7.17	63.3

Sources: Pathak and Ram , 2004

6. Recycling of Agriculture waste

Composting is the best method of recycling. Enriching of the nutrient value of compost is possible with gypsum. Rock phosphate , microbial inoculants and pressmud resources production from sugar factories is a good sourced amendment for acid and sodic soils. For quick decomposition of agricultural waste application of efficient strategies of micro-organics is a practical. (Table -7)

Table 7: Nutrient potentiality of various organic resources

Types of organic resource	Total nutrients (Mt yr-1)				
	Availability (Mt yr^{-1})	N	P_2O_5	K_2O	Total (N+ P_2O_5+K_2O)
Crop residues	273	1.28	1.97	3.91	7.16
Cattle manure	280	2.81	2.00	2.07	6.88
Rural compost	285	1.43	0.86	1.42	3.71
Forest litter	19	0.10	0.04	0.10	0.24
City garbage	15	0.23	0.15	0.23	0.61
Press mud	3	0.03	0.079	0.055	0.164
Sewage water (million cubic meters)	6351	0.32	0.14	0.19	0.65
Industrial waste water (million cubic meters)	66	0.003	0.001	0.001	0.005
Total		6.203	5.20	7.976	19.419

Conclusion

The integrated management should we based on the need of fertilizers nutrients and amendments for optimum supply of nutrients to the crop using all the possible nutrient sources for sustainable crop production.

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Impact of Climate Change on Resource Management

U.P.S. Bhadauria[1], S.K. Sharma[2] and Sanjay Jain[3]

[1]Principal Scientist
Zonal Agricultural Research Station, Morena
[2]Seniro Scientist
College of Agriculture, Indore
Rajmata Vijayaraje Scindia Krishi Vishwa Vidyalaya, Gwalior (M.P.)
[3]Technical Officer
College of Agricuture Engineering
JN Krishi Vishwa Vidhyalaya, Jabalpur-482004 (MP)

A perceptible climate change has become a reality in last decade. The global annual mean temperature has increased by 2000, night time minimum temperature was increasing at twice the rate of day time temperature as per report of the fourth International Panel on Climate Change (IPCC), 2007, projecting a general global warming scenario due to the green house effect, which conjectures that the temperature will increase significantly at the end of 2100. In 2005, temperature hit 500C in India, Pakistan and Bangladesh. According to the India Meteorological Department, 2006 was the warmest year in India since 1901 and annual mean temperature averaged +0.590C for the country. Above normal temperature has been recorded for 1953, 1958, 1980, which stabilized from 1998 to 2006. December 2006 and February 2007 were the recent warmest months and temperature rise has been above national average of +2.00C and in northern region it was more by 6-80C. In addition there was an increasing trend of extreme rain events and hazard of the heavy unpredictable rain, decrease trend of moderate rain events (Bains et al., 2007). Overall hot and extreme events which occurred once in 100 years are expected to increase ten due to CO_2 concentration increasing in atmosphere with the growth rate of 0.3 to 0.5% annually (Table 1).

Table 1: Relative contribution of trace gases in the atmospheric global warming (IPCC, 2007)

S. No.	Gases	Relative contribution (%)	Growth rate/year (%)
1.	CFC	15-25	5
2.	CH_4	12-20	1
3.	O_3	8	0.5
4.	N_2O	5	0.2
	Total	40-50	
5.	CO_2	50-60	0.3-0.5

Climate Change: Following Impact of climate change are expected on agriculture

- Increase in temperature (1.4-6.1^{0}C), IPCC, 2007
- Change in precipitation and storm activity
- Widespread runoff
- Reduction in water availability
- Droughts
- Permanent changes in pest distributions following extreme events
- Adverse impact on coastal agriculture due to rise in sea levels (17.5-57.5cm) and sea-water intrusion by 2100 and another 10-20cm rise if polar ice melting continues, IPCC, 2007.

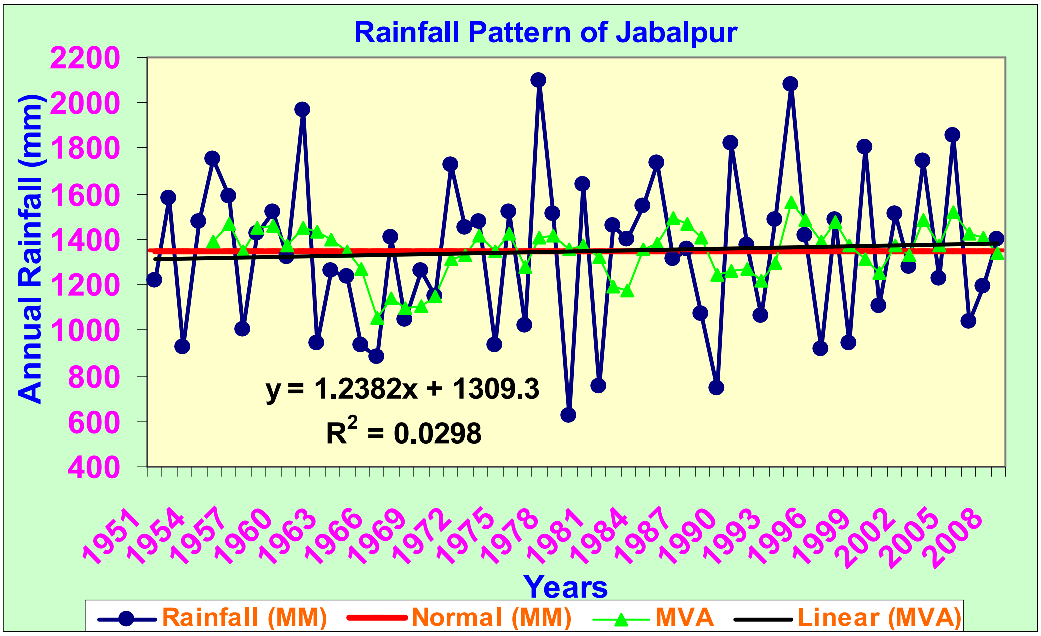
Table 2: Estimates of future levels of CO_2

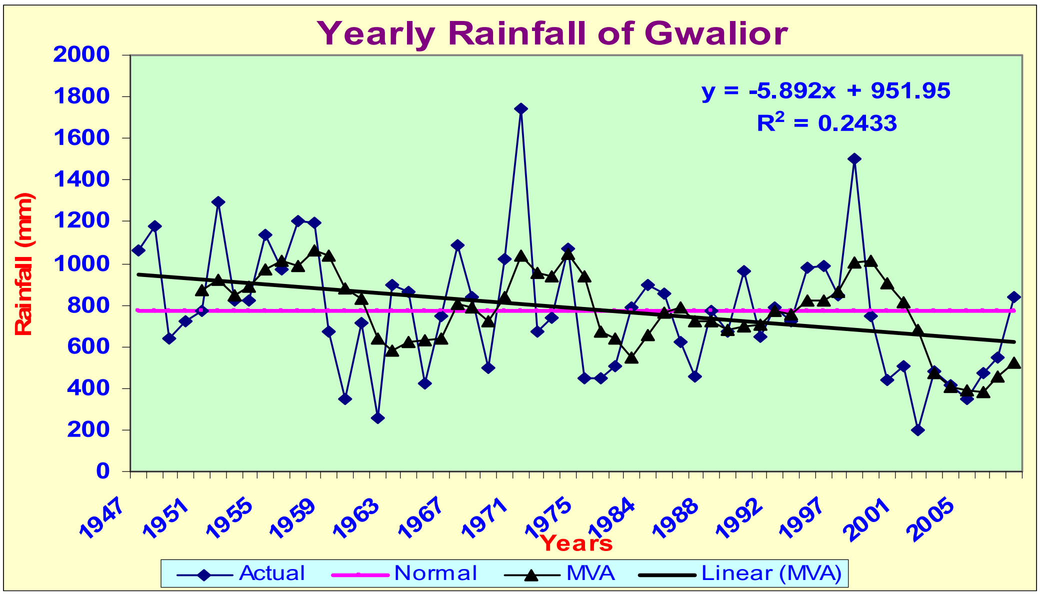
Year	CO_2 (PPM)
2000	369
2010-2015	388-398
2050-2060	469-623
2100	478-1099

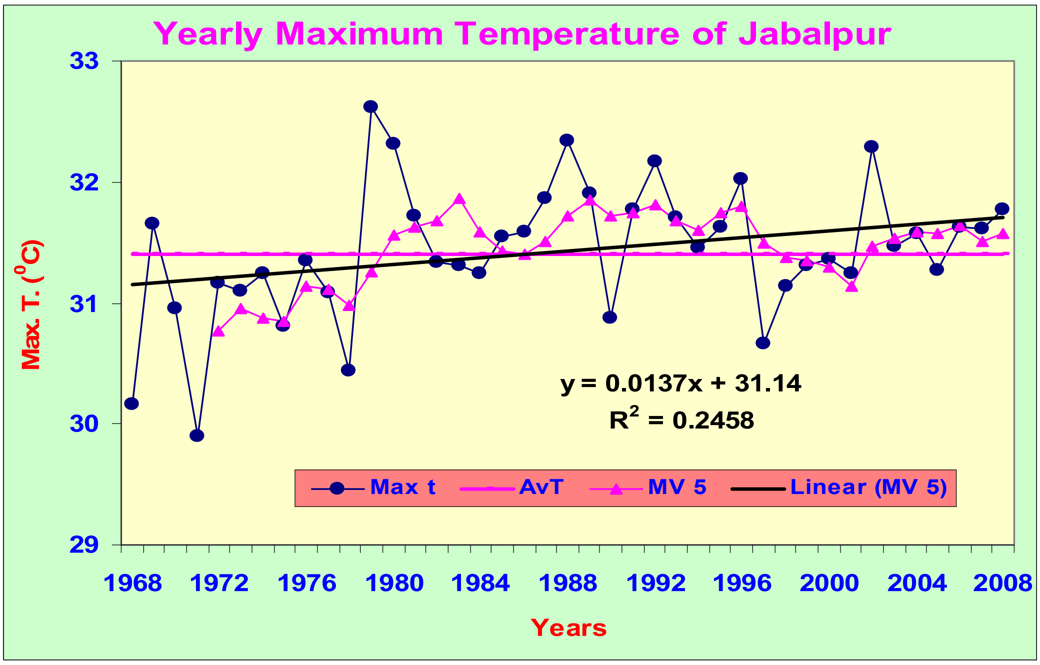
All these changes with significant regional variations will have a decisive effect on agricultural production and sustainable food security, particularly in developing countries will become a challenge. This challenge will be worse due to the predicted adverse effect of climate change in most food insecure developing countries (Rosenzweig and Parry 1994, Rosenzweig and Hillel 1998). In addition it will trigger changes in the type, amount and relative importance of pest and diseases. Uncertainties about the exact location specific nature of the climate changes, specific host pathogen response, limit the ability to predict the overall impacts hence a lot of research efforts was needed to develop physical–biological linkages to enable confident projections (Chakraborty et al, 1998). The changing distributions of temperature and rainfall are the most important climatic factors affecting agriculture. The magnitude and direction of these changes in different regions may vary which must be critically analyzed for enhancing agriculture production.

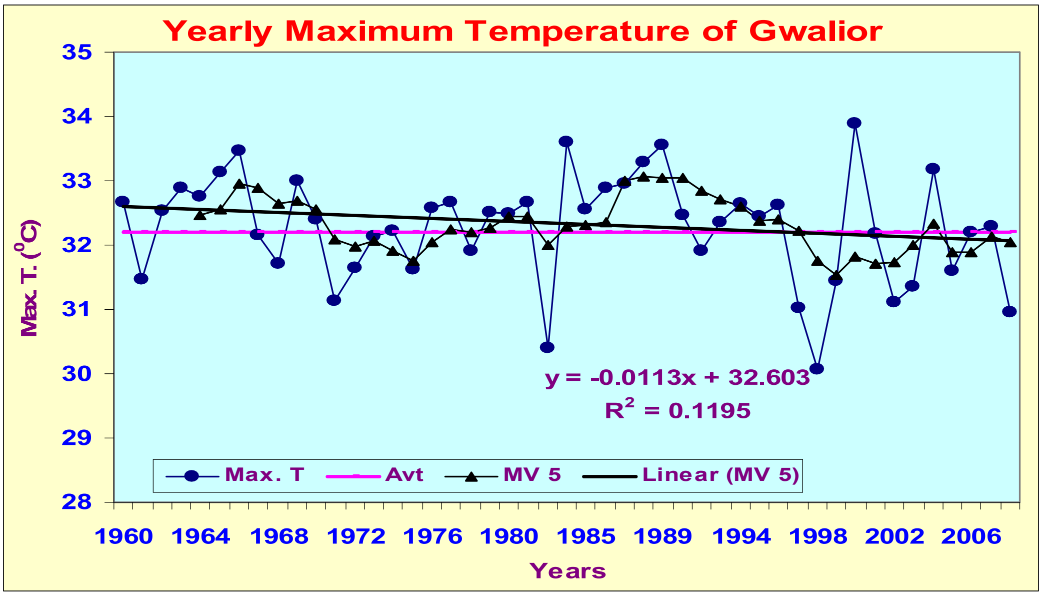
The historical data of rainfall and temperatures of two diverse locations (Jabalpur and Gwalior) were analyzed and depicted herein (fig. 1 to 6) shows different trend for both the parameters and locations i.e. there was an increasing trend of rainfall at Jabalpur and decreasing trend at Gwalior. Similarly increasing trend of maximum temperature was obtained at Jabalpur while decreasing trend was obtained at Gwalior. Interestingly the decreasing trend in minimum temperature was obtained at both the places. The decreasing trend in minimum temperature may be detrimental for pulse crop especially in their reproductive phenophases.

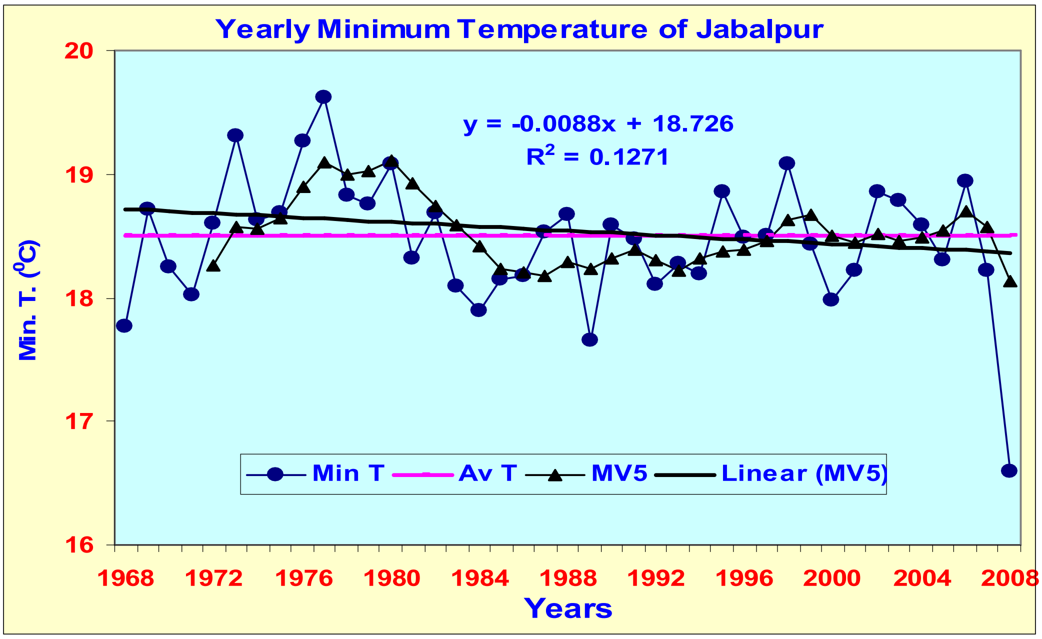
Under changing scenario it is inevitable to sustain agriculture production through judicious use of inputs, agronomical practices and better resource management. Soil, water and solar radiation are natural resources which are to be managed properly for their efficient utilization for sustaining agricultural production.

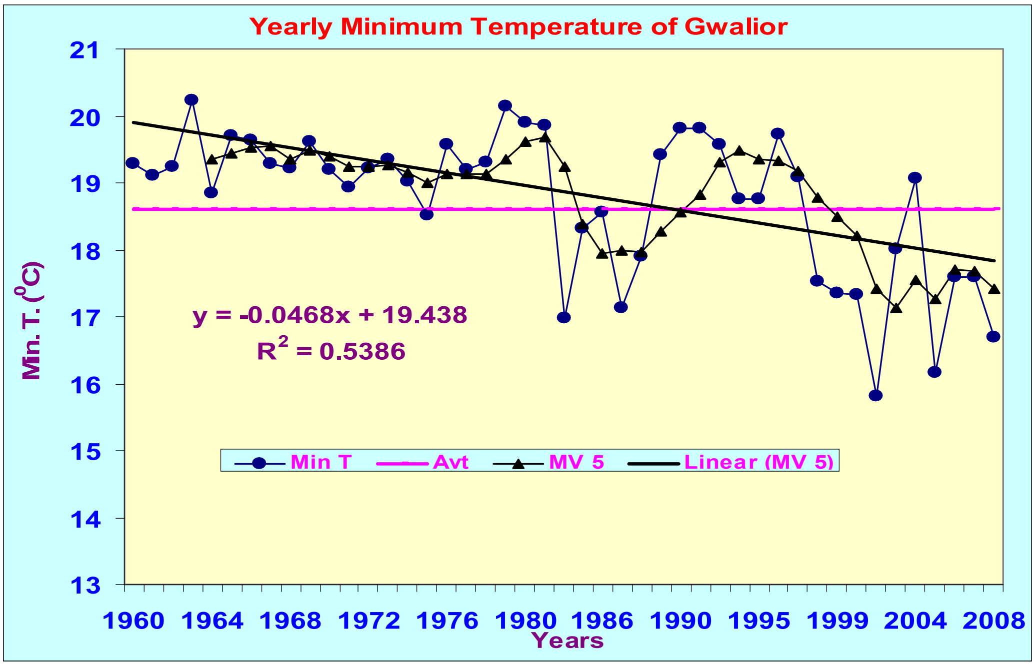

Rainfall Pattern of Jabalpur
Annual Rainfall (mm)
y = 1.2382x + 1309.3
R^2 = 0.0298
Years
Rainfall (MM)
Normal (MM)
MVA
Linear (MVA)


Yearly Rainfall of Gwalior
y = -5.892x + 951.95
R^2 = 0.2433
Rainfall (mm)
Years
Actual
Normal
MVA
Linear (MVA)


Yearly Maximum Temperature of Jabalpur
Max. T. (^{0}C)
y = 0.0137x + 31.14
R^2 = 0.2458
Max t
AvT
MV 5
Linear (MV 5)
Years


Yearly Maximum Temperature of Gwalior
35
34
33
32
31
30
29
28
Max. T. (°C)
y = -0.0113x + 32.603
R² = 0.1195
Max. T
Avt
MV 5
Linear (MV 5)
1960 1964 1968 1972 1976 1980 1985 1989 1994 1998 2002 2006
Years


Yearly Minimum Temperature of Jabalpur
20
19
18
17
16
Min. T. (°C)
y = -0.0088x + 18.726
R² = 0.1271
Min T
Av T
MV5
Linear (MV5)
1968 1972 1976 1980 1984 1988 1992 1996 2000 2004 2008
Years


Yearly Minimum Temperature of Gwalior
21
20
19
18
17
16
15
14
13
Min. T. (°C)
y = -0.0468x + 19.438
R² = 0.5386
Min T
Avt
MV 5
Linear (MV 5)
1960 1964 1968 1972 1976 1980 1986 1990 1995 1999 2004 2008
Years

Water is a precious gift of nature which is important for economic, agricultural & industrial development. In India with 2.4% of land area & 17% of population has only 4% of fresh water resources of the world. Per capita availability of water declined from 5300 m3 in 1955 to 2464 m3 in 1990 and may fall below 1000 m^3, the threshold of water scarcity. Water is the prime mover in agricultural development, especially in rainfed agriculture. For making significant strides in the progress of farm sector of any country, it is necessary that a wise use of water resources is made at farm level. It is particularly important for a large country like India, situated as it is in the tropical belt and experiences extreme variation in climate and rainfall across the country. The groundwater resources availability & utilization status is given in Table 3.

Table 3: Groundwater Resources Availability & Utilization Status

Sr. No.	Region/ States	Replenishable GW Resource (bcm)	Net Annual GW available (bcm)	Annual GW draft (bcm)	Stage of GW Development (%)
1	Northern Himalayan	5.40	4.92	1.84	37
2	North-Eastern	33.99	30.98	5.63	18
3	Eastern Plain	111.63	102.50	43.97	43
4	North-Western	80.78	73.85	72.17	98
5	Western-Arid	27.38	25.40	24.48	96
6	Central Plateau	90.72	85.53	36.11	42
7	Southern Peninsular	82.78	75.65	46.4	61
8	Islands	0.34	0.32	0.01	4
	Total	433.02	399.26	230.63	58

South-west monsoon is the primary contributor of about three-fourths of the total precipitation to rain water. There are extreme variations in rainfall, the westernmost part getting less than 100 mm annually and the eastern most part receiving 100 times more. Floods and droughts can strike the country simultaneously at different places. Of the mean annual rainfall, 30% of the country gets less than 750v mm and 42% receives between 750 and 1250 mm rainfall. Only 20% of the land area is blessed with rainfall range of 1200 to 2000 mm, thereby leaving 8% area that secures about 2000 mm rain water annually.

Central and peninsular regions of India are dominated with Vertisols and associated soils spread between $08^0 45'$ and 26^0 00' N latitude and 66^0 00' and 83^0 45' E longitude. They cover an area of about 76.4m ha (table one), constituting almost 22.2 percent of the total geographical area of India (Murhty, 1981, Murthy et al., 1982). The major portion of these soils lies in the states of Maharashtra, Madhya Pradesh, Gujarat, Andhra Pradesh and Karnataka, where semiarid to subhumid monsonic conditions persist. Of the total area under block soils in India, about 22.0 m ha i.e. 28.8 percent area falls under high rainfall (>1000 mm annual), Mainly in the states of Maharashtra, Madhya Pradesh and Gujarat. In the state of Madhya Pradesh, these soils are located in assured rainfall (>700mm) regions and occur on relatively flat to sloping lands. Soil and water erosion is a serious problem in these soils under their present land use. These soils have higher proportion of water dispersible clays and, therefore, are quite susceptible of erosion. Steep land slope, high intensity of rains, poor infiltration rate of water, *Kharif* fallowing and lack of adoption of suitable conservation measures are some of the factors contributing runoff induced soil and nutrient erosion and related hazards. Fallowing of sizable area of these soils during rainy season, for obvious reasons, coupled with high intensity of rains for few days in 3-4 spells not only lead to degradation of fertile lands through erosion but also inefficient utilization of land and water resources.

The major challenge in rainfed agriculture is therefore, to minimize yearly variations in crop yields due to aberrant weather conditions and to stabilize production at a reasonably acceptable level. The only certain thing about monsoon rains is their uncertain temporal and spatial distribution, and crops usually face moisture stress of various intensities at one stage or other during the growing season. Therefore, long term strategic approaches to efficiently conserve and utilize rain water on the one hand and in-season tactical approaches to mitigate the adverse effects of weather aberrations on the other are needed. Any worthwhile outcome from specific in season corrections could expected only when a sound soil, water and crop management strategy is adopted in general.

Table 4. Distribution of Vertisols and associated soils in India (Murthy, 1982)

State	Total area under Vertisols and associated soils (m ha)	Percent of gross area under Vertisols and associated soils in India	Percent of total geographical area in India
Maharashtra	29.9	39.1	7.9
Madhya Pradesh	16.7	21.9	5.1
Gujarat	8.2	10.7	2.6
Andhra Pradesh	7.2	9.4	2.2
Karnataka	6.9	9.0	2.1
TamilNadu	3.2	4.2	1.0
Rajasthan	2.3	3.0	0.7
Orissa	1.3	1.7	0.4
Bihar	0.7	1.0	0.2
Uttar Pradesh	Negligible	Negligible	Negligible
Total	76.4	-	22.2

Management constraints

Present level of productivity in rainfed area is very low (0.8 t/ha) and it is required to be at least 2 t/ha by 2020 to keep pace with population growth. Further, the rainfed semi arid tropics (SAT) region produces about 91% of coarse cereals, 90% of pulses, 81% of oilseeds and 69 % of cotton. Moreover, there is hardly any scope to expand the net sown area and therefore, this increased production need to come from the same land. The extent of use of inputs like seeds of improved varieties and fertilizers is currently quite low in these areas, therefore scope exists for increasing productivity through integrated management of all available natural resources and use of improved agro-technologies.

Vertisols are characterized by a narrow moisture range for optimum tillage operations because they are sticky and plastic when wet and very hard when dry. Vertisols, therefore, pose a serious problem of management that is why they are left fallow (18 m ha in India and out of that 12 m ha in M.P. State) during rainy season (Krantz and Russell, 1971; Kampen , 1979; Murthy, 1981) and cropped only during post rainy season on profile stored moisture. Moreover, the rainy season fallow in these soils leaves the land subject to run-off and erosion (Tomar and Tembe. 1988; Verma, 1988) these soils which are inherently very productive are, therefore, needed to be managed properly for augmenting the agricultural production.

During rainy season the upland crops in these soils experience both the situations of water stagnation and droughtiness. In view of the poor in filterability of black soils and high cost involved in providing sub-surface drainage, the basic requirement of the farmers of these rainfed areas is for such a system which will provide adequate and effective means of surface drainage as well as assured root zone moisture recharge for kharif crops. To develop technologies of land and water management for various black soils long term field experimentations were, therefore, carried out with a view to provide an adequate drainage and favourable moisture regime even during dry spell in kharif season to upland crops, sufficient pounding of water to paddy, and channelize the excess run-off water to a farm pond for recycling it to provide supplemental irrigation to rainy and post rainy season crops

Management options

(a) Water Conservation Measures

Good information has been generated on measures for conserving rainwater *in-situ* and its safe disposal on cost effective basis such as ridge and furrow system graded furrows, raised and sunken bed system, broad bed and furrows and broad bed and tied furrows.

Ridge-furrow system along with water harvesting

Long term experiments were conducted at Jabalpur in which whole experimental area was divided in to 3 parts viz., catchment area of about 2 ha used for growing upland crops. Flat level land of 0.5 ha used for growing paddy and farm pond of 0.33 ha used for collecting run-off water. Soybean, maize and sorghum were grown on ridges and flat beds super imposed on 1.2, 0.6 and 0.3 per cent slopes in the catchment area. Run-off water was first collected in the flat area used for growing paddy than excess clean water was collected in the farm pond.

The performance of soybean, maize and sorghum improved significantly in different seasons when planted on ridges. The grain yield of soybean, maize and sorghum increased by 50 to 100 per cent depending upon the amount and distribution of rainfall in that year. Ridges were also found to reduce the weed growth as well as provide the adequate aeration during the wet period. Table 2 revealed that the soybean yield can be enhanced by more than 100 percent by adopting ridge and furrow system for the growing of soybean in deep vertisols.

The result of run-off collection showed that surplus of 24.7 ha cm of water was available for further use by the post rainy season crops grown in the catchments area. Some of the water was also used to meet the seasonal water needs of the paddy crop. The net amount of run-off water available for the post rainy season crops was found sufficient for two irrigations to wheat and chickpea grown in the catchments area.

The result of these experiments suggest a viable technology for raising successful kharif crops on relatively flat lands of slow permeable soils and undulated topography under high rainfall conditions. Our field evaluation of RSB system and run-off harvesting in small farm pond and recycling it for supplemental irrigation during dry spell and subsequent cropping has indicated that these practices can make the double cropping feasible in Vertisols of central India which are usually monocropped. Furthermore, reasonable good performance of wheat, chickpea, safflower and linseed with average yield of 1298, 1807, 1382 and 1104kg ha^{-1}, respectively, in the following rabi season demonstrated the potential of these technologies for raising and stabilizing agricultural production in rainfed areas in both the seasons.

Table 5: Soybean seed yield on ridge and furrow system of deep Vertisols.

Treatment	Grain yield, $kgha^{-1}$
Ridge and Furrow system	16.70
Flat bed System	7.98
% increase	109.3

Source: Sharma et al.2005

Raised-sunken bed technology

Series of field experiments have been conducted in Vertisols of JNKVV Research Station, Jabalpur, M.P., India from 1972-1998, to evaluate the wide range of possible cropping systems. In the first part (Technologist for flat lands) soybean, black gram, sesame and pigeon pea were grown on 6,9,12 and 15 m wide and 30-35 cm high raised beds with intervening 6m wide sunken beds (used for growing paddy) created in vertisols during rainy season of 1979, the highest grain yield of soybean, black gram sesamum and pigeon pea was recorded in 6m and 9m wide 30-35 cm high raised beds in different seasons except 1979, 1981 and 1989 which were the very low rainfall years, in addition to provide adequate surface drainage to the test crops, the raised beds were also found to minimize the adverse soil moisture conditions during the prolonged dry spell and also provide better moisture conditions for planting of rabi crops by the side seepage of water from sunken beds. Intercropping of soybean-pigeon pea proved better as compared to the sole soybean-chickpea and soybean-safflower cropping sequences. These long term results further suggest that intercropping of pigeon pea with soybean proved better as compared to the sole crop of each. The total productivity of soybean +pigeon pea intercropping was more than 3.80 t ha^{-1} which is a very good production under rainfed conditions. The performance of various kahrif and rabi crops has been depicted in table 3 and 4

Table 6: Effect of land configuration on the yield (Kg/ha) of soybean and pigeon pea grown as sole and intercrop in a Vertisols of high rainfall area.(Tomar et. al. 1996)

Land Configuration	Cropping System	1990-91	1991-92	1992-93	1993-94	1994-95	1995-96
Improved system (Raised bed 6 m wide)	Soybean sole	2425	2523	3107	1733	1969	1755
	Pigeon pea sole	2012	2004	2532	1825	1626	1174
	Soybean +	1805	1977	2310	1433	1631	1344
	Pigeon pea	1805	1608	2394	1436	1426	900
Farmers practice (Flat bed)	Soybean sole	849	125	581	1050	1469	1113
	Pigeon pea sole	128	167	Failed	Failed	Failed	Failed
	Soybean +	650	95	581	1050	1469	1113
	Pigeon pea	125	151	Failed	Failed	Failed	Failed
Seasonal rainfall (mm)		1631	1215	1055	1391	1090	1132

Source: Tomar et. al. (1996)

Table 7: Performance of post rainy season crops on Raised and Sunken bed.

Land configuration	Crop	86-87	87-88	88-89	89-90	90-91	Geometric mean ±SE
Raised bed 6m width	Chickpea	2146	1866	1842	1722	1579	1822±84
	Safflower	1412	1424	1240	1488	1348	1380±38
Sunken bed 6m width	Linseed	1170	949	1416	938	1048	1091±79
	Wheat	989	1972	1218	1047	1162	1236±159

Source: Tomar et. al. (1996)

Management of soil temperature

Based on soil and air temperatures, suitable time of planting of rabi crops was evaluated. Results showed that best performance of wheat was obtained when the crop was planted from 10th November to 30th November (Fig.1). Higher temperatures (Max. temp.>22 and min.>20 ^{0}C) during early October and severe low temperatures in December and January (<7 ^{0}C) adversely affected the germination, stand and establishment of wheat, chickpea, linseed, safflower and sunflower. Initiation of emergence and completion of germination of safflower, linseed and sunflower required about 153 and 307 cumulative degree days, respectively.

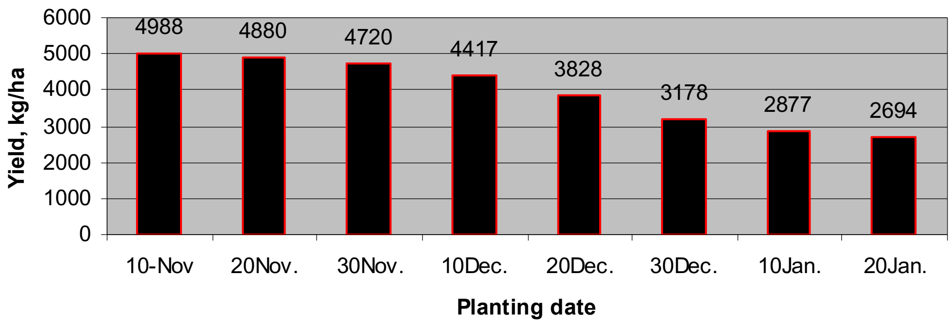


Fig.7: Wheat yield Reduction trend under late planted condition.

Source: Tomar and Sharma (2009)

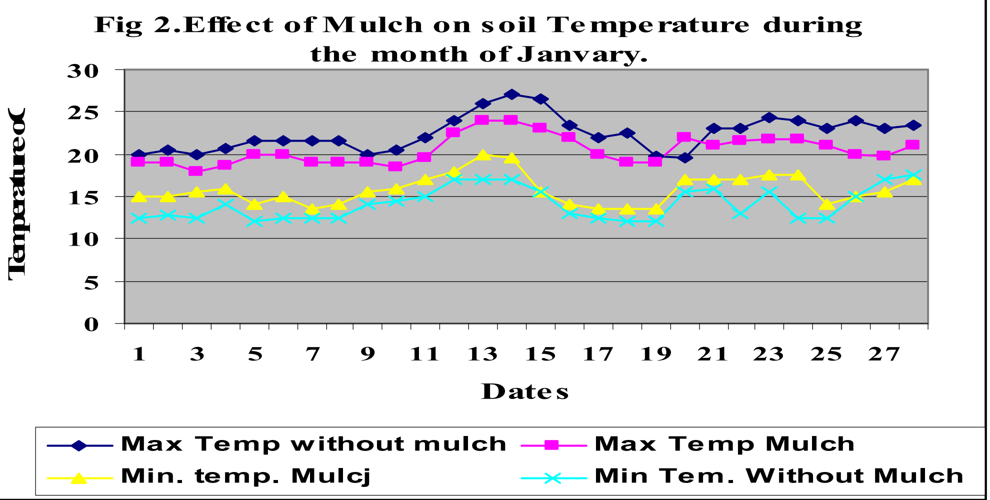


Table: 8. Effect of Planting date, irrigation and mulch on the seed yield (kg ha^{-1}) of rabi crops.

Crops	Yield, kgha^{-1}		
	No mulch	Soil mulch	Straw mulch
Chickpea	1430	1750 (+22.4%)	1800 (25.9%)
Linseed	905	968 (+6.9%)	1043(+15.2%)
Wheat	1730	1837(+6.2%)	1835(+6.1%)
Safflower	1755	1942 (+10.6%)	1822(+3.8%)
	Water Use Efficiency, Kgha^{-1} mm^{-1}		
Chickpea	6.5	8.1 (+24.6%)	9.4(+44.6%)
Linseed	3.9	4.3(+10.3%)	4.6(+17.9%)
Wheat	6.6	8.2 (+24.2%)	7.5(+13.6%)
Safflower	6.8	8.1(+19.1%)	7.6(+11.8%)

Note: Values given in the parentheses are the % increase over No mulch.

Fore oilseed crops (Safflower, sunflower and linseed) best time of planting is 30.th October to 10[Th] November. Planting of these crops due to high temperatures during month of February and March when the crop of these planting date is at flowering and seed development stage (Maximum soil temperature at 5 cm depth was around 38 ^{0}C). Application of straw mulch increased the water use efficiency, moderated the diurnal variation in soil temperature (during cold day mulch increased the minimum temperature by 2-3 ^{0}C and during warm days decreased the maximum soil temperature by 6-7 ^{0}C) and provided a better thermo stable regime more congenial for plant roots which resulted in increased seed yields of linseed safflower, sunflower and wheat in these soils (Fig 2). Branching stage irrigation in linseed and safflower and critical stages irrigation in sunflower and wheat (four irrigations) significantly increased the grain / seed yield of these crops.

Climate change due to anthropogenic emissions of gases and aerosols are of major concern for global warming and increased frequency of extreme weather events. The recent trends in changes in minimum and maximum temperature and rainfall pattern are moving in different directions in various parts of country. Adaptation of improved soil and water management technologies for enhancing crop production and productivity specially in rainfed areas in black soils is inevitable under changing environment.

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Role of Women for Sustainable Use of Natural Resources in Conserving Biodiversity

Asha Shukla

Director
Women Study Centre
Barkatullah University, Bhopal

Women participation in conserving biodiversity is the prime need of the present generation who have inherited ecology and environmental surroundings in terms of land water and air. Sustainability has become the need of life at every step right from world bank international agency and every country citizen are talking about sustainability, it is not only the agriculture development but it is applicable in all respect of life. World of Conservation strategy (UNC 1980) brought in light and have strongly promoted by the Brunllant Report, it is a development that present generation meets the needs without compromising the ability of future generation to meet their own needs'' (WCED 1989).

India is diversified strong nation with strength almost equal strength of young man & women, who contribute substantially in building the country to super power. On 3rd January 2009, while inaugurating the Indian Science Congress at Shillong

The natural resource management for sustainable agriculture and the Hon'ble Prime Minister, of India Shri Man Mohan Singh made the observation stating "The best science is done by young people. Our Institutions must be receptive to the needs of young people they must promote younger talent and allow youth to lead, seniority and age may be relevant in bureaucratic systems, but scientific institution must be led by intellectual leaders irrespective of age.

Women's play an important role in the society fighting through every situations they come across, for conserving biodiversity using natural resources for enhanced livelihood in rural and tribal areas. The women faces many problems, to supplement their income and sustain their livelihood, people depend on forest produce, agriculture, medicinal herbs etc. The shifting cultivation is one of the major agricultural activity they perform, destroys the forest cover exposing soil, and during rain the arable top fertile soil is eroded and effects the microclimate of the area, due to which water depletion becoming a major problem, effecting the productivity.

The women have now come forward to protect deforestation, and degradation of biodiversity through conservation of local land races. A number of programme and scheme has been implemented by the state Govt. for empowerment of women's who are interested in conserving soil and water taking several steps to renovate ponds, and enhance water conservation through NREGS, creating awareness for adopting innovated technology enhancing agriculture production, use of organic supplements rather than inorganic fertilizers, adoption of SRI techniques, IPNS, IPM , and other techniques to save the soil health. In Koraput district of Orissa, Ludhiana in Panjab and in Madhya Pradesh at Gaderwara of Narsinghpur, project on Community Managed Bio industrial Watersheds for sustainable use of natural resources and enhanced lively hoods is in action, in collaboration with M. S. swaminathan research foundation Chennai, Agriculture university JNKVV Jabalpur and a NGO ASA. The project is being funded by Tata Trust Mumbai. The main objective is to extend the techniques of sustainable management of natural resources, conservation of biotic and abiotic sources, watershed management by farm women and men as well as landless laborers, for food and nutrition security, environment quality, and enhanced livelihood opportunities. A lot of work has been done by the scientist of the Agricultural university intervention in soil and water management, crop diversification, and productivity enhancement and post harvest. Value additions activities and training women community in making then self reliance help in conservation of biodiversity.

The proportion of women's participation in agricultural production and post harvest activities is increasing. Under good Agricultural practices farming under integrated condition requires female labors. Earlier it was believed that it was a women who first demonstrated crop plants and there by initiated the art and the science of farming, is stated by professor M.S. Swaminathan, women use to gather seeds and grow them for fuel food, feed fiber etc. In Madhya Pradesh at Gaderwara microwatershed of Devri Midwani villages women's have participated in many activities contributing in horticulture, food security, vermin composting, running petty industry, Dona making, training in cutting tailoring, value addition training on seasonal crop products for enhancing their livelihoods. Women's are the back bone (They have many other responsibilities) of the house. And discharge their duties right from they leave the bed in morning till they go to sleep. They have to prepare, meals, maintain children assist male in agriculture in all respect of social rituals. The women are also involved in selection of seeds, sowing, planting, weeding, harvesting crop, processing etc. Hence now only importance and vital role of women in agriculture development has been realized and are given due, position having recorded 48% women's farmers are actively have self employed farmers in the country. 75 million women's are reported to be engaged in dairying, and 20 million in animal husbandry. Women in rural India are working as agricultural labors and in food processing sector and petty cottage industries.

To bring awareness among women establishing training and educational institutions are of great importance because the women mass are getting mobilized towards technological empowerment, the grass root education needs to be reorganized their recognition in the society and enhancing their livelihood. They should be trained in moral science and basic nutrition and finally management of biodiversity and biotechnology, renewable energy management sustainable management of natural resources. The issue related to nutrition security and post harvest technology are equally important for both men and women. More and several farm activities are traditionally carried by men. The biodiversity is the variety and variability of plants and animal species on our earth crust. It is whole some of genes, species and ecosystem in the area. India has vivid heritage of biodiversity as wide habitats, forests, costal waste lands, number of species occurring in all ecosystem having diversified life forms.

Mainstreaming gender is an important component of the policy framework, for Agri. Extentention. (PFAE) developed by the Ministry of Agriculture GOI. New programmes in agriculture should be developed, as has been taken up by other institutions and Agriculture University. Project on watershed management by use of natural resources at Micro watershed, village Devri and Midwani of Gaderwara has conducted multifarious activities in training women groups for bringing them in stream have been observed to have great impact in building their moral high conducting training on farm women's

Non pesticidal management: Heliothis pest control on pigeon pea and chickpea with botanical pesticide have been demonstrated, methods of bio pesticide preparation, its handling and techniques of spay has been demonstrated.

Vermicompost production : vermicompost units have been established in villages with production of 5 -10 tons getting extra income which is being utilized by the women for betterment of their family.

Waste land development: Women SHGs have also participated in the developing the waste land common in and around their villages by raising fire wood and forest plants, like subabul, babul, also they have planted various fruit plants trees , like Tamarind, Aonla, Jamun, Gwava .

Herbal medicines: Training on establishing medicinal herbal garden and its importance in livelihood have been given, to the women community, who have skill to conserve them.

Enlightenment of women will change the face of Indian agriculture. Various programs have started at – KVK and (NCWA) National Culture for women in agriculture vocational training are organized to train them in various activities to bring awareness in them for implication in agricultural farming system identifying gender for developing women specific technologies under different production system. Various research work are being taken and have been observed that there was remarkable participation of women in fields of their interest in various groups, of farm women in growing vegetables, nursery, vermicompost , bio pesticides, and IPM, post harvest technology, value additions, etc.

In Orissa, women are actively and intensively engaged in rice cultivation women's routine is very tedious. They are engaged from time they leave the bed, getting up in morning till they go to bed Invest maximum hour contributing to family members. In agriculture women's are generally engaged for sowing, weeding, harvesting, post harvest operations. Similar pattern of work is observed form their paid women family plus pond labour.

A project under occupational health hazard of farm women, house hold activity, farm activities, post harvest activities, livestock management, were assessed under innovated technologies. Production technology, process of produce for value addition, etc.

During the field activities performed by the women in field had to face health hazards due to activities on farm, Health hazards faced by farm women also need to be monitored and they should be made aware in use of heavy animals of chemical fertilizer, pesticide etc. which affects the human health there are some of the farm activities monitored to study their ill effect on the women health.

ACTIVITIES	HEALTH AZARDS
Farm activities -	
Transplanting	50%
Harvesting	26.5%
Post harvest activities	-
Threshing	50%
Drying	33%
Part boiling	67%
Live stock management –	
Shed cleaning	47%
Fodder collection	23%
Mulching	27.5%

Plant biodiversity is an irreplaceable resource which provides material for improvement in agricultural and forestry programmes women's are intensively engaged in these fields for accessing productivity and sustainability of soil. Farmer's activity practicing subsistence agriculture preserves the biodiversity of crop and livestock's. Activities of human have badly caused losses to the genetic biodiversity, threatening the species which are at the verge of extinction. The biodiversity is also lost due to high consumers demand. The women are thus play and major role in conserving biodiversity individually and in community. For conservation of biodiversity India has in acted biological diversity act 2002 and have set up a National Biodiversity Authority (NBA) in 2003 with a mandate of promoting conservation of biological resources in a sustainable manner. Women in rural areas grow at least 50% of the world's food. Women accounted for 93% of total employment in dairy production (World Bank 1991). Women participation in watershed development activities are of great importance which are being implemented in different states. Subordination of women's is not the cause of biological difference, but it is the strong process of socialization. Thus they are deprived, marginalized and have been excluded from social, cultural economical developmental processes. The major observation of women's role is limited to the formation by self help group SHGs. Their involvement in planning decision making bodies is nil. They are unable to establish conceptual linkages between Natural Recourse Management and women at grass root level. If women are associated in the committee headed by men or separately by them they will work exceedingly well, in conserving biodiversity.

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Recent Advances in BNF Researches

D. L. N. Rao

Project Coordinator
All India Network Project on Soil Biodiversity-Biofertilizers
Indian Institute of Soil Science, Bhopal-462 038 (M.P.)

Introduction

Nitrogen has revolutionized crop yields and food availability worldwide; the Haber-Bosch process of manufacturing ammonia is considered the most valuable invention of the previous millennium. But this has come at a substantial economic and environmental cost. Intensive cropping with use of high analysis fertilizers coupled with an enormous reduction in recycling of organics or other wastes has led to a continuous decline in the organic carbon levels in Indian soils, impaired soil physical properties, reduced soil biodiversity, aggravation of demand for nutrients not applied etc., all of which are contributing to stagnating yields and reduced factor productivity. Not surprisingly, there is a renewed emphasis now on biological technologies like composting, legume BNF, Biofertilizers, integrated nutrient management, and Biopesticides etc.

Recent Estimates of BNF

Nitrogen fixation, along with photosynthesis is the basis of all life on earth. Currently, approximately 2 tons of industrially-fixed nitrogen are needed as fertilizer for crop production to equal the effects of 1 ton of nitrogen biologically-fixed by legume crops. Therefore, biologically-fixed nitrogen influences the global nitrogen cycle substantially less than industrially-fixed nitrogen. World population has now been increasingly relying on nitrogen fertilizers in order to keep up with the demands of food and economic growth rates. As population is increasing, producing enough food in India will require us to increase N consumption by 2.5% per annum.

Biological nitrogen fixation (BNF) in natural terrestrial ecosystems contributes globally about 107 million tonnes of nitrogen (Galloway et al 2004) each year. Cultivation induced BNF in agricultural crops and fields adds another 33 m t per year (Smil 1999). Thus total terrestrial nitrogen fixation is 140 m t N/year. The break-up in agriculture is as follows: symbiotic BNF by *Rhizobium* associated with seed legumes- 10 m t/yr, leguminous cover crops (forages and green manures)- 12 m t/yr., non-*Rhizobium* N fixing species- 4 m t/yr, cyanobacteria in wet rice fields-4-6 m t/yr and endophytic N fixing organisms in sugarcane- 1-3 m t/yr. Relative to cultivation induced BNF, about 3 times as much N is fixed by the Haber-Bosch process, about 100 m t N per year of ammonia. The industrial fixation of nitrogen is increasing each year with the setting up of more plants.

From the average values of BNF in legumes, cereals, oilseed, fibre, horticultural and fodder crops in India cultivated over 190 million ha., a conservative estimate for BNF inputs in Indian agriculture, based on the responses measured in AICRP-BNF, amounts to 3.68 million tonnes every year. In forests, permanent pastures and grazing lands, miscellaneous tree crops, culturable wastelands, and fallow lands amounting to 121 m ha, a conservative estimate for

BNF inputs from these lands works out to 0.52 million tonnes per year (Rao 2003) . Thus total BNF inputs in India amount to 4.20 million tonnes of nitrogen per year which (Rs. 4830/t; 100 US $/t) works out to Rs. 4410 crores every year. (approximately US$ 918 million). Considering that BNF efficiencies are at least twice that of fertiliser urea nitrogen, the corresponding monetary benefits would also be twice as much.

Recent Advances in Nitrogenase

The biological fixation of nitrogen is an anaerobic process catalyzed by the enzyme nitrogenase and requires a source of reductant, ATP and ammonia assimilating machinery. Enormous progress in almost all aspects of biological nitrogen fixation has been made in the past century, especially in the recent two decades, in genetics and biochemistry. Nitrogenase contains two metallo-components, dinitrogenase (Mo-Fe Protein) and and dinitrogenase reductase (Fe protein). One of the advances has been the determination of the crystallographic structures of both nitrogenase components. Nitrogenase is encoded by a set of operons which includes regulatory genes (such as nif LA), structural genes (such as nif HDK) and other supplementary genes. *Klebsiella pneumoniae* has been the most well studies and provides a model for the regulation, synthesis and assembly of nitrogenase. A 24kb base pair DNA region contains the entire *K. pneumoniae nif* cluster which contains 20 genes. In nitrogenase, the Fe protein (structurally encoded by nif H) specifically transfers electrons to the MoFe protein (structurally encoded by nif D and nif K) in a reaction that is coupled with the hydrolysis of Mg ATP. Structural similarities are apparent between nitrogenase and other electron transfer systems, including hydrogenases and the photosynthetic reaction centre. Chl L is similar to Nif H (~35%), Chl NB is similar to both Nif D and Nif K (~19%) .

Alternative nitrogenases were discovered more than 25 years ago in *Azotobacter vinelandii* which use vanadium, iron, instead of molybdenum in an environment lacking molybdenum. *Streptomyces thermoautotrophicus* is recently found to be able to fix dinitrogen, but it harbours a very unusual N_2-fixing system which is not sensitive to O_2, requires less ATP (4-12), and is not inhibited by CO. There may be more types of such prokaryotic nitrogenases with versatile features yet to be discovered. Because many prokaryotic enzymes do evolve into the eukaryotic version, it would be difficult to rule out the possibility of the existence of a eukaryotic nitrogenase. If eukaryotic nitrogenase does exist in nature, then it may well be utilizing light as an energy source. Efforts need to be made for searching for an eukaryotic nitrogenase.

Prospects of Cereal Nitrogen Fixation

There have been several cycles of research efforts to induce cereals to fix N (although the desirability and eventual benefits of such efforts are open to debate) after the initial high-hopes of the mid-seventies. The second major effort on rice and other non-legumes in the nineties also has not produced any “selection” or “bred” variety that can fix a substantial amount of N. Now a third attempt is “on” spurred by scientists in this area for reinvestment for BNF within cereals (rice, wheat, maize) driven by recent advances in understanding of nitrogen fixation biology. Three approaches are currently considered as promising and are discussed below.

Root nodule symbioses in cereals

During bacterial recognition of a suitable plant host, rhizobia and legumes undergo signaling crosstalk, whereby the plant secretes flavonoids that trigger the bacteria to secrete nodulation (Nod) factors that promote nodule formation within the plant. Recently, Myc factors, which are part of the crosstalk between 70 to 90% of terrestrial plants (including cereals) and arbuscular mycorrhiza endosymbiotic fungi, were discovered to be very similar structurally to Nod factors. Most rhizobia enter root cells through a complex plant structure called an infection thread. Although further research is needed to understand infection thread development, some legumes and most actinorhizal plants are colonized by symbiotic bacteria through the more primitive root-hair-independent method of crack entry invasion, such as entry at epidermal damage points. These routes can be used initially for developing root nodule symbioses strategies in cereals.

Endophytes

It has been known for more than a century that some nitrogen-fixing endophytic bacteria form nodule-independent association with cereal crops. Pursuing this approach will also require screening for new cereal endophytes that fix nitrogen at high rates. Once these endophytes are identified and cultured they could be used in improved microbial inoculants. However this has some limitations which are discussed later.

Transfer of `Nif‘‘ into Organelles

The direct transfer of nitrogen fixation (*nif*) genes to the plant will require engineering the complete biosynthetic pathway of the nitrogenase enzyme into cereals. It will also be necessary to find the correct sub-cellular, low-oxygen, environment to allow nitrogenase to function. Two logical places are chloroplasts and mitochodria; both can provide the high concentration of adenosine 5’ -triphosphate and reducing power required for nitrogenase activity. Chloroplast genomes of lower plants encode an oxygen-sensitive enzyme related to nitrogenase. Conversely, mitochondria have efficient oxygen-consuming respiratory enzymes, functioning oxygen-sensitive enzymes, and iron sulphur cluster machinery highly similar to the nitrogenase iron-sulphur cluster components. What is lacking is the development of a plant mitochondria transformation method; therefore, the *nif* genes could be transformed into the nuclear genome and the proteins targeted to mitochondria, with expression potentially regulated in a tissue or developmental-specific manner. However it is a major challenge to interface plastid physiology with requirements for nitrogenase activity. The technology is available but there are gaps in knowledge of both plant and microbial physiology.

Wither Endophyte N fixation ?

Three well known researches on free-living and endophytic N_2-fixng bacteria associated with non-legumes and most notably with tropical grasses and cereal crops are-*Azotobacte*r, *Azospirillum* and *Gluconacetobacter*. In all of them the initial premise that the bacteria increased plant growth due to N_2-fixation has been revised to include other growth-stimulating effects of the bacteria like production of indole acetic acid.

Heterotrophic N fixation

Acetylene-reduction assay has been used widely and indiscriminately for measuring N_2-fixation but this assay has serious errors when applied to rhizosphere –associated or free-living N_2-fixation measurements in soil. The ability of non-symbiotic or associative or endophytic nitrogen fixation to contribute agronomically significant quantities of nitrogen has been questioned by several workers (Giller and Merckx, 2003). The ultimate test of the contribution from N_2-fixation is to measure the net inputs from N_2-fixation over long periods (>10 years) in the field which sounds simple but it is difficult to control and measure all of the processes. Earlier claims for a significant role of N_2-fixation from heterotrophic bacteria in experiments in UK put emphasis on this type of data, but examples where positive N balances over long periods in the field were described were later attributed to inputs from N_2-fixation by cyanobacteria (blue-green algae) None of the studies which claim for substantial inputs from root associated or endophytic N_2-fixation have excluded potential inputs due to N uptake from deep soil horizons or from cyanobacterial N_2-fixation. The investigations in Brazil using ^{15}N aided N balances remain some of the best and most closely-controlled studies. But the huge amounts of tap water used for irrigation could contribute upto 20-30 kg N $ha^{-1}y^{-1}$ of unlabelled N (Urquiaga *et al* 1992).

Endophytic N fixation

Rhizosphere of cereals like rice is particularly abundant in species of *Azospirillum* and *Pseudomonas* and in members of the Enterobacteriaceae. In addition, various members of the genera *Alcaligenes, Azotobacter, Burkholdera, Clostridium, Flavobacterium, Xanthobacter etc.,* have also been isolated from paddy field soil or wetland rice with regard to endophytic diazotrophs. *Serratia marcescens* inoculation of rice resulted in large numbers of this bacteria within intercellular spaces, senescing root cortical cells, aerenchyma, and xylem vessels but they were not observed within intact host cells (Gyaneshwar *et al* 2001). In rice endophytes may be only a relatively small subpopulation of a much larger rhizosphere diazotroph population and hence their actual contribution could be minor. There are fundamental question about how efficiently the endophytes can actually function within grasses when no obvious “symbiotic” structures appear to be present. In all N_2-fixing symbioses identified so far, specialized organs have evolved to house the diazotrophs, such as nodules on legumes and actinorhizal plants, and leaf cavities in *Azolla*. At present, it is difficult to see how the apparently random distribution of bacteria within intercellular spaces, aerenchyma, dead cells, and xylem vessels that typifies endophytic associations cam perform functions analogous to those of such highly evolved organs

The ecological role of endophytes still remains uncertain. Simply demonstration of the presence of bacteria that actively express nitrogenase genes within a graminaceous plant does not mean that the amounts of N_2-fixtion are of importance. Contributions of non-symbiotic N_2-fixation for cereals or pastures under agricultural conditions need to be >20 kg N ha^{-1} yr^{-1} assimilated by the crop to make a useful difference in productivity. Of all the candidate crops, sugar cane remains the most likely candidate, not least because of the abundance of C in a readily utilizable form.

The role of N_2-fixing endophytes thus remain open to question. Some requirements of future research to determine the amount of N derived from N_2-fixation by endophytes will be to ascertain the relative abundance of non-N_2-fixing bacteria and N_2-fixers within the plants. A detailed and robust quantitative understanding of both the C and N budgets of grasses and their associated rhizosphere and endophytic bacteria is required to properly assess the potential of N_2-fixation in these plants.

Recent advances in Legume BNF

Legumes have been estimated to contribute 20% of the nitrogen needed for global grain and oilseed production. They can potentially fix about 80% of their own N need and in addition can contribute to the yield of subsequent crops. But all these potential benefits can be harnessed only under certain conditions. Mere inclusion of a legume in a cropping system does not ensure high BNF. There can be two approaches to harness BNF: Improved crop, soil and water management to achieve maximum efficiency of BNF including *Rhizobium* inoculation or selection of host genotypes to ensure a higher proportion of nitrogen fixation in the plant (P_{fix}). Of these the first strategy is well known for almost 50 years and continues to play its rightful role. The second approach on host plants selection is more recent. There has also been a considerable revision of rhizobial taxonomy with the discovery of newer nodule inhabitants. The debate on indigenous versus exotic strains of rhizobia seems settled in favour of the former but specific instances remain of the superior performance of exotic strains for example the USDA strains of soybean.

Selecting for High Nod legumes

Presence of a large genotypic variability for traits such as nodule number, nodule mass have been known since early seventies and eighties for many legumes. However, an effort to use this variability in breeding for improved N_2-fixation has been limited. In addition to the breeding method used for developing a material, absence of any natural selection pressure for nodulation or N_2-fixation during its development may be responsible for the occurrence of the different nodulation types within a material even up to the release stage. This view gained strength from the fact that during a screening for high nodulating plants at high mineral N in soil, both high and low nodulating plants were observed in 85 out of 90 advanced breeding lines of chickpea (Rupela 1994). Using appropriate screening procedures several different nodulation types [high nodulating (HN), low nodulating (LN), non-nodulating (NN)] have been identified within several chickpea and pigeonpea cultivars (Rupela 1994). Preliminary studies of Venkateswarlu and Katyal (1994) also indicated plant to plant variability within cultivars of groundnut. High-nodulating (HN) selection generally grew better than the NN and LN selections of a given cultivar. At ICRISAT, the HN-selection of chickpea cultivar G 130 produced 31% more grains than its LN-selection at low soil N (N1) level. The HN-selection of G 130 yielded better even at high soil N (N2) level. At pH 9.0-9.2, a genotype selected for high-nodulation outperformed the four others used in the study of Rao *et al* 2002. Nodulation was reduced in all the five chickpea genotypes as the electrical conductivity increased from 1.1 to 8.1 dSm^{-1} but the high nodulating selection CSG 9372 had more tolerance and formed about 3x more nodules than the salt tolerant line (CSG 8927) even at 6.2 dS $m^{-1.}$

The above studies thus suggest a scope of enhancing N_2-fixation in legumes through host plant selection. But progress has been slow. One likely reason of slow progress may be due to the fact that it would take a multidisciplinary team to achieve success such a complex trait as nitrogen fixation, in addition to the complex trait 'yield' (it may be noted that breeding legumes for high yield, per say, has not been as successful as in cereals). Also, any breeding program has to combine several traits (such as pest and drought resistance) along with yield to ensure that the resultant materials are potentially acceptable to farmers. Much of the breeding work is conducted at research stations. Soils at research stations are likely to have higher soil nitrogen than at farmers' fields. High soil-N is known to suppress nitrogen fixation by legumes. For promoting N_2-fixing traits, breeders should grow their legumes at low soil-N (preferably <10 µg mineral N g^{-1} soil) fields, prepared specially for the purpose. Breeders generally handle large numbers of genotypes and materials. In some materials, genes for N_2-fixation may be co-segregating with genes for the other traits. It is likely, therefore, that trait combinations associated with enhanced N_2-fixation will be identified if appropriate assessment methods are applied to the segregating populations. If genetic variation for N_2-fixation existed in breeding populations, the high N_2-fixing lines would be produced as a normal outcome. Recent developments in the field of genomics (particularly on *Medicago* and *Lotus*) would provide a better understanding of the expression and regulation of symbiotic genes. It should also open up opportunities for biotech assisted germplasm enhancement and bio-informatics assisted gene mining and utilization. These developments may lead to a better targeted breeding of legumes for high BNF than hitherto possible. Breeding for high N_2-fixation is feasible and should also be on our research agenda (Rupela and Rao 2002).

Rhizobial Taxonomy

Until 1992, there were four genera of root nodulating bacteria: *Rhizobium*, *Bradyrhizobium*, *Sinorhizobium* and *Azorhizobium.* Later, four more genera added were *Mesorhizobium*, *Allorhizobium*, *Methylobacterium* and *Burkholderia*. The nomenclature of some of the old species been revised (Young 1996). The study of new geographically dispersed host plants has been a source of many new genera and species and is expected to yield many more. More than 63 species of rhizobia are recognized. A number of new entrants include *Devosia, Ochrobactrum and Phyllobacterium* in alpha-proteo bacteria and *Burkholderia* and *Cupriavidu*s in beta-proteobacteria. It should, however, be noted that these are not new bacteria. These were known or associated with their relevant legumes all along but due to the advances made in molecular biology techniques, their nomenclature has improved. For scientists interested in developing N_2-fixation technologies for use on farmers' fields this fast advancing nomenclature of the bacteria presents a complex situation. However, for all practical purposes, the symbiotic relationship between the bacteria forming root nodules in a given host legume remains same as ever and may not affect field oriented breeding programs on high N_2-fixation.

Improving BNF through Soil Management

Conserving Soil Moisture:

Nodulation is highly sensitive to drought stress and sudden drought drastically reduces the functioning of the already formed nodules. Drought stress drastically reduces the number of rhizobia. BNF can be improved by modifying the soil hydro-thermal regimes through simple practices like straw mulching, reduced tillage, deep sowing etc (Wani et al 1995) and other soil moisture conservation like opening deep furrows

(20 cm) after every 3 m distance to capture rain water (Venkateswarlu 2004).

Correcting Soil Constraints:

Correcting soil constraints and alleviating nutrient deficiencies improves BNF inputs significantly as shown in a number of studies, particularly in acid soils. For example liming increased the grain yield of soybean by 60% in acid soils of Manipur; Lime + *Rhizobium* improved rhizobial population and grain yield (Raychaudhuri et al 1997). In acid soils of Orissa, application of micronutrients (molybdenum and cobalt) boosted nodulation and BNF in green gram. *Rhizobium* inoculation increased the grain yield (25.7%) resulting in additional N fixation of 7.1 kg N/ha and P uptake of 0.6 kg/ha. Application of micronutrients alongwith inoculation further enhanced the grain yield dramatically (+78.4%) over uninoculated control resulting in additional N fixation of 24 kg N ha^{-1} and additional P uptake of 3.4 kg ha^{-1} respectively (Pattanayak et al 2000). The inhibitory effect of salinity on root hair infection and symbiotic process leading to nodulation and nitrogen fixation in legumes is well known. Although some authors argued that it could be overcome by inoculating with salinity tolerant rhizobial strains and even proposed molecular manipulation for transferring `osm' genes from other bacteria into rhizobia, it is clear that the success of a symbiotic function under stress is more dependent on the tolerance of the host plant rather the microsymbiont. Indeed, Rao and Sharma (1995) showed that the rhizobial strains most effective in normal soils are also the most effective ones under salinity stress. Rao *et al* (2002) further showed using ^{15}N measurements, the crucial importance of selecting tolerant plant varieties to increase BNF under saline stress (discussed above).

Organic Amendments

Organics have been found to boost the proliferation of *Rhizobium* and enhance nodulation and nitrogen fixation in a number of legumes and oilseeds. *Rhizobium* inoculation increased the pod yield of groundnut by 391 kg ha^{-1} while application of FYM alone @ 5 Mg ha^{-1} increased the yield by 151 kg ha^{-1}. Combined application of FYM and *Rhizobium* increased the yield by 729 kg ha^{-1}. These and similar results in other legumes led to the recommendation released by from AICRP on BNF at Parbhani `Apply *Rhizobium* inoculants alongwith FYM @ 5 t/ha'. Addition of farm yard manure is known to boost microbial activity and rhizobial proliferation which results in improvement of BNF in legumes. Ndfa (nitrogen derived from air) in soybean improved from 46.1% in control to 62.5% at 4 Mg FYM ha^{-1} (Kundu *et al.* 1998). Other studies also showed beneficial influence of organics on legumes. FYM @4t/ha +VAM+ *Rhizobium* had best effect on clusterbean yield and soil microbial properties in an arid soil (Tarafdar and Rao 2001).

Regular Inoculation

Surveys on rhizobial populations in the AICRP on BNF for the major grain legumes have shown populations to be well below the threshold in all areas and below 100 cells/g. (Raverkar et al 2005) due to the extremely high soil temperature and drying of surface soil layers in summer. Recent studies on diversity of rhizobial populations in the AINP on Biofertilizers have also thrown up challenging issues for rhizobial strain selection strategies for major pulse growing regions in the country. In a five year survey of the entire state of Madhya Pradesh, it was found that wherever rhizobial inoculation was practiced by farmers along with FYM and fertilizer application (IPNS) there was best nodulation and grain yield (Rawat *et al* 2008). This underscored the need to promote awareness for adoption of integrated approach in nutrient management along with use of good quality rhizobial inoculants to promote soybean yield and BNF .

Epilogue

There is an urgent need to improve the inputs of organics and BNF in Indian agriculture. Development of effective and competitive rhizobial strains tolerant to high temperature, drought and nitrate; acidity and other abiotic stresses is of continuing high priority. Soil management practices such as soil reclamation, correcting nutrient deficiencies, application of organics and screening of segregating material in legumes in low N soils are some of the quickest means to increase the contribution of BNF in Indian agriculture. Where inoculation is not feasible the selection/breeding for high nodulating cultivars could be an option. Developing transgenic inoculants, nitrogen-independent cereals, endophytic N fixation requires a very careful re-look and stronger justification for funding.

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