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Carbon sequestration for soil health enhancement and mitigating climate change

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Abstract

The atmospheric concentration of carbon dioxide (CO_2) has increased globally by 40 per cent since the pre industrial era. During the years 2000 to 2011 the atmospheric load of C increased at a rate of 4.0 to 4.3 Gt C y^{-1}. Bidirectional soil-atmosphere interaction plays an important role in global C cycle and C sequestration in soil is considered a viable option for mitigating atmospheric concentration of CO_2. Several strategies involving improved management of agro-ecosystems have been proposed for C sequestration in soil and vegetation. Management practices that increase C input to the soil and reduce soil respiration or both lead to net C sequestration in soils. Increased C input in agro-ecosystems can be achieved through intensification of agriculture, improved water and nutrient management, application of organic materials, residue recycling, growing of high biomass producing crops, changing from monoculture to rotation cropping, ad adoption of agroforestry systems. Soil carbon loss could be decreased by adopting conservation agriculture and minimizing soil disturbance, and checking erosion through reduced tillage intensity. A combination of improved management practices depending on soil, crop and climatic conditions may be required to attain desired results. Greater C sequestration in soil has co-benefits of restoring soil fertility and its capacity to perform ecosystem functions. This paper presents a brief review of the management practices leading to C sequestration in soil and discusses the influence of SOM on soil quality and the processes that affect soil's capacity to perform ecosystem functions.

Keywords: Carbon sequestration, soil health

The atmospheric concentration of carbon dioxide (CO_2) has increased globally by 40 per cent from 278 ppm in the pre industrial era to 390.5 ppm in 2011 (Ciais et al. 2013). During 2002-2011 the atmospheric CO_2 concentration increased at a rate (2.0 ± 0.1 ppm y^{-1}) higher than any previous decade since direct measurements of atmospheric concentration commenced in 1958. Although 2/3rd of the anthropogenic CO_2 emissions come from the combustion of fossil fuel (375 ± 30 Pg C), there is also a substantial contribution from land-use changes (180 ± 80 Pg C). Less than half of the total C emitted have accumulated in the atmosphere, the remaining has been absorbed by the ocean and in terrestrial ecosystems. The global C budget shows that compared to atmospheric increase of 3.1 Gt C y^{-1} in 1990s the atmospheric load increased at a rate of 4.0 to 4.3 Gt C y^{-1} during the years 2000 to 2011 (Table 1). Net CO_2 emissions from land use changes during 2000s are estimated at 1.1 Pg C y^{-1} (Houghton et al. 2012). Efforts are being made to reduce or stabilize the atmospheric CO_2 concentration. A number of strategies have been proposed and are being implemented to achieve this goal. The three main strategies to lower CO_2 emissions include reducing energy use, developing low or no-carbon fuel, and sequestering CO_2 through natural and engineering techniques involving

Table 1. Global carbon budget (Pg C yr^{-1}) during 2002 to 2011. Errors represent ± standard deviation. Positive fluxes indicate emissions to the atmosphere and negative fluxes are losses from the atmosphere (sinks) (adapted from Ciais et al. 2013)

	Pg C yr^{-1}
Atmospheric increase	4.3 ± 0.2
Emission from fossil fuel and cement production	+8.3 ± 0.7
Net ocean to atmosphere flux	-2.4. ± 0.7
Net land to atmosphere flux	-1.6 ± 1.0
Land use change	0.9 ± 0.7
Residual terrestrial sink	-2.5 ± 1.3

carbon capture, transport and storage (CCS). Engineering or abiotic techniques of C sequestration besides being expensive have biogeochemical and technical limitations and have potential human health and environmental impacts. Therefore, C sequestration in soil and vegetation is considered an important option for mitigating atmospheric abundance of CO_2.

Soils constitute the largest pool of actively cycling carbon in terrestrial ecosystems and stock about 1500-2000 Gt C (to a depth of 1m) in various organic forms and 800 to 1000 Gt as inorganic carbon or carbonate carbon. The total quantity of CO_2-C exchanged annually between the land and atmosphere as gross primary productivity is estimated at ~120 Gt C y^{-1} and about half of it is released by plant respiration giving a net primary productivity of ~60 Gt C y^{-1}. Heterotrophic soil respiration and fire return ~60 Gt C y^{-1} to the atmosphere. The main source of CO_2 in agriculture is the decomposition of soil organic matter (SOM). Globally, soils have lost an estimated 55-78 Gt C y^{-1} because of land-use changes; therefore soils have considerable capacity to sequester C and mitigate atmospheric C load (Nieder and Benbi 2008). However, the rate and magnitude of soil C sequestration differs with factors such as soil quality, antecedent C level, climatic conditions, land-use, and management that influence C turnover and retention in soil. In the last three decades several studies have enumerated the effect of agricultural management on organic matter turnover and soil's feed-back to global climate change. A number of management practices have been evaluated and recommended for enhanced soil C sequestration. In view of the projected climate change in near future and soil's role in mitigating atmospheric CO_2 concentration, the management of soil organic C (SOC) and soil health enhancement assume great significance. Besides mitigating atmospheric CO_2 concentration, greater C storage in soil influences soil quality and its capacity to perform ecosystems functions. This paper presents a brief review of the management practices leading to C sequestration in soil and discusses the influence of SOM on soil quality and the processes that affect soil's capacity to perform ecosystem functions. The paper mainly focuses on Indian agro-ecosystems.

Linking soil quality and ecosystems functions

The 68th UN General Assembly declared 2015 the International Year of Soils (IYS). The IYS 2015 aims to increase awareness and understanding of the importance of soil for food security, climate change adaptation and mitigation, and essential ecosystem functions. It calls for the sustainable management and protection of soil resources to develop and maintain soil health for different land users and population groups. Soil health cannot be directly measured; it is a functional concept that elaborates how fit the soil is to perform multiple functions and provide essential ecosystem services. Generally, a composite of physical, chemical and biological attributes called soil quality indicators are used to develop soil quality index (SQI) that describes soil health or soil quality for a specified ecosystem function (Nieder and Benbi 2008). The commonly used physical indicators of soil quality include soil texture, depth of soil and rooting, soil bulk density, aggregation, infiltration, water holding capacity, water retention characteristics and soil temperature (Table 2). Chemical parameters used to assess soil quality include total soil organic matter (SOM), active organic matter content, pH, electrical conductivity, and available nutrient concentrations. Total soil organic matter content defines a soil's carbon storage, potential fertility (nutrient availability), and stability. Active organic matter content defines a soil's structural stability and the quantity of food available for microbes. Microbes can only grow and function at an optimum pH range; most microbes cannot function at low pH and high pH. The electrical conductivity (EC) of the soil can be an indicator of plant and microbial activity thresholds. Above or below different predetermined EC levels, specific plant and microbial communities will not function successfully (Brady and Weil 1999).

Table 2. Commonly used physical, chemical and biological indicators of soil quality

Indicator	Soil property
Physical	Soil texture, aggregate distribution, aggregate stability, maximum rooting depth, bulk density, penetration resistance, porosity, hydraulic conductivity, infiltration, water holding capacity, mineralogy,
Chemical	Organic C, labile C, organic C fractions of different oxidizability, total N, mineral N, pH, electrical conductivity, available nutrient status, cation exchange capacity, potentially toxic elements, organic chemical contaminants
Biological	Microbial biomass C and N, potentially mineralizable N, soil respiration, metabolic quotient, respiratory quotient, enzyme activities, phospholipid fatty acid, DNA

Biological parameters that can be used to indicate soil health include microbial biomass C and N, potentially mineralizable N, specific microbial respiration rates, microorganism numbers, and the presence of mycorrhizae. The microbial C and N masses are important for determining microbial health as in general a C:N ratio of 8:1 is necessary for adequate soil function. The C:N ratio indicates whether the organic matter is having substantial amount of carbon and nitrogen to sustain microbes. Measurement of potentially mineralizable N in soil could be used to estimate indigenous soil N supply. Microbial activity indicators include the microbial respiration or the CO_2 evolution rates. No single parameter is sufficient to describe soil quality. It is interplay of physical, chemical and biological parameters similar to three vertices of a triangle that determines soil quality and its capacity to deliver ecosystems services

Soil physical, chemical and biological parameters

Soil organic matter exerts a major influence on soil physical, chemical and biological properties. The soil physical properties most commonly influenced include bulk density, aggregate stability, and moisture retention. Soil bulk density is generally lower in soils with relatively higher organic matter content and addition of organic amendments is known to decrease it (Benbi et al. 1998). Decrease in soil bulk density with addition of organic amendments may be attributed to the dilution effect of adding less dense organic matter to the more dense mineral matter and the increased aggregation. The increase in aggregate formation and aggregate stability is mainly due to the production of organic macromelecules by microorganisms that bind primary particles and microaggregates to form macroaggregates (Fig. 1; Benbi and Senapati 2010). The addition of organic amendments to soils has been found to be an effective method to

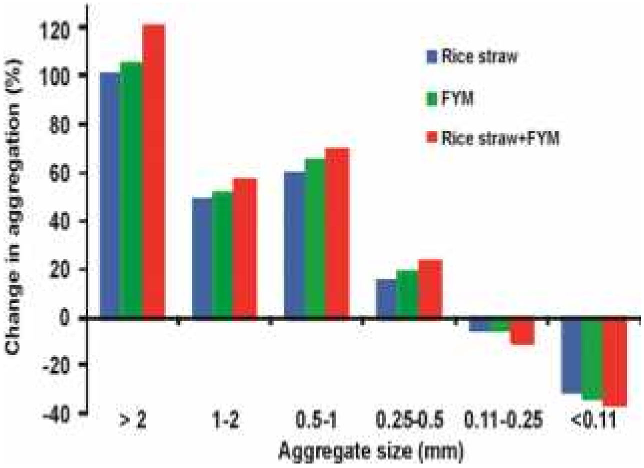

Fig 1. Effect of farmyard manure and rice straw application on aggregate size distribution in soil under rice-wheat system

Table 3. Soil quality and sustainability indices in several long-term field experiments under different systems of nutrient management

Treatment	Nutrient index	Microbiological index	Crop index	Sustainability index
29-year-old experiment on maize-wheat cropping system				
Control	0.68	0.86	0.50	0.59
100%NPK	0.92	0.91	0.71	0.93
100%NPK+ FYM	1.25	1.22	1.66	2.43
18-year-long experiment in rice-wheat cropping system				
Control	0.73	0.81	0.59	0.65
100%NPK	1.03	0.87	0.93	1.16
FYM+GM	1.24	1.32	1.35	2.20
17-year-old experiment on rice-wheat cropping system				
Control	0.84	0.79	0.59	0.70
100%NPK	0.92	0.81	0.95	1.03
50%NPK+50% N (FYM)	1.32	1.19	1.42	2.24
50%NPK+50% N (GM)	1.12	1.22	1.33	1.93

FYM Farmyard manure, WS wheat straw, GM green manure increase total aggregation and the proportion of water-stable aggregates (Benbi et al. 1998; Sodhi et al. 2009a). Soil aggregation, besides influencing C storage improves soil quality and its capacity to perform various functions. Soil organic matter can influence water retention directly and indirectly. The direct effect depends on the morphological structure of the organic materials and through their effect on reducing evaporation. The indirect effect is through its impact on soil aggregation and pore size distribution, and thus on water holding capacity of soil. The SOM imparts dark color to the soils and thus can enhance soil warming resulting in promotion of temperature-dependent biological processes such as mineralization of C, N and S. The chemical properties that are mainly influenced by SOM include nutrient availability, exchange capacity of the soils, reaction with metals and contaminants and its capacity to act as proton buffer. The ability of SOM to adsorb both cations and anions from the soil solution is important for maintenance of soil quality. It contributes 25-90% of the cation exchange capacity of surface layers of mineral soils. The soil biological properties or processes influenced by SOM include mineralization, microbial biomass and enzyme activities.

Apparently, SOM influences a number of soil properties that influence soil functions. Therefore, soils with relatively higher organic matter content are better in performing ecosystem functions. Management practices such as residue recycling and integrated use of inorganic fertilizers and organic manures enhance soil quality and production system sustainability (Benbi et al. 2011). Results of several long-term experiments show that application of FYM, residue recycling, and green manuring impart greater sustainability through improvement in soil quality expressed as nutrient, microbiological and crop yield indices (Table 3). Therefore, regular addition of sufficient amounts of organic materials to the soil is important in the maintenance of microbiological properties and improvement of soil health.

Enhancing soil C sequestration

Agro-ecosystems can play an important role in mitigating CO_2 emissions through C sequestration in soils and vegetation. The carbon sequestration potential of a soil depends on climate, the type of vegetation it supports, the nature of parent material, soil drainage, the edaphic environment, soil organic matter (SOM) content and its decomposability and land management practices. Improved management of agro-ecosystems can significantly enhance C sequestration in soils. Management practices that increase C input to the soil and reduce heterotrophic respiration or both lead to net C sequestration in soil (Table 4). Increased C input in agro-ecosystems can be achieved through selection of high biomass producing crops, residue recycling or residue retention, application of organic materials, adoption of agroforestry systems, intensification of agriculture, elimination of summer or winter fallow, changing from monoculture to rotation cropping, and switching from annual crops to perennial vegetation. Soil C loss could be decreased by adopting conservation agriculture and minimizing soil disturbance, checking erosion through reduced tillage intensity, and using low quality organic inputs. Technological options that have been found to be

Table 4. 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	

efficient for soil C sequestration in Indian agro-ecosystems include intensification of agriculture, balanced application of fertilizers, integrated nutrient management, crop residue recycling, mulch farming and/conservation agriculture, agro-forestry systems, and choice of cropping system.

Intensive agriculture

Intensive agriculture with improved nutrient and water management can increase water and nutrient use efficiency (NUE) and biomass production by plants, thereby increasing C inputs to soil and reducing organic matter decomposition rates. Results of a 25-year study from 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 2). Intensification of agriculture besides improving crop yield saves emissions that would have occurred because of land-use changes required for meeting the food demands of the growing population.

Nutrient management

In intensive agricultural systems, judicious and balanced use of fertilizers has been reported to increase SOC concentration by 6 to 100 percent compared with unfertilized control in different agro-ecosystems in India (Benbi 2013a). Addition of fertilizer N not only increases crop yield but also causes shift in soil microbial community composition yielding communities that are less capable of decomposing recalcitrant soil C pools and thus leading to an increase in soil C sequestration rate (Ramirez et al. 2012). Integrated use of inorganic fertilizers and organic amendments such as farmyard manure (FYM) and crop residues to soil improves SOC. The organic amendments, besides being source of organic matter, enhance crop yield leading to greater crop mediated C input to the soil (Biswas and Benbi 1997, Benbi et al. 1998). Results from a number of long-term experiments in India show that application of FYM along with NPK resulted in greater C accumulation in soil compared with unfertilized control and NPK only. The magnitude of change in SOC varied with cropping system, climatic conditions and soil type. In rice-wheat system in Punjab, C sequestration has been shown to be linearly related to crop-mediated and exogenous C input. Depending on the soil type and climatic conditions 8 to 21 per cent of the added C is sequestered in the soil (Benbi et al. 2012b). The addition of organic sources, such as crop residues, animal manure and compost improves the formation of maro-aggregates and C storage inside the aggregates, which is protected from decomposition (Sodhi et al. 2009a; Benbi and Senapati 2010). Generally, crop residues with high C:N ratio or manures and composts that have already undergone certain degree of decomposition before being added to the field could provide greater C stabilization with longer residence time than those with low C:N ratio such as green manures (Sodhi et al. 2009b; Benbi and Khosa 2014).

Application of organic amendments not only influences quantity but also quality of SOM (Benbi et al. 2012b). Characterization of SOM composition through physical fractionation technique shows (Fig. 3) that

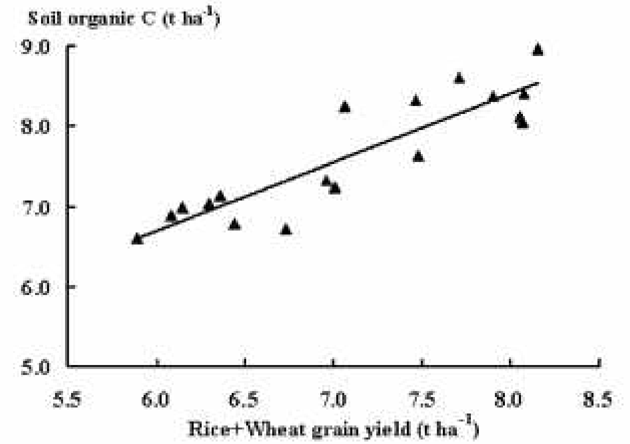

Fig 2. Relationship between soil organic carbon and total rice and wheat grain yield in Punjab (adapted from Benbi and Brar 2009)

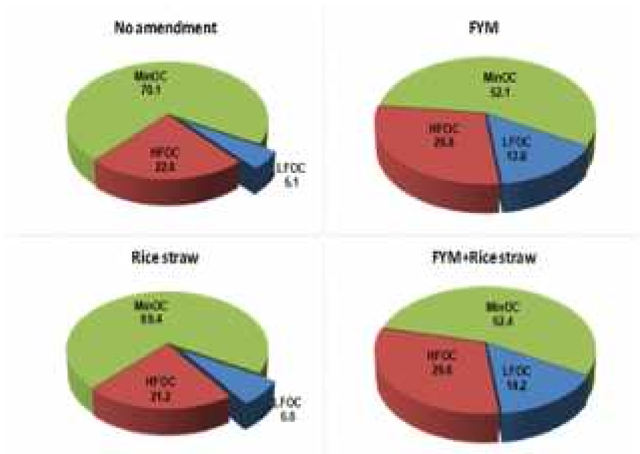

Fig 3. Effect of farmyard manure (FYM) and rice straw application on physical pools of soil organic carbon in rice-wheat system (redrawn from Benbi et al. 2012b)

addition of organic amendments influences light fraction organic C (LFOC) or particulate organic C (POC) to a greater extent than the sand-sized heavy fraction (HF) and silt- and clay-sized mineral associated organic C (MinOC). In rice-wheat system addition of FYM alone or in combination with rice straw enlarged the LFOC pool by 263 and 383%, and HFOC pool by 62 and 127%, respectively with insignificant effect on MinOC. The effect of rice straw application was relatively small and it increased LFOC by 66%, with no effect on HFOC (Benbi et al. 2012b). Characterization of organic matter composition using chemical methods showed that long-term application of FYM and rice straw resulted in build-up of not only labile but also the recalcitrant pool of SOC emphasizing the need for continued application of organic amendments for permanence of the accrued C (Benbi et al. 2015a). The water soluble C exhibited the greatest sensitivity to management suggesting that it may be used as a sensitive indicator of management-induced changes in SOM under rice-wheat system.

Biochar application

Addition of biomass-derived biochar to agricultural soils, with very long turnover time has been suggested to improve C stabilization in soil. A number of studies have documented the positive effect of biochar application on C sequestration in soil. It is estimated that upto 50% of the initial biomass C can be sequestered through conversion to biochar. The technical potential for C sequestration over a century through biochar application has been estimated at 130 Pg C (Woolf et al. 2010). Besides C sequestration, biochar is reported to have several other benefits such as reduction in CH4 emission from paddy soils, availability and uptake of nutrients, improvement in soil fertility etc. A study of the decomposition of rice residue-derived by-products including rice straw (RS), rice straw-derived biochar and compost (RSC), rice husk (RH), and rice husk ash (RHA) showed that the decomposition of organic sources depended on the size of decomposable and recalcitrant C pools (Benbi and Yadav 2015). Rice straw and rice-husk with larger decomposable pool decomposed at a faster rate than biochar and RSC with smaller decomposable pool. Rice straw and RH exhibited a smaller mean residence time than biochar and RSC (Fig. 4). Relatively lower MRT for RS (180-400 days) and RH (255-529 days) suggest that their incorporation in soil may lead to only short-term C accrual in soil. On the contrary, high MRT (1100-2000 days) for RSC and biochar, implies that these are likely to stay longer in soil resulting in long-term C sequestration. Because of aromatic structure of biochars, these are recalcitrant and have the potential for long-term C sequestration in soil. However, the effect and the stability of biochar vary with the type of feedstock, pyrolysis temperature and soil type.

Conservation agriculture

Carbon emissions from agricultural soils could be reduced by adopting conservation agriculture and minimizing soil disturbance, checking erosion through reduced tillage intensity and using low quality organic inputs. No-till agriculture greatly reduces the degree of soil disturbance normally associated with cropping. Physical disturbance associated with intensive soil tillage increases the turnover

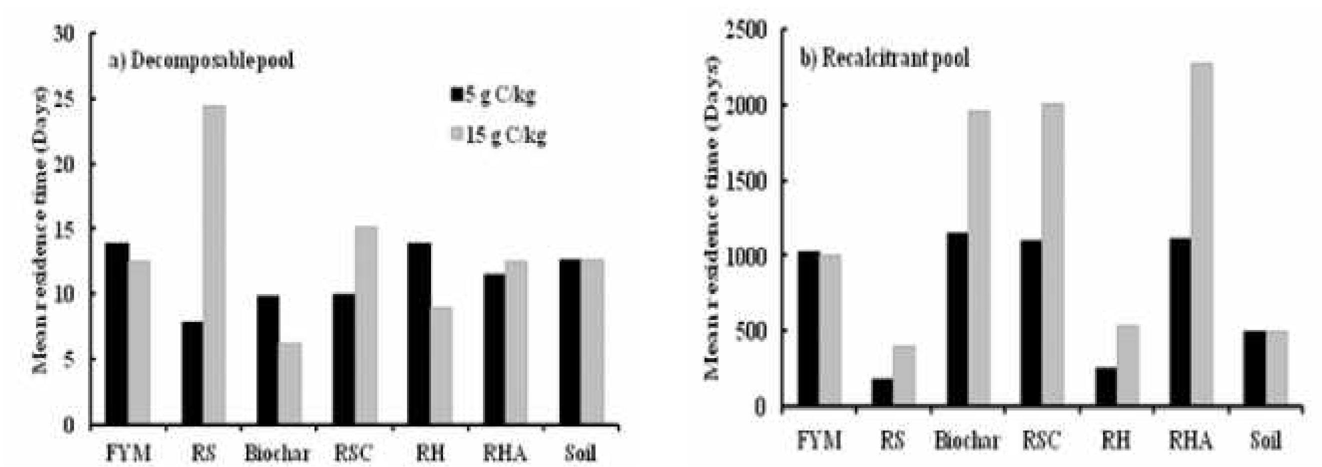

Fig 4. Mean residence time for a) decomposable and b) recalcitrant pools in FYM, rice straw (RS), rice straw-derived biochar, rice straw compost (RSC), rice husk (RH), rice husk ash (ash) applied at 5 and 15 g kg^{-1} soil

of soil aggregates and accelerates the decomposition of aggregate associated C. Tillage breaks the soil aggregates, increases the oxygen supply and exposes the protected organic matter, which enhances organic matter decomposition and triggers emission of CO_2. Increased rate of decomposition, besides leading to release of CO_2 result in loss of soil organic C. No-till increases aggregate stability and promotes the formation of recalcitrant C fractions within stabilized micro- and macro- aggregate structures, and reduces soil erosion. Croplands under no-till systems have been shown to increase soil C compared with more intensive tillage operations. Analysis of results from long-term experiments showed that a change from conventional tillage (CT) to no-till (NT) could sequester 57±14 g C m^{-2} y^{-1} (West and Post, 2002). Carbon sequestration rates, with a change from CT to NT, can be expected to peak in 5 to 10 yr with SOC reaching a new equilibrium in 15-20 year. However, the effect is generally more in tropical climates than temperate climates. An analysis of the published data showed that converting from conventional to no-tillage increased SOC storage over 20 years by 23 per cent in tropical moist climates compared with 10 per cent in temperate dry climates (Ogle et al. 2005). There is not much information available on C sequestration in relation to conservation agriculture in Indian agro-ecosystems.

Land-use effects

The amount of organic matter input and its rate of decomposition are governed by the interactive effect of climate, soil properties, and land use, which in turn determines C sequestration in soil. Soil organic matter content generally decreases in the sequence forest, grassland, and arable land. Change in land use from forest to agriculture generally results in loss of SOC. Agricultural land in 2002 was estimated to cover 5,023 million ha of which 3,488 million ha (or 69%) was under pasture and 1,405 million ha (28%) under cropland. From 1961 to 2002, agricultural land gained almost 500 million ha from other land uses. During this period, on average 6 million ha of forest land and 7 million ha of other land were converted to agricultural land, particularly in the developing countries. Cultivation of undisturbed soils in north Indian state of Punjab resulted in decrease of total organic C stocks by 21-36% (Benbi et al. 2015b). Proper choice of land-use and cropping system can enhance C sequestration in soils. Average global C sequestration rates, when changing from agriculture to forest or grassland have been estimated to be 33.8 and 33.2 g C m^{-2} y^{-1}, respectively (Post and Kwon 2000). But there is a large variation in the length of time and the rate at which C may accumulate in the soil, related to the productivity of the recovering vegetation, physical and biological conditions in the soil, and the past history of SOC inputs and physical disturbance. Enhancing rotation complexity such as changing from monoculture to continuous cropping, changing crop-fallow to continuous cropping, or increasing the number of crops in a rotation can sequester on an average 20±12 g C m^{-2} y^{-1} (West and Post 2002).

Agroforestry is considered an important option for C sequestration. The estimates of C sequestration potential of agro-forestry systems vary widely (1.3-173 t C ha^{-1}) depending on tree species, climatic conditions and age of plantation. Poplars are among the fast growing tree species and can be harvested at a short rotation of 6 to 7 years. Because of economic benefits associated with poplar-based agroforestry systems and their role in preventing land degradation, this land-use is considered feasible for irrigated agro-ecosystems of India. Besides influencing C sequestration, agroforestry systems play an important role in improving soil quality and its capacity to perform ecosystem functions. Agro-forestry and other tree-based agro-ecosystems have the potential to reduce erosion and runoff, improve soil physical properties and promote nitrogen fixation and efficient nutrient cycling. Poplar-based agroforestry systems are reported to have 88% higher SOC stocks than the rice-wheat system (Benbi et al. 2012a). But most of the SOC under agro-forestry systems is characterized by labile or active C fractions (Fig.5) and is thus less stable and can be lost through decomposition if the land-use is altered. Carbon sequestration could be higher under submerged rice soils as compared to aerobic soils due to incomplete decomposition of organic materials, and decreased

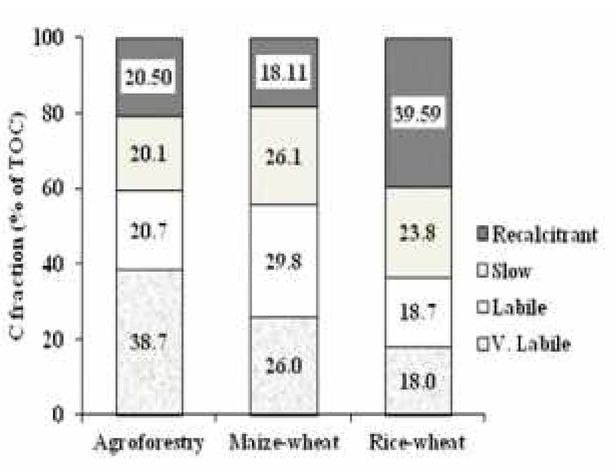

Fig 5. Distribution of total organic C in fractions of varying lability in agroforestry, maize-wheat, and rice-wheat systems

humification of organic matter under flooded conditions (Benbi and Brar 2009). Data from landscape studies in China also show that paddy ecosystems have the ability to accumulate organic C faster than other agro-ecosystems (Wu 2011). Irrigated rice also contributes towards C sequestration because of the presence of photosynthetic aquatic biomass.

Carbon sequestration and soil functions

A number of ancillary benefits can be associated with practices primarily aimed at enhancing C storage in soil. These co-benefits such as restoring soil fertility, enhancing crop productivity, reducing erosion and associated loss of nutrients such as N and P and imparting greater biodiversity enable soil to optimally perform ecosystem functions. Higher SOC content promotes water productivity, reduces energy use in tillage operations and provides sustainability to crop production system. There is a strong relationship between crop yields and the amount of SOC in the root zone. It is estimated that 24 to 40 million Mg of additional food grains can be produced annually if SOC pool in the soils of developing countries can be enhanced by 1 Mg ha^{-1} y^{-1} (Lal 2006). 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. 6). With the application of chemical fertilizers the effect of SOC concentration on wheat productivity was smaller indicating

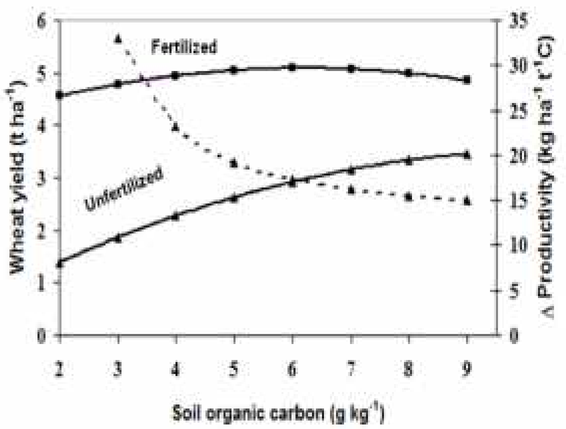

Fig 6. Influence of soil organic carbon (SOC) concentration on wheat yield (solid lines) and productivity (dashed line) per ton organic carbon in the 15-cm plough layer

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. Higher SOC content compensates for fertilizer N. Each Mg of C sequestered in the plough layer has been reported compensate for 4.7 kg fertilizer N ha^{-1} (Benbi and Chand 2007), which indirectly reduces C emissions related to fertilizer N production and application (Benbi 2013b). Direct and indirect emissions of C through N, P and K use range between 0.8 and 1.8 kg C per unit nutrient used.

There are considerable opportunities for enhancing C sequestration and soil quality in Indian agro-ecosystems. 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 and economic feasibility. Since no single land-management strategy in isolation may be adequate to enhance C sequestration, a combination of land-management practices may be adopted for greatest benefits. Prospects of C sequestration should be carefully analyzed before implementation as a suggested measure may be counter-productive if it involves direct or indirect investment of C.

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Potassium response and requirement in crops grown in Vertisols: experiences from long term fertilizer experiment

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Abstract

Long term fertilizer experiments (LTFE) were initiated with the aims to monitor the response of crops to nutrient in different soils and cropping systems to sustain productivity and food security of the country. The results generated over the years in LTFE , it was observed that the soils which are considered rich in K crop started showing response to applied K in these soils. So to assess the response of crop to applied K, the data generated over the years were examined for K response. The results revealed that at Jabalpur gradual response to potassium was seen since inception of the experiment in soybean. However, in case of wheat response to applied K was observed since inception with a magnitude higher than the soybean. At Akola both sorghum and wheat showed response to applied K which was increased with time in-spite of available K content more than the yard sticks prescribed for K. Analysis of soil K status revealed that absence of K in fertilizer schedule resulted decline in K status at the rate 2.1 to 9.7 kg ha^{-1} and addition of P accelerated the mining of K. The addition of K (NPK and NPK+FYM) declined in available K status which was arrested and some cases led to increase in available K form. Thus the results indicate that there is need to modify or raise the K limits for rating the Vertisols as high and accordingly K- recommendation be made for Vertisols.

Keywords: Potassium response in Vertisols from long term fertilizer experiments

Potassium is an essential nutrient for plant growth. It plays an important role in plant growth and metabolic activities. During post Green Revolution era, use of high analysis fertilizers in large quantity as well as irrigation at the advent of high yielding varieties accelerated the mining of potassium. It resulted in inadequacy of K in many soils. All India Coordinated Research Project on Long-Term Fertilizer Experiments (LTFE) indicated decline in yield because of hidden hunger of K in different soils of India. Thus, at several locations availability of K has become yield limiting factor. Regular monitoring of the soil is essential to know soil potassium status to avoid loss in productivity. Long term fertilizer experiments provide an opportunity to study impact of continuous fertilizer application on K-status and crop requirement under different cropping systems. It could help in formulating strategies for efficient utilization of potassium through applied fertilizer and manure. Keeping this in view, the results emanated from long term fertilizer experiments in relation to potassium requirement of different crops grown in Vertisols is discussed in this paper

Experimental details

The Vertisol group of soils with different cropping systems includes Akola (Sorghum-wheat), Jabalpur (Soybean-wheat), Coimbatore (Finger millet-maize), Junagadh (Groundnut-wheat), Raipur (Rice-wheat) and Parbhani (Soybean-safflower) centres of AICRP LTFE (Table 1). These soils belong to Vertisol order and classified as Typic Haplustert at Jabalpur, Akola, Raipur and Parbhani, Junagadh under Vertic Ustochrept and Coimbatore under Vertic Ustopept. The recommended dose of 100% NPK for each crop grown at different location of AICRP LTFE is given in Table 2.

Nutrient Status in Soil

Nitrogen

The Vertisol group of soils under AICRP LTFE are poor in N-status (Table 3). Even 100% recommended dose of NPK could not maintain the level of N in the soil. At all the centres the soils are very low in N since inception of

Table 1. Details of experimental sites for Vertisols and associated soils under AICRP LTFE

Location (Year of start)	Taxonomic Class	Cropping system	AESR	Latitude	Longitude	Altitude
Akola (1986)	Typic Haplusterts	Sorghum-wheat	6.2	20º42' N	77º 02' E	307 m
Jabalpur (1972)	Typic Haplusterts	Soybean-wheat	10.1	23º10' N	79º 59' E	411 m
Coimbatore (1972)	Vertic Ustopept	Fingermilete-Maize	8.1	11º02' N	76º59' E	426 m
Junagadh (1996)	Vertic Ustochrept	Groundnut-wheat	2.4	21º30' N	70º26' E	61 m
Raipur (1996)	Typic Haplusterts	Rice-wheat	11.0	21º17' N	81º45' E	695 m
Parbhani (2006)	Typic Haplusterts	Soybean-Safflower	6.2	19º 08' N	76º 5' E	300 m

AESR = Agro-Ecological Sub-Region

Table 2. Nutrient rates used under various cropping systems at different centres of LTFE

Location	Crop	Fertilizer rates at 100% NPK based soil test (kg ha^{-1})			FYM added (t ha^{-1})
		N	P	K	
Coimbatore	Finger millet	90	20	14	12.5
	Maize	135	29	29	-
Jabalpur	Soybean	20	35	17	15
	Wheat	120	35	33	-
Junagarh	Groundnut	25	22	0	-
	Wheat	120	26	50	-
Raipur	Rice	100	26	33	5
	Wheat	100	26	33	-
Akola	Sorghum	100	50	40	10
	Wheat	120	26	50	-
Parbhani	Soybean	30	26	25	10
	Safflower	60	18	0	

(Source: Swarup and Wanjari 2000; Singh and Wanjari 2009)

Table 3. Effect of long term fertilizer and manure use on soil available N, P, and K (kg ha^{-1}) at different locations of LTFEs

Location	Available N			Available P			Available K		
	Initial	Control	NPK	Initial	Control	NPK	Initial	Control	NPK
Akola	120	170	273	8.4	12	29	358.0	228	386
Coimbatore	199	159	177	12.3	6	18	907.2	445	594
Raipur	236	218	241	16.0	11	25	474.0	448	428
Jabalpur	193	192	263	7.6	9	29	370.0	175	266
Critical range*		280-560			11-25			121-280	

(Source: Singh and Wanjari 2009; *Dhyan Singh et al. 1999) the experiment. The N-status in soil has either declined or maintained when no fertilizer or manure was added (absolute control).

Phosphorus

The vertisols group of soils at Akola and Jabalpur are poor in initial P-status (Table 3). However, 100% recommended dose of NPK could either maintain the level of soil P or enhanced the content at all the centres. The P-status in soil has declined at only Coimbatore and Raipur but little increase was recorded at Akola and Jabalpur which might be due to retention of crop residues in absolute control.

Potassium

The soils under Vertisols group in long term fertilizer experiments indicated that the imbalanced (control, N and NP) nutrient application declined potassium status compared to initial values as well as the status under balanced nutrient application (NPK, NPK+FYM, NPK+Zn). Absence of K supply resulted decline in K status in all the five soils except Akola and Parbhani because of less number of years of cultivation. However, application of FYM over and above NPK supply maintained K status

Table 4. Average crop yield (kg ha^{-1}) in Vertisols at different locations of AICRP-LTFE

Location	Crops	Control	N	NP	NPK	150%NPK	NPK+Zn	NPK+FYM
Akola	Sorghum	290	1975	2701	3353	4204	3686	4201
	Wheat	155	981	1398	2043	2531	2019	2597
Jabalpur	Soybean	814	1021	1652	1818	1833	1797	2004
	Wheat	1238	1668	4071	4419	4743	4345	4850
Junagadh	Groundnut	750	803	838	951	993	968	1037
	Wheat	1745	1489	2409	2536	2630	2451	3063
Raipur	Rice	2337	3614	5055	5124	5560	5143	5447
	Wheat	1002	1459	2140	2141	2477	2149	2388
Parbhani	Soybean	1379	1881	2142	2272	2535	2326	2498
	Safflower	914	1087	1145	1346	1499	1353	1480

(Source: AICRP LTFE Annual Report 2006)

Table 5. Potassium uptake (kg ha^{-1}) in different crop as influenced by nutrient management option in Vertisols and associated under AICRP LTFE (2008-09)

Location	Crops	Control	N	NP	NPK	NPK+FYM
Akola	Sorghum	9.31	107.20	146.0	190.5	276.3
	Wheat	16.40	14.33	19.59	50.35	71.36
Jabalpur	Soybean	13.10	18.28	25.31	32.43	42.16
	Wheat	35.73	71.77	124.71	168.57	237.85
Junagadh	Groundnut	11.97	10.58	12.75	16.21	27.23
	Wheat	21.89	15.48	22.24	42.94	74.35
Raipur	Rice	71.46	120.64	166.84	189.25	213.70
	Wheat	36.32	43.82	84.97	77.55	108.82
Parbhani	Soybean	31.66	41.66	45.92	57.21	61.66
	Safflower	58.27	79.25	79.35	90.11	94.91
Coimbatore	F. Millet	57.9	66.1	83.0	119.1	151.3
	Maize	37.4	43.5	51.2	63.3	78.5

(*Junagadh 50% NPK+FYM)

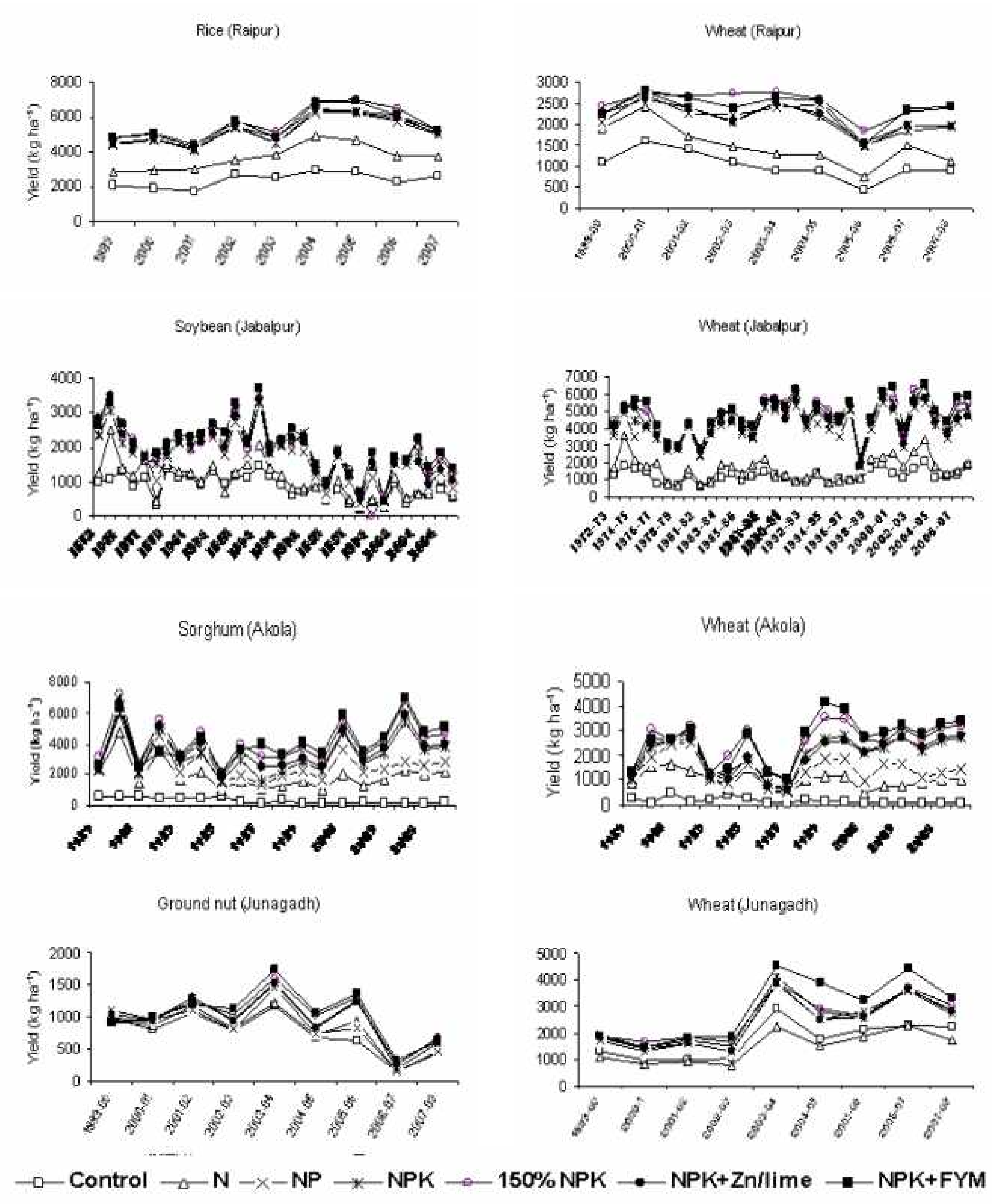

Fig 1. Yield trends of rice- wheat, soybean-wheat, sorghum-wheat and groundnut-wheat cropping systems in long term fertilizer experiments in India

Table 6. Response to K in Vertisols at LTFEs in India

Vertisols of Jabalpur, Akola and Junagadh

Years	Jabalpur		Years	Akola		Years	Junagadh	
	Soybean	Wheat		Sorghum	Wheat		Groundnut	Wheat
1972-75	6	294	-	-	-	-	-	-
1977-81	18	108	-	-	-	-	-	-
1982-86	172	164	1989-92	150	230	1999-00	0	164
1987-92	198	248	1993-96	401	241	2001-02	172	161
1993-97	272	488	1997-00	415	659	2003-04	99	259
1998-03	177	521	2001-04	936	757	2005-06	240	149
2004-09	203	527	2005-08	1279	1176	2007-09	121	141

Vertisols of Parbhani and Raipur

Year	Parbhani		Year	Raipur	
	Soybean	Safflower		Rice	Wheat
2006-07	10	180	1999-01	33	141
2007-08	46	228	2002-04	75	-52
2008-09	333	195	2005-08	92	-40

Table 7. Effect of different long term treatments on rate of decline in available potassium in soil at Jabalpur

Treatments	Available K (kg ha^{-1})	Changes from initial (kg ha^{-1})	Increase / decrease (kg ha^{-1} yr^{-1})
Control	279	-191	-2.3
100% N	291	-79	-2.1
100% NP	234	-136	-3.6
50 % NPK	242	-128	-3.4
100 % NPK	268	-102	-2.7
150 % NPK	296	-74	-1.9
NPK+FYM	315	-55	-1.5
Initial	370		

Table 8. Scenario of potassium balance in soybean-wheat system at Jabalpur

Treatments	Total K added (kg ha^{-1})	Total K uptake (kg ha^{-1})	Apparent K balance (kg ha^{-1})	Apparent K balance (kg ha^{-1} yr^{-1})
Control	0	2745	-2745.0	-72
100% N	0	3728	-3728.0	-98
100% NP	0	8235	-8235.0	-217
100% NPK	2109	9272	-7163.0	-189
150% NPK	3184	11052	-7868.0	-207
NPK + FYM	5861	12993	-6232	-164

(Source : Dwivedi et al. 2007)

but improved it. This is partly due to K supply through FYM and partly due to mobilization of K from non exchangeable form by FYM.

Crop Productivity

Application of K resulted in increase in yield of both the crops in sequence at Akola, Jabalpur and Parbhani though soils were high in available K status. However, crop did not show any response to applied K at Junagadh and Raipur even though soils of Junagadh are low in K status (Table 1). At Junagadh irrigation water was responsible for non-response of crop to K as good amount of K was added through water during winter season. At Raipur, however, soil K was sufficient to meet K requirement of crops but in the years to come K could be a limiting nutrient.

The yield trends for each crop at each LTFE location is depicted in Figure 1. The trends indicated that imbalanced treatment showed lower magnitude level compared to balanced nutrient application. The yield due to control and 100% N at Akola and Jabalpur has touched the X-axis indicating very low productivity under these treatments. The yield of soybean at Akola and groundnut at Junagadh has declined over the years compared to the initial yield levels. The yields at Raipur for both the crops could not exhibit any sign of decline which may be because it was a new experiment.

Potassium Uptake by crops

The K uptake by different crops follows the similar trend to that of yield at each centre. The gradual increase in uptake was observed in the order of control <N <NP <NPK <NPK+ Zn <150% NPK <NPK+FYM (Table 2). The low K-uptake under control was due to low yield recorded with different crops at each centre. The K uptake with 100% NPK nutrient application was 190 and 50 for sorghum and wheat at Akola, 32 and 168 for soybean and wheat at Jabalpur, 16 and 43 for groundnut and wheat at Junagadh, 189 and 77 for rice and wheat at Raipur and 57 and 91 for soybean and safflower at Parbhani, respectively. The variation in amount of uptake indicated that the requirement of potassium varies from crop to crop, even in same group and depends on productivity level.

Table 9. Change in available K at different LTFE locations (kg yr^{-1})

Location	Control (kg ha^{-1})	N (kg ha^{-1})	NP (kg ha^{-1})	NPK (kg ha^{-1})	150% NPK (kg ha^{-1})	NPK+ FYM (kg ha^{-1})
Jabalpur	- 2.3	- 2.1	- 3.6	- 2.7	- 1.9	- 1.4
Raipur	- 3.3	- 6.8	- 9.7	- 5.0	- 1.3	- 3.1
Coimbator	- 4.2	- 3.4	- 3.0	- 0.3	+ 0.3	+ 0.8
Akola	- 1.7	- 5.0	- 4.2	+ 0.9	+ 2.6	+ 3.4

Table 10. Response of K years after inception of experiment in Vertisols at Jabalpur and Akola

Crop	Response of K (kg ha^{-1}) years after cultivation						
				Jabapur			
	5	10	15	20	25	30	35
Soybean	6	18	172	198	272	177	203
Wheat	294	108	164	248	488	521	527
Available K	352	334	316	298	280	262	244
				Akola			
	4	8	12	16	20	-	-
Sorghum	150	401	415	936	1279	-	-
Wheat	230	241	659	757	1176	-	-
Available K	341	324.4	307.6	290.8	272	-	-

Potassium response

At Jabalpur gradual response to potassium was observed since inception of the experiment. On the contrary in wheat magnitude of response to K was higher than the soybean. At Akola both sorghum and wheat exhibited response to K and very high response was seen in recent years. At Junagadh no definite trend was seen in both groundnut and wheat.

Rate of decline in soil available K at Jabalpur

The data were subjected to estimate changes in available K status compared to the initial value (Table 7). The negative values were observed with respect to change in available K status in soil in Vertisols of Jabalpur. However lower negative estimates were seen in NPK+ FYM treatment. There was negative rate of decline (kg ha^{-1} yr^{-1}) in available K in all the treatments (Table 8, 9). Similarly all treatments showed depletion of K in potassium balance also (Table 8). It indicates that even in Vertisols like Jabalpur showing symptoms of decline in soil K status. It was probably due to either no consideration of contribution from soil or higher removal of K by crops under intensive and irrigated system as in case of long term fertilizer experiments.

Available K status vs crop response to K in Vertisols and associated soils

Available status of K with time was computed by calculating rate of decline in available K at Jabalpur and Akola (Table 10). On perusal of available K status and crop response at Jabalpur indicated that soybean started showing response to applied K when available K status reached to 316 kg ha^{-1} whereas wheat showed response to K even before. Similarly at Akola, sorghum started giving response to applied K at 324.4 kg ha^{-1} whereas a larger response in both the crop noted at available K status of 307.6 kg ha^{-1}. It means middle value of K status is 312 kg ha^{-1} (average of 307.8 & 316.0) could be considered as critical value for Vertisols. This is greater than the threshold value (280 kg ha^{-1}) being used for rating the soil as high in K status. Thus, for Vertisols there is need to increase the threshold value of K in soil to get the actual recommendation of K to sustain the productivity and maximized benefit from applied nutrient.

Sustainable Yield Index (SYI)

The SYI is best way to express the sustainability of particular nutrient management option (Wanjari et al. 2004). The sustainable yield index indicates possibility of getting yield based on observed yield with reference to maximum obtained yield under set of management. There was gradual increase in SYI addition of N, P, K, Zn and manure in each crop and at all locations which indicate crops responded to these nutrients (Table 11). Thus, values of SYI were largely found maximum in integrated nutrient management treatment. It shows that the imbalance nutrient application has resulted in low yield as well as low sustainability.

Table 11. Sustainable yield index for various long term treatments at different LTFE centres

Location	Crop	Control	N	NP	NPK	150%NPK	NPK+ Zn	NPK+FYM	Ym (kg ha^{-1})
Akola	Sorghum	0.01	0.14	0.20	0.27	0.38	0.32	0.38	7215
	Wheat	0.01	0.15	0.21	0.31	0.42	0.31	0.40	4178
Jabalpur	Soybean	0.13	0.14	0.27	0.32	0.30	0.30	0.36	3720
	Wheat	0.13	0.14	0.48	0.53	0.55	0.51	0.57	6550
Junagadh	Groundnut	0.25	0.27	0.27	0.32	0.35	0.34	0.36	1789
	Wheat	0.24	0.20	0.33	0.36	0.40	0.34	0.41	4531
Raipur	Rice	0.28	0.41	0.61	0.61	0.66	0.62	0.65	6962
	Wheat	0.25	0.36	0.64	0.64	0.78	0.66	0.73	2798
Parbhani	Soybean	0.32	0.45	0.45	0.50	0.53	0.47	0.49	3407
	Safflower	0.31	0.36	0.39	0.49	0.51	0.48	0.54	2037

Ym = denotes maximum possible yield under set of management practices

Conclusion

The absence of K in fertilizer schedule resulted decline in productivity over a period of time in Vertisols and associated soils which are considered high in K. Thus, external application of potassium is gradually playing a role to make up the soil fertility, crop productivity and sustainability in Vertisols as well. Results revealed that crops are responding to K in Vertisols and associated soils at available status to greater than yard sticks being used to categorize soils into high category. Therefore there is need to modify or raise the K limits for rating the Vertisols as high and accordingly K- recommendation be made Vertisols.

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Nutrient management for crop production

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Abstract

Soil is understood as a product of weathering of rocks, whose ultimate properties are scripted by 5 natural processes like leaching, eluviation, illuviation, Podzolization and Gleying. Due to diverse conditions of weathering (forces of climate and biotic pressure), final physicochemical and biological characteristics vary across locations.Soil is composed of solid mineral matter, pool of living, or dead organisms, liquid and gases, a soil is multiphasic and anisotropic. Men's management interventions, however, can significantly alter the nature and properties inherited from rocks or imposed by soil forming processes. For instance, farming nature's way or conservation agriculture sustains soil organic carbon (SOC) repeated tillage provokes the destruction. There is nothing in whole of nature which is more important than or deserves as much attention as soil. Truly, it is the soil which gives the world a friendly environment for mankind. It is the soil which nourishes and provides for the whole of nature, the whole of creation depends on the soil which is the ultimate foundation of existence.

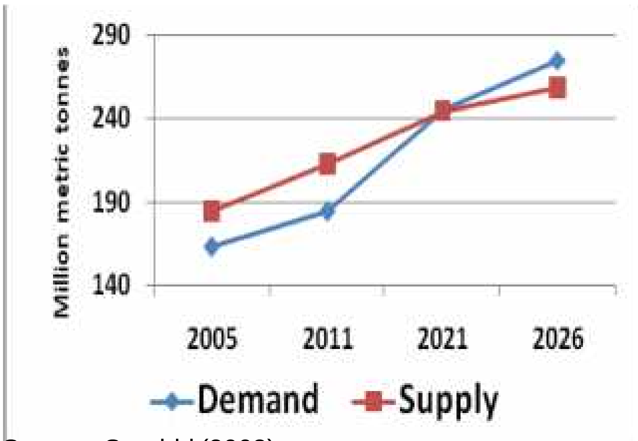
Soil is an essential component of the world's production and ecosystem but it is also a fragile and non renewable resource. It is very easily degraded and is slow, difficult and expensive to regenerate.

Keywords: Nutrient Management, Crop Production

India is the second most populous country in the world. A large percentage of Indian population depends on agriculture for its subsistence. India has 17.31% of the world's population and occupies only 2.4% of the worlds land area. Fast growing population causes stress on the available natural resources to meet the food requirement (Singh 2012). The continuous increase in population in the country demands for additional food grain. For example in the year 2021 the projected food grain demand would rise to 245 million tonnes, while the net sown area in the country has shown an insignificant increase during past five decades. Under such a precarious situation the gap between demand and supply is obvious as depleted in Fig 1.

Long term studies both in India and abroad have vividly demonstrated that it is impossible to attain yields of crops without external supply of nutrients viz. organic manure, use of inorganic fertilizers and use of inorganic fertilizers+ Organic manure (INMS).

The art of agriculture in India dates back to pre historic time. The use of dung as manure appears to have been practiced since Rigvedic age (Rig Veda 1, 161, 10, 2500-1500 BC). The value of Green manure has been known as far back as 1000 B.C. Use of stems of sesamum



Source : Surabhi (2008)

Fig 1. Future supply and demand balance for total cereals in India

as manure is found in Atharva Veda (11, 8.3). Practice of use of phosphatic fertilizer like bones dates back to about 300 BC. Value of excreta of goats and sheep was recognized in post vedic age i.e. between 500 B.C. to 500 AD (Kautalya Arthasastra). Other manures like Oil cakes etc. appear to have come into use in this country from 1000 to 1400 AD. Thus O.M. found its use in field from the time man began cultivating the soils. Organic sources of plant nutrients are organic manures- FYM, Compost, Vermicompost and Bio-Gas Slurry, phospho-compost, press-mud, turning of green manuring crops and crop residues. India was dependent on organic sources of nutrients till 1950 and production of food grains was 52.9 million tonnes. Crop activity as a result of organic farming in presented in Table 1.

Marginal yield increase during 1951-52 was attributed to the use of 0.49 kg ha^{-1} nutrient use and it is also evident that use of organic nutrients was so inadequate that crops were not able to yield as per their potential. The most important organic resources of essential plant nutrient are listed (Table 2).

The most conservative estimates show that hardly 270-300 Mt of organic manures of different kinds contributing around 4 to 6 Mt of NPK are available in the country (Kanwar and Katyal 1997). These sources are only partial substitutes for factory produced inorganic fertilizers and cannot be expected to meet the entire need for plant nutrients for high crop yields. In rice-wheat cropping system (RWCS) at Karnal, application of 15.30 t FYM ha^{-1} to rice was 88.92% efficient to the application of 150 N, 60 P 60 K/ha, while in wheat an application of 20-40 t FYM ha^{-1} was only 38-45 % as efficient as an application of 150 N, 60 P 60 kg ha^{-1}. Several studies on different crops indicate that FYM applied either on nutrient basis or otherwise it was less effective than fertilizer, its efficiency varied with crop and season (Prasad 2008).

Table 1. Crop productivity as a result of organic farming

Crop	Crop productivity (kg ha^{-1})	
	1921-25	1951-52*
Rice	426.7	714
Wheat	340.2	653
Mustard	226.2	393
Ground nut	514	649

*0.49 kg ha^{-1} nutrients use

Table 2. Important organic resources of essential plant nutrients

Nitrogen (%) (N)	Crop residues (0.40-1.60), Animal dung (0.50-1.80), FYM (0.5-1.0), Compost (0.5-2.0), Oil cake (3.0-6.0), Animal meals (1-10), Leaf litter (1.42-2.30) Green manure, Biofertilizer
Phosphorus (%) (P)	Crop residues (0.16-0.36), Animal dung (0.20-2.30), FYM (0.15-0.20), Compost (0.2-1.0), Oil cake (1.0-1.8), Leaf litter (0.12-0.20) Green manure, Biofertilizer
Potassium (%) (K)	Crop residues (0.93-1.64), Animal dung (0.03-1.40), FYM (0.5-0.6), Compost (0.5-1.5), Oil cake (1.0-1.5), Leaf litter (0.83-2.10), Green manure
Calcium (%) (Ca)	Poultry excreta (2.28), Cow dung (0.37), Pig dung (0.21), FYM (0.91), Horse dung (0.26), Leaf litter (1.88-2.80), Wheat straw (0.81), Soybean straw (1.12)
Magnesium (%) (Mg)	Poultry excreta (1.39), Cow dung (0.53), Pig dung (0.21), FYM (0.19), Horse dung (0.49), Wheat straw (0.09), Soybean straw (1.13), Leaf litter (1.88-2.80)
Sulphur (%) (S)	Poultry excreta (0.74-0.99), Piggery manure (0.56), FYM (0.49), Leaf litter (0.25-0.54)
Zinc (mg kg^{-1}) (Zn)	Poultry excreta (90), Piggery manure (198.5), FYM (14.5), Goat & sheep excreta (90), Leaf litter (31.70-60.50)
Copper (mg kg^{-1}) (Cu)	Poultry manure (fresh 4.4, rotted 6.9), Piggery manure (12.8), FYM (2.8), Leaf litter (9.00-16.70)
Iron (mg kg^{-1}) (Fe)	Poultry manure (fresh 1,010; rotted 1,075), Piggery manure (1600), FYM (1465), Leaf litter (325.50-680.80)
Manganese (mg kg^{-1}) (Mn)	Poultry manure (fresh 187.0; rotted 190.0), Piggery manure (168.0), FYM (69.0), Leaf litter (62.50-175.50)
Boron (mg kg^{-1}) (B)	Poultry manure (fresh 12.0; rotted 15.0), Piggery manure (8.0), FYM (5.0)
Molybdenum (Mo)	Poultry manure (fresh 41.5; rotted 65.0), Piggery manure (13.5), FYM (11.5)

Source: Bhattacharyya (2007)

Crop residues

The crop residues derived from cereals and other major cultivated crops constitute important sources of organic materials. The main components of plant residues are carbonaceous compounds viz; cellulose and lignin, the total NPK content of some crop residues are given in Table 3.

Considering one third of the total values of crop residues as remaining portion is used as fuel, cattle feeding, packaging material and building material etc. Considering nutrient (%) NPK for rice (2.17), wheat (1.82), Jowar (2.09), millet (1.75), maize (2.05), pulses (3.29), oilseed (1.94), soybean (3.20), groundnut (3.20), sugarcane (1.86) and potato (1.79).

Crop residues supplies organic matter, prevents soil erosion and nutrient losses and maintains soil in good physical condition, improve microbial and enzymatic activity, soil physical properties e.g. structure and moisture retention, improves nitrogen use efficiency and micronutrient uptake. These residues are also good source of potassium. Regular return of residues in soil contributes to the buildup of soil nutrient pool over a period of time. Incorporating crop residues helps in maintaining soil organic carbon (SOC), besides supplying nutrients (Table 4).

Table 3. Nutrient potential of crop residues

Crop	Nutrient (%)				Tonne $Tonne^{-1}$
	N	P_2O_5	K_2O	Total	residue
Rice	0.61	0.18	1.38	2.17	0.0217
Wheat	0.48	0.16	1.18	1.82	0.0182
Sorghum	0.52	0.23	1.34	2.09	0.0209
Maize	0.52	0.18	1.35	2.05	0.0205
Pearlmillet	0.45	0.16	1.14	1.75	0.0175
Barley	0.52	0.18	1.30	2.00	0.0200
Fingermillet	1.00	0.20	1.00	2.20	0.0220
Pulses	1.29	0.36	1.64	3.29	0.0329
Oil seed	0.80	0.21	0.93	1.94	0.0194
Groundnut	1.60	0.23	1.37	3.20	0.0320
Sugarcane	0.40	0.18	1.28	1.86	0.0186
Potato tuber	0.52	0.21	1.06	1.79	0.0179

Source: Bhattacharya (2007)

Table 4. Total crop residues and their available nutrient (9 million tonnes) content (2002-03)

Crop	Total residues (million tonnes)	Crop residues available for recycling * (million tonnes)	Nutrient available for recycling** (million tonnes)
Rice	108.97	36.32	0.788
Wheat	97.65	32.53	0.586
Jawar	10.62	3.54	0.074
Millet	6.94	2.31	0.040
Maize	15.45	5.15	0.105
Pulses	11.14	3.71	0.122
Oil seed	30.12	10.04	0.195
Soybean	9.12	3.04	0.972
Groundnut	8.72	2.90	0.093
Sugarcane	281.57	93.85	1.746
Potato	23.16	7.72	0.138
Total	603.46	201.11	4.859

Organic farming

Organic farming is a system devoid of the use of any chemical or genetically modified inputs, in which the biological potential of the soil and of the organic sources and underground water resources are conserved and protected by adopting suitable cropping pattern including agro-forestry and methods of organic replenishment (Marwaha 2011). It is a system that is designed to produce agricultural products by the use of methods and substances that maintain the integrity of organic agricultural products until they reach the consumer.

The availability of organic sources of nutrients is estimated of the order of 9.1 million tonnes (Tandon 1997), including cattle manure, rural compost, city refuse, sewage sludge and press mud, all these sources cannot cater the need of crops, besides the nutrients through organic sources are low analysis and are extremely slow release, besides being bulky. Also, it is well known fact that lot of cattle dung is conventionally being used by the farmers for making dung cakes (Uppley). Thus the actual availability of organic sources may be far less than the estimated potential quantities.

Why to use inorganic fertilizers

Dr. Norman Borlaug (2002) who said "switching on food production to organic would lower crop yields. We can use all the organic material that is available but we are not going to feed six billion people with organic fertilizers". Dr. Borlaug (2005) reaffirmed his such a belief and called for a gene revolution and extensive use of chemical fertilizers to double global food supply by 2050 and vanish world hunger. Similar views were expressed by an FAO representative in an IFA seminar held in Rome in March 2003, who called organic agriculture as a myth.

Due to its lower productivity and high cost of production, organic farming will leave many more people hungry in the country, as M. S. Swaminathan (2003) said recently that a hungry man is an angry man if that man happens to be a young man then we may have more of social strife and unrest in the society. That organic farming is a myth created by a constant disinformation campaign.

Inorganic fertilizers

The oldest continuous fertilizer experiment in the world at Rothamsted in the U.K. shows that, where mineral fertilizers have been continuously used for more than 150 years, the soil is more productive now than at any time in the past. At the Askov experimental station in Denmark, after 90 years, the plot receiving NPK fertilizers had an 11 percent higher organic carbon content than the control plots. A long term trial in Japan, after 50 years of NPK fertilization there was no decrease in yield over the years in the fertilized plots. The yield without fertilizer was about 40 percent of the fertilized plot.

At Grignon, in France, wheat grown on plots without fertilizers since 1875 yields about 700 kg ha^{-1} whereas NPK fertilized plots give over 7000 kg ha^{-1}. The findings of the long term fertilizers experiments clearly brought out that it is not possible to sustain productivity without external supply of nutrients. Increase in yield of maize wheat and other crops with the use of fertilizer over the control (no fertilizer) was recorded at several locations of LTFE (Singh and Wanjari 2013).

Importance of fertilizers

Fertilizers may be regarded as a valuable and concentrated food for plants, their raw material, by and large, being natural. The proof of this is that during the last 35 years when the chemical fertilizers were used in considerable quantities though at much lesser rate but in an imbalanced form, as compared to several developed and developing countries of the world, the average life expectancy in India has increased from 45-62 years therefore, in the real sense the problem lies more with the wrong and indiscriminate use of chemicals be the pesticides or fertilizers or any other chemical, rather than with their use per se.

The continuous mining of nutrients from soils coupled with inadequate and imbalanced fertilizers use has resulted in emergence of deficiencies of secondary and micronutrients. The deficiency of N, P, K, S, Zn and B is quite wide spread in Indian soils and is 89, 80, 50, 42, 48, and 33% respectively (Fig 2). The deficiency of Cu, Fe and Mn was 13.7, 16.1 and 7 percent. whereas in alluvial soils of gird region the deficiency of Zn, Cu, Fe and Mn was 91, 8, 2.2 and 2.5 (Bhind), Datia, 67, 1, 0 and 0, Guna, 82, 0, 4 and 0, Gwalior, 81, 0, 0, and 0, Morena, 92, 8.3, 1.7 and 0 and Shivpuri 57, 0, 0 and 0, respectively. Thus wide spread deficiency of zinc has been reported in soils of gird region (Tomar et al. 1995).

The long term fertilizers trials have clearly indicated that balanced and integrated nutrient management improves the soil organic matter content as well as soil quality which is an index of better soil health.

The growth in per unit fertilizer consumption from 0.49 kg ha^{-1} in 1951-52 to 126.6 kg ha^{-1} during 2013-14 and subsequent increase in food grain production from 51.9 to 264.8 million tonnes during this period has proved the prime role of fertilizers in Indian agriculture. The existing sources of organic manure are limited and may not cater to need of crop requirement; therefore, the pivotal role of fertilizers for future crop production cannot be ignored.

The crop production is a function of soil, climate, irrigation, fertilizers, plant protection and management practices. Among these fertilizers is the kingpin contributing to about 50% of the increased food grains production in the world. Thus it is crystal clear that fertilizer has played a pioneer role in enabling India towards self sufficiency in food grain production. The sharp growth in fertilizer consumption from 0.13 million tonnes in 1955-56 to 24.72 million tonne in 2013-14 registered the hold of fertilizer input in Indian agriculture. Considering the future demand of food grains production to meet the ever increasing population, it is expected that growth in fertilizers consumption has to be a continuous process for sustaining the crop productivity.

Though recent dogma of organic farming and ecological thinkers talk about curtailment of fertilizers in order to save the environments, this concept has very little relevance when the fertilizer consumption trend in the country is seen (Table 5). Although the data in table 6 also shows a continuous increase in fertilizers consumption and food production.

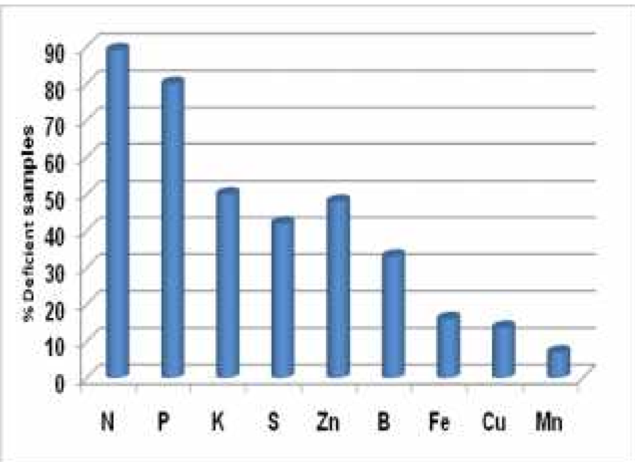


Fig 2. Nutrient status in Indian soils

Fertilizers use and food security

While there is no doubt that nutrient constraints can be alleviated by organic manure additions and by strengthening of soil biological practices but the problem of soil fertility decline is so serious (Kanwar and Katyal 1997). That it may not be possible to cover all of it with the use of organic manure alone.

Fertilizers consumption in India has grown from 69000 tonnes of NPK during 1950-51 to 24.72 million tonnes during 2013-14 which is an increase from 0.52 kg to 146 kg ha^{-1} corresponding by the food production has

Table 5. Consumption of fertilizer nutrient (N, P_2O_5 and K_2O) during plan periods

Year	Consumption ('000 tonnes)				Growth per annum during plan period (%)			
	N	P_2O_5	K_2O	$N+P_2O_5+K_2O$	N	P_2O_5	K_2O	$N+P_2O_5+K_2O$
1955-56 (Ist Plan end)	107.5	13.0	10.3	130.8	14.3	8.1	11.4	13.4
1960-61 (IInd Plan end)	211.7	53.1	29.0	293.8	14.5	32.5	23.0	17.6
1965-66 (IIIrd Plan end)	574.8	132.5	77.3	784.6	22.1	20.1	21.7	21.7
1973-74 (IVth Plan end)	1829.0	649.7	359.8	2838.6	8.6	11.2	16.2	10.0
1978-79 (Vth Plan end)	3419.5	1106.0	591.5	5116.9	13.3	11.2	10.5	12.5
1984-85 (VIth Plan end)	5486.1	1886.4	838.5	8211.0	9.4	10.4	6.7	9.3
1989-90 (VIIth Plan end)	7385.9	3014.2	1168.0	11568.2	6.1	9.8	6.9	7.1
1996-97 (VIIIth Plan end)	10301.8	2976.8	1029.6	14308.1	5.1	-2.2	-5.4	2.4
2001-02 (IXth Plan end)	11310.2	4382.4	1667.1	17359.7	1.9	8.0	10.1	3.9
2006-07 (X Plan end)	13772.9	5543.3	2334.8	21651.0	4.0	4.8	7.0	4.5
20011-12 (P) (XI Plan end)	17311.4	7664.7	2664.1	27640.2	4.7(4.5)	6.7(-4.8)	2.7(-4.2)	5.0 (-1.7)
2013-14 (P) (XII Plan 2nd year)	17018.8	5645.4	2057.0	24721.2	1.2	-15.1	-0.2	-3.2

(P) = Provisional. ( ) + Growth over the previous year increased from 50 Mt to 264.8 Mt (Fig 3). The country has become self-sufficient in food production, and the main contributing factor considered is fertilizers in addition to improved/high yielding variety of seed, enhanced irrigation facilities and effective plant protection measures. Fertilizers alone contribute over 50% in increased crop/ food production.

Imbalance Use of NPK

Imbalanced use of plant nutrients as well as wide NPK ratio has led to the mining of nutrients and it is the main cause for decline in crop yield and crop response ratio (Table 7).

Table 6. Food grain production (Mt) and fertilizers consumption (Mt) in India

Year	Production (Mt)	N	P	K	Total
1999-00	209.8	11.59	4.80	1.68	18.07
2000-01	196.81	10.92	4.22	1.57	16.71
2001-02	212.85	11.31	4.38	1.67	17.36
2002-03	174.77	10.47	4.02	1.60	16.09
2003-04	213.19	11.08	4.12	1.60	16.8
2004-05	198.36	11.71	4.62	2.06	18.39
2005-06	208.6	12.72	5.20	2.41	20.33
2006-07	217.28	13.77	5.54	2.34	21.65
2007-08	230.78	14.42	5.52	2.64	22.58
2008-09	234.47	15.09	6.51	3.31	24.91
2009-10	218.11	15.58	7.27	3.63	26.48
2010-11	244.78	16.56	8.05	3.51	28.12
2011-12	259.8	17.30	7.91	2.58	27.79
2012-13	257.1	16.82	6.66	2.61	26.09
2013-14	264.8	17.02	5.65	2.06	24.73

Source: Ministry of Agriculture, GOI (2014-15)

Table 7. All India consumption trend of fertilizers nutrients

Year	Nitrogen (N)	Phosphorus (P_2O_5) '000 tonnes	Potassium (K_2O)	$N+P_2O_5+K_2O$ (Kg/ha)	N:P:K
1960-61	212	53	29	1.9	7.3:1.8:1.0
1970-71	1479	514	2366	13.9	6.3:2.2:1.0
1980-81	3678	1214	624	31.8	5.9:1.9:1.0
1990-91	7997	3221	1328	67.6	6.0:2.4:1.0
2000-01	11310	4372	1667	90.2	6.8:2.6:1.0
2007-08	14419	5514	2636	115.7	5.5:2.1:1.0
2008-09	15090	6506	3312	127.7	4.6:2.0:1.0
2009-10	15580	7274	3632	135.8	4.3:2.0:1.0
2010-11	16890	8001	3391	145.0	5.0:2.4:1.0
2011-12	17300	7914	2575	142.3	6.7:3.1:1.0
2012-13	16820	6653	2062	130.8	8.2:3.2:1.0
2013-14	17018	5645	2057	126.6	8.3:2.7:1.0

Source: Indian journal of fertilizers (2014)

Data on balance sheet of nutrients (Table 8) clearly indicates that about 8-10 Mt of N, P and K is mined annually in India.

Soils are also being depleted of secondary and micronutrient. Thus, from single plant nutrient deficiencies in the past, Indian soils are currently witnessing multi-nutrient deficiencies. To meet food grains requirement of 300 Mt by 2025, 45 Mt of $N+P_2O_5+K_2O$ is estimated to be required per annum. Out of this 35 Mt is proposed to be met from the chemical fertilizers and the rest from organic manures (Prasad 2012).

Nutrient use efficiency

Soil tests, environmental and climatic data, and production goals determine the uses of the nutrients in a system (Singh 2012). Hence application of nutrients at the right rate, right time and in the right place is the best management practice for achieving optimum nutrient efficiency (Robert 2008). An effective nutrient management involves development of site specific nutrient recommendations including balanced NPK doses, timely application of fertilizers using appropriate methods, development and production of slow-release nitrogen

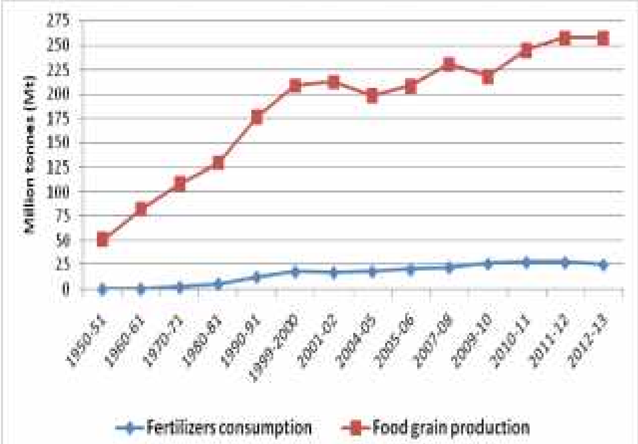


Fig 3. Food production and fertilizers consumption (Mt) trend

Table 8. Balance sheet of NPK in India

Nutrient	Gross balance sheet (Mt)			Net balance sheet (Mt)*		
	Addition	Removal	Balance	Addition	Removal	Balance
N	10.9	9.6	1.3	5.5	7.7	-2.2
P_2O_5	4.2	3.7	0.5	1.5	3.0	-1.5
K_2O	1.4	11.6	-10.2	1.0	7.0	-6.0
Total	16.5	24.9	-8.4	8.0	17.7	-9.7

*The net values were arrived at by adjusting nutrient use efficiency (52% for N, 35% for P_2O_5 and 70% for K_2O). This also included residual effects on the removal side, this was taken as 80% of crops uptake for N, P and 60% for K. Source: Prasad (2012).

Table 9. Nutrient use efficiency in India

Nutrient	Efficiency (%)
Nitrogen	30-50
Phosphorus	15-20
Potassium	70-80
Sulphur	8-12
Zinc	2-5
Iron	1-2
Copper	1-2

Source :Tiwari (2002)

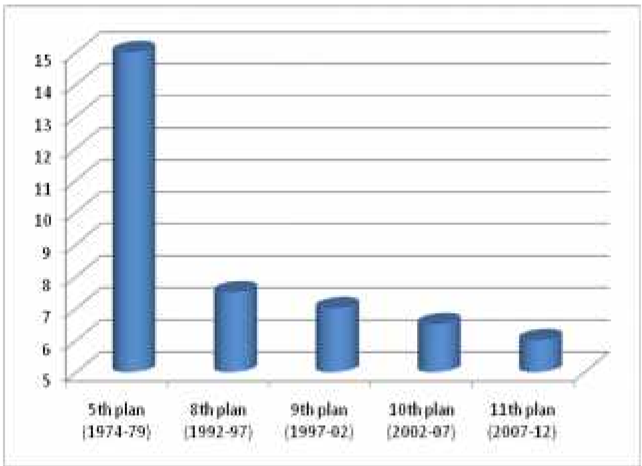


Fig 4. Trend in response ratio in plan periods

fertilizers and nitrification inhibitors and developing and practicing an integrated plant nutrient supply system.

Response ratio, measured as kg grain produced per kg NPK use declined from 15.0 during 5th plan (1974-79) through 7.5 in 8th plan, 7.0 in 9th plan and 6.5 in 10th plan to 6.0 during 11th plan (2007-12) as demonstrated in Fig. 4.

Nutrient use efficiency given in Table 9 clearly indicates that use efficiency of micronutrients is very low. Nitrogen use efficiency has also shown declining trend over a period of time while in various other countries the use efficiency is improving (Table 10).

Nutrient deficiency in Indian soil

As a resulted of green Revolution, deficiencies of micronutrients from different parts of country have been reported at time to time (Nene 1965; Takkar and Nayyar 1981 and Takkar and Randhawa 1978). Growing of high yielding varieties use of high analysis NPK fertilizers, increase in irrigated areas and increase in cropping intensity catalysed the depletion of the finite reserves of micronutrients (Rattan et al. 2009). As a consequence, deficiencies of micronutrients have been on the rise one by one in the country over last four decades (Fig. 5).

It is thus important that to achieve desired yield of different crops, their nutrient requirement including major and micronutrients may be met out through different sources such as inorganic fertilizers and organic sources. It is thus apparent that to achieve production levels, there is a need of use of nutrients in integrated manner through different sources.

Integrated nutrient management

What is INM concept

Integrated nutrient management system (INMs) is a concept which aims at the maintenance of soil fertility, and plant nutrient supply in an optimum amounts for sustaining soil health and crop productivity through optimization of the befits from all possible sources of plant nutrients in an integral manner. The three main components of INMS as defined by FAO (1998) are:

1. Maintain or enhance soil productivity through a balanced use of fertilizers combined with organic and biological sources of plant nutrients.
2. Improve the stock of plant nutrients in the soils
3. Improve the efficiency of plant nutrients, thus,

Nutrients							
Mo						Mo	Mo
B					B	B	B
Mn				Mn	Mn	Mn	Mn
S				S	S	S	S
K			K	K	K	K	K
Zn			Zn	Zn	Zn	Zn	Zn
P			P	P	P	P	P
Fe		Fe	Fe	Fe	Fe	Fe	Fe
N	N	N	N	N	N	N	N
Year	1950	1960	1970	1980	1985	1990	2005

(Source : Rattan et al. 2009)

Fig 5. Progressive expansion in the occurrence of nutrient deficiency in India

Table 10. Change in nitrogen use efficiency in different countries in relation to time

Country	Year	Nitrogen use efficiency	Change (%)	Rate of change (% per year)
India	1970	60	-	-
	2004	20	- 60	-1.7
USA	1980	42	-	-
	2000	57	+ 36	+1.6
U K	1981-85	36	-	-
	2001-02	44	+ 23	+1.1
Japan	1985	57	-	-
	2001	75	+ 32	+1.8

*Indian Journal of Agronomy, June, 2009

limiting losses to the environment.

There are micro-and secondary nutrient deficiencies which generally remain unattended, and covering their importance of collective use of manures and fertilizers for sustainable crop production has been tested and proven through long term experiments. The results showed that with regular application of recommended doses of NPK, productivity stagnated or declined after initially increasing for 5-6 years Nambiyar (1995). Combining application of fertilizers and manures unfailingly sustained productivity. Hence, to enhance soil productivity and lost fertility, a renewed but vigorous emphasis on integrated application of natural nutrient sources and chemical fertilizers is necessary. The results of numerous field experiments in different parts of India have, indicated "fertilizer-induced un sustainability of crop productivity.

The integrated nutrient supply including the use of chemical fertilizers with organic sources like green manure, FYM, crop residues, biofertilizers, helps not only in bridging the existing wide gap between the nutrient removal and addition but also in ensuring balanced nutrient proportion, in enhancing nutrient response efficiency, and in maximizing crop productivity of desired quality.

Integrated nutrient management strategies for sustainable food security and livelihood

Adequate plant nutrient supply holds the key to improving the food grain production and sustaining livelihood. Nutrient management practices have been developed, but in most of the cases farmers are not applying fertilizers at recommended rates. They feel fertilizers are very costly and not affordable and also there is a risk particularly under dry land conditions. Therefore, INM plays an important role which involves integrated use of organic manures, crop residues, green manures, biofertilizers etc. with inorganic fertilizers to supplement part of plant nutrients required by various cropping systems and thereby fulfilling the nutrient gap.

Response of nutrients to crops under different cropping system

Maize - wheat system

Maize and wheat yield presented in table 11 is based on the average of data recorded for the years (1994-2012). It has been found that crop response to N, P, K and FYM enhanced at both the centers with the passage of time. The yield responses to FYM added alongwith 100% NPK compared with 100% NPK alone application was also found to increase over the years. This clearly demonstrates beneficial effect of conjoint application of inorganic + organic manure.

Pearlmillet -mustard system

Aapplication of only N resulted in marginal increase in yield of both the crops over control (Table 12), however, inclusion of P increased the yield of pearlmillet to the tune of 10 quintal and that of mustard 3 quintal. Inclusion of K further increased the yield of both the crops. Beneficial effect of incorporation of FYM with NPK

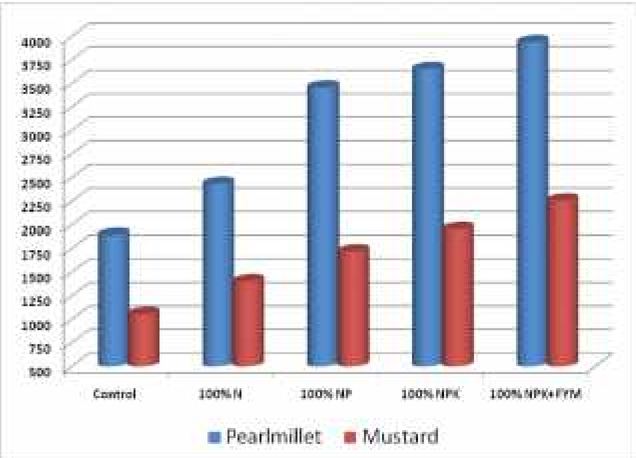


Fig 6. Productivity of peralmillet and mustard as affected by different treatments at Gwalior

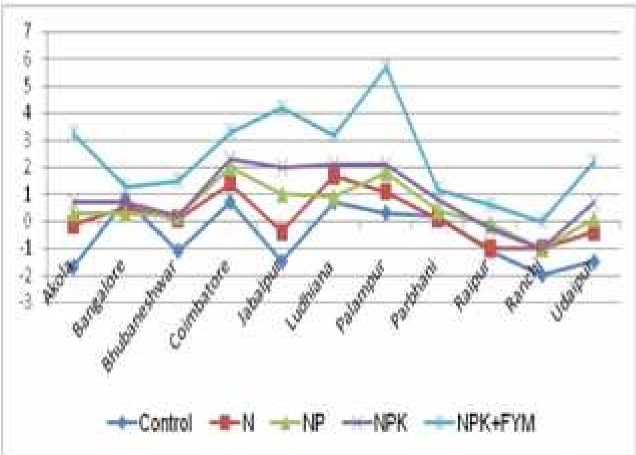


Fig 7. Changes in organic carbon (g kg^{-1}) in different location of India from initial status under different nutrient treatments

recorded for pearlmillet and mustard clearly indicate that for sustainability of these crops optimum NPK+FYM is required (Fig. 6).

Soybean -wheat system

Data of soybean -wheat system at Rachi and Jabalpur (Table 13) indicated that application of N showed drastic adverse effect on the productivity of soybean and wheat, this treatment even produced lower yield than control. Integration of P with N resulted increase in yield of soybean to a very low magnitude. However, it enhanced the yield of wheat to the extent of 20 q ha^{-1}. This may be due to non availability of K because of shallow root system of soybean, whereas wheat root goes as deeper as 1 m and it appears it absorbs K from lower layer, which is evident by the fact that application of K increased soybean yield. Incorporation of FYM with NPK resulted in the increase in yield of both the crops.

Soil organic carbon

Soil organic carbon is regarded as the constituent of soil which governs soil health and nutrient availability. Table 14 reveals that balanced application of nutrients alone and in combination with FYM increased the SOC content compared to initial. It is evident from the results that the treatments which produced higher yield also showed increasing trend of SOC, it is because of more incorporation of large amount of biomass of roots stubbles

Table 11. Mean yield (1994-2012) of maize and wheat in Inceptisol of New Delhi

Treatments	Maize		Wheat	
	New Delhi	Udaipur	New Delhi	Udaipur
Control	1220	1696	2350	1815
100% N	1750	2358	3370	3041
100% NP	2040	2802	4150	3640
100% NPK	2460	3087	4630	3986
100% NPK+FYM	2760	3543	5020	4562

Table 12. Mean yield (2003-2015) of pearlmillet and mustard in Inceptisol of Gwalior (MP)

Treatments	Yield (kg ha^{-1})		
	Pearlmillet	Mustard	Peralmillet + Mustard
Control	1894	1057	2951
100% N	2434	1404	3838
100% NP	3458	1722	5180
100% NPK	3653	1954	5607
100% NPK+FYM	3938	2257	6195

Table 13. Mean yield of soybean and wheat

Treatments	Yield (kg ha^{-1})					
	At Ranchi			At Jabalpur		
	Soybean	Wheat	Soybean+Wheat	Soybean	Wheat	Soybean+Wheat
Control	579	720	1299	975	1503	2478
100% N	296	420	716	1250	1909	3159
100% NP	863	2490	3353	1900	4644	6544
100% NPK	1567	2800	4367	2161	5703	7864
100% NPK+FYM	1911	3340	5251	2470	6191	8661

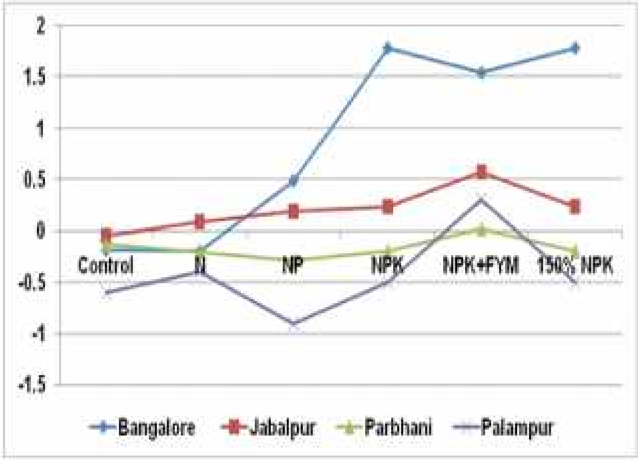


Fig 8. Changes in available Zn (mg kg^{-1}) from initial status under different nutrient treatments

and leaves. Increase or decrease in SOC with respect to control is depicted in Fig. 7.

Micronutrient deficiency

Amongst the micronutrients, deficiency of zinc is wide spread particularly in MP, it is therefore most widely applied nutrient continuous absence of zinc in fertilizer schedule resulted decline in available status compared to initial. Zinc status found to be less in low yielded plots (control, 100% N and 100% NP) compared to 100% NPK and 150% NPK. This is due to addition of larger root biomass as a result of higher productivity which on decomposition mobilized Zn from soil. Application of FYM with NPK also improved the status of zinc in soil (Table 15). Changes in available Zn in compression to initial content are shown in Fig 8.

Table 14. Effect of nutrient management on soil organic carbon (g kg^{-1}) in different location of India

Location	Soil organic carbon (g kg^{-1})					
	Initial	Control	N	NP	NPK	NPK+FYM
Akola	4.6	2.9	4.5	4.9	5.3	7.85
Bangalore	4.5	5.3	5.0	4.8	5.2	5.8
Barrackpore	-	5.5	5.9	6.4	6.3	8.2
Bhubaneshwar	4.3	3.2	4.4	4.5	4.5	5.8
Coimbatore	3.0	3.7	4.4	5.0	5.3	6.3
Jabalpur	5.7	4.2	5.3	6.7	7.7	9.9
Jagtial	7.9	8.1	8.0	8.2	8.4	10.8
Junagarh	-	6.2	6.7	7.8	7.7	-
Ludhiana	2.2	2.9	3.9	3.1	4.3	5.4
Palampur	7.9	8.2	9.0	9.7	10.0	13.6
Parbhani	5.5	5.7	5.6	5.9	6.3	6.7
Pattamlir	-	11.9	13.7	14.4	14.5	17.8
Raipur	6.2	5.1	5.2	6.1	5.9	6.8
Ranchi	5.0	3.0	4.0	4.0	4.0	5.0
Udaipur	6.8	5.3	6.4	6.9	7.5	9.0

Source: Annual report (2012-13) AICRP on LTFE published by IISS, Bhopal

Table 15. Effect of cropping and nutrients on available Zn status (mg kg^{-1}) of soil at different centers of LTFE

Location	Available Zn (mg kg^{-1})						
	Initial	Control	N	NP	NPK	NPK+FYM	150% NPK
Bangalore	2.34	2.16	2.15	2.83	4.12	3.88	4.12
Jabalpur	0.33	0.28	0.42	0.52	0.56	0.90	0.56
Parbhani	0.98	0.85	0.78	0.70	0.79	1.00	0.79
Palampur	1.90	1.30	1.50	1.00	1.40	2.20	1.40
Akola	-	0.35	0.38	0.47	0.70	0.98	0.70

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Potential of carbon sequestration in soils under different agro-ecosystems of India

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Abstract

Globally soil organic matter (SOM) contains more than three times as much carbon as either the atmosphere or terrestrial vegetation. Rapidly rising concentration of atmospheric CO_2 has prompted studies on soils as potential C sinks. However, currently, there is much uncertainty and debate as to the total potential of soils to store additional carbon, the rate at which soils can store carbon, the permanence of this carbon sink, and how best to monitor changes in soil carbon stocks. Vast areas of land in arid, semi-arid and drier part of sub-humid eco-regions of the country are considered to be the prioritized areas for SOC management and restoration. Positive effect of balanced fertilization and integrated nutrient management in SOC sequestration potential and efficiency have also been highlighted in light of results obtained in long-term fertilizer experiments. Given that many mitigation options in the agricultural sector have numerous co-benefits in terms of food security, environmental sustainability and farm profitability, governmental policies that promote adoption of the best management practices should be pursued regardless of whether soil C sequestration mitigates GHGs emission and the role agricultural soils play in any C pollution reduction scheme.

Keywords: Soil organic C sequestration, potential, climate change, mitigation

The soil is the largest terrestrial pool of organic carbon as about 1150 Pg compared with about 700 Pg in the atmosphere and 600 Pg in land biota (Lal and Kimble 1997). Historically, approximately 78 Pg C has been lost from the global soil pool due to land-use conversion for agriculture with approximately 26 Pg attributed to soil erosion and 52 Pg attributed to mineralization (Lal 2004a). Conversion of native forest and pasture to crop land has been found to reduce SOC stocks by an average of 42% and 59%, respectively (Guo and Gifford 2002). These large historic losses and the concomitant potential to return to preclearing SOC conditions are precisely the reason many researchers believe there is great potential for agricultural soils to sequester large amounts of atmospheric CO_2 relative to current SOC levels. The global potential of soil organic carbon sequestration is estimated at 0.6 to 1.2 Gt C year^{-1}, comprising 0.4 to 0.8 Gt C year^{-1} through adoption of recommended management practices on cropland soils, 0.01 to 0.03 Gt C year^{-1} on irrigated soils, and 0.01 to 0.3 Gt C year^{-1} through improvements of rangelands and grasslands (Lal 2004a).

There is widespread interest in increasing soil carbon content in many of the world's agro-ecosystems, and India is no exception to that. Whilst soils are the largest sink for terrestrial carbon, the capacity of soils to 'store' stabilized carbon in the longer term is compromised substantially due to practices that either accelerate the loss of soil organic matter (SOM) or limit its formation and retention. Declines of some 50-75% of the original total SOM content of soils due to land use changes (i.e., 60 Mg C ha^{-1}) are common (Lal 2004a). Rebuilding the 'lost' soil carbon is a high priority for agricultural and practitioners and policy makers not only as an effective means to mitigate climate change but also to reinstate benefits to plant health and ecosystem services derived from SOM, including soil physical structure, fertility-nutrients and water, and beneficial root-soil-microbe interactions (Schmidt et al. 2011).

The great majority of agronomists and soil scientists agree that most agricultural soils can store more carbon and even a modest increase in carbon stocks across the agro-ecosystem would lead to a significant GHG mitigation. However, currently, there is much uncertainty and debate as to the total potential of soils to store additional carbon, the rate at which soils can store carbon, the permanence of this carbon sink, and how best to monitor changes in soil carbon stocks. It is very important to think that this technical carbon sequestration potential may not be fully realized due to a host of economic, social and political constraints besides management and climate issues. Also, important agro-ecosystem for prioritized soil C sequestration and their potentials, soil C management strategies have also been discussed.

Soil carbon and its importance

The importance of soil organic carbon (SOC) in sustaining productivity is well known. Organic carbon (OC) serves as soil conditioner, nutrient source, substrate for microbial activity, preserver of the environment and the major determinant for sustaining or increasing agricultural productivity (Schnitzer 1991). Soil contains large amounts of carbon in both organic and inorganic forms. Organic C is found in soils in the form of various organic compounds, collectively called soil organic matter (SOM). Globally, the top one metre of soil stores approximately 1500 Pg as organic C and an additional 900-1700 Pg as inorganic C (mostly carbonates) and exchanges 60 Pg C yr^{-1} with the atmosphere, which contains ~750 Pg C as carbon dioxide (CO_2) (Eswaran et al. 1993; Schlesinger 1997). The sheer size of the soil carbon pool and the annual flux of carbon passing through the soil are two of the reasons that SOC can play a significant role in mitigating GHG emissions.

Organic matter is the vast array of carbon compounds in soil. Originally created by plants, microbes, and other organisms, these compounds play a variety of roles in nutrient, water, and biological cycles. For simplicity, organic matter can be divided into two major categories: stabilized organic matter which is highly decomposed and stable, and the active fraction which is being actively used and transformed by living plants, animals, and microbes. The amount of soil organic carbon (SOC) in soil depends on soil texture, climate, vegetation and historical as well as current land use/management. Soil texture affects SOC because of the stabilizing effect of clay on soil organic matter (SOM). Organic matter can be trapped in the very small spaces between clay particles making them inaccessible to micro-organisms and therefore slowing decomposition. In addition, clay offers chemical protection to organic matter through adsorption on clay surfaces, which again prevents organic matter from being decomposed by bacteria. Soils with high clay content therefore tend to have higher SOC than soils with low clay content under similar land use and climate conditions. Climate affects SOC amount as it is a major determinant of the rate of decomposition and therefore the turnover time of C in soils. In temperate grassland, high organic matter inputs combined with slow decomposition rates (determined by climate) lead to high SOC amounts, whereas in tropical areas, decomposition and the turnover of SOC tend to be faster, which resulted in poor buildup of soil organic matter (SOM).

Factors of soil carbon sequestration

The amount of soil C storage is controlled primarily by two fundamental factors: input by net primary production (its quantity and quality) and its decomposition rate. Decomposition of native organic matter in soil is mainly governed by soil microbes, with about 10-15% of the energy of organic C utilized by soil animals (Wolters 2000). Evolution of CO_2 during decomposition of organic matter is chiefly regulated by soil moisture and temperature. Under the temperate environment, it is governed mostly by soil temperature whereas under the tropical environment it is affected more by soil moisture availability. Sollins et al. (1996) presented a conceptual model of the processes by which plant leaf and root litter is transformed to soil organic C and CO_2. Stability of the organic C in soil is the result of three general sets of characteristics. Recalcitrance comprises molecular-level characteristics of organic substances, including elemental composition, presence of functional groups, and molecular arrangement, that influence their degradation by microbes and enzymes. Interactions refers to the inter-molecular interactions between organics and either inorganic substances or other organic substances that alter the rate of degradation of those organics or synthesis of new organics. Accessibility refers to the location of organic substances with respect to microbes and enzymes. Depending upon how soil is managed, it can serve as a source or sink for atmospheric carbon dioxide (CO_2). As the atmospheric CO_2 concentration continues to increase globally, more attention is being focused on the soil as a possible sink for atmospheric CO_2. Carbon storage and sequestration in agricultural soils is considered to be an important issue.

Carbon sequestration in agricultural soils has three situations i.e potential, attainable and actual. Ingram and Fernandes (2001) conceptually defined this terminology while describing carbon sequestration situation in agricultural soils. But till now, we could not come across any methodology by which attainable carbon content of soil could be determined. Mostly it is determined by using the different process based or empirical C models. The actual condition of soil carbon is easily accessed by determining carbon content in laboratory. The potential of soil carbon sequestration could be very high but it could not be attained due to several other limitations. SOC potential is the soil carbon level that could be achieved under non-limiting condition other than soil type. The term "Attainable" is defined as more pragmatic for carbon sequestration in mineral soils, being more relevant to management than "potential" and thereby of greater practical value (Ingram and Fernandes 2001). Surface area of clays and other minerals influences organic C that can be protected against decomposition. In order to attain SOC potential, C inputs from plant must exceed the C protective capacity of a soil and offset losses due to decomposition. The attainable soil C sink capacity is generally 50 to 66% of the potential capacity (Lal 2004 a & b). Under dry land conditions (no irrigation) these factors limit the amount of residue that can be added to a soil. The value of SOC attainable is the best scenario for any production system. Decreased productivity, induced by the reducing factors, leads to lower returns of organic carbon to soil and lower actual organic carbon contents (SOC actual) (Badlock 2008). Invariably, a dryland/arid ecosystem has less net primary productivity than the irrigated/ humid eco-system, which ultimately governed the net carbon input to the soil. Followed by this, it is the ability of soil to stabilize/ decompose the carbon coming to it. Furthermore, net carbon input to the soil depends on type of land use followed in the region.

Major portion of SOC is retained through clay-organic matter complex formation, indicating the importance of inorganic part of the soil as a substrate to build the SOC (Pal et al. 2014). Smectites and vermiculites have the largest specific surface area, and are capable of accumulating greater amounts of OC than the non-expanding minerals. It, however, is paradoxical that smectitic Vertisols of India of the arid and semi-arid climates are low in OC content (0-30 cm depth). The OC in clayey, smectitic Vertisols (Haplusterts) decreases rapidly from humid to arid ecosystem, despite that they possess large surface area and bulk density (Pal et al. 2003; Goswami et al. 2000).

The importance of expanding 2:1 clay minerals in the accumulation of SOC is well demonstrated in the ferruginous red soils (Alfisols and Ultisols) of north-eastern, eastern, western and southern parts of the country. Studies indicate that even in the Ultisols of Kerala (Chandran et al. 2005) and Meghalaya in the north-eastern regions of India (Bhattacharya et al., 2000), the presence of smectite and/or vermiculite either in the form of interstratifications with 0.7 nm mineral or in a discrete mineral form is quite common. The presence of these minerals favours the accumulation of OC in the soil. Therefore, besides the dominating effect of humid climate with cooler winter months with profuse vegetation, the soil substrate quality (quality and quantity of expanding clay minerals) is of fundamental importance in the sequestration of OC in the soil (Swift 2001).

The amount of carbon present in the soil is the function of land use change, soil type, climate (rainfall and temperature) and management practices. The potential of soil for carbon sequestration could be very high provided all the other conditions/factors should be favourable for that. Furthermore, while defining potential we hardly take into account of soil factors which fundamentally determine carbon storage. Regardless of potential, the amount of carbon a soil can actually capture is limited by factors such as climate, soil and can be reduced further due to poor soil fertility, occurrence of insect pest and disease incidence.

Another important factor for C stabilization and sequestration is level of C saturation in soil in a given soil-crop-climate situation. Saturation refers to the maximum level of C that a particular soil will be able to retain as stabilized SOM based on the physicochemical properties of the soil (Six et al. 2002; Stewart et al. 2007) with additional increases in inputs remaining as unprotected POM that will be rapidly cycled back to the atmosphere (Stewart et al. 2008). While the idea of C saturation is conceptually and theoretically appealing, the idea is yet to be proved with datasets from long-term agricultural experiments across the globe. However, Stewart et al. (2008) found evidence for saturation in several but not all mineral-associated C pools defined by a physical and chemical fractionation scheme (Six et al. 1998). Reactive mineral surface area is a finite resource, especially in top soils, thus this is the stabilization mechanism which would likely exhibit saturating behaviour. If soils do indeed have a defined carbon saturation level, then similar management practices may result in positive sequestration in one soil that is far from its maximum C stabilization level, while no change in another soil that is much closer to its saturation value (Six et al. 2002). Conversely, it has got a wide ramification in loss of C depending upon the level of soil C saturation. Carbon saturation may be particularly important for understanding the long-term sequestration potential of input intensive practices, such as, manuring and other forms of organic matter amendment.

Soil C stock in different agro-ecological zones of India

Soil organic carbon stocks in upper 30 and 150cm depth of Indian soils are 4.72 and 4.77% of the tropical regions and about 1.4 and 1.2% of the total carbon mass of the world, respectively, although the soils of India cover nearly 11% of the total area of the world. The share of Indian soil in SOC stock as compared to that of the world is not substantial because of less area in Indian soils being under organic matter rich soils like Histosols, Spodosols, Andosols, Mollisols and Gelisols (Pal et al. 2014). The C stocks for Indian soil in terms of each soil order is estimated at 0-30 and 0-150cm depths since such quantitative data reflect the kinds of soil with different amount of organic (SOC), inorganic (SIC) and total carbon (TC) (Table 1). As per this estimate, the SOC stocks of Indian soils in 0-30 and 0-150cm depth are 9.55 and 29.92Pg, respectively, while the SIC stocks are 4.14 and 33.98Pg, respectively. The data clearly reflect that SOC and SIC contents follow a reverse trend with depth (Bhattacharyya et al. 2000). Indian soils classified under Inceptisols, contribute about 23 and 19% of the total SOC stock in upper 30 and 150cm depths, respectively, while Entisols contribute nearly 6 and 8% of the total SOC stock of Indian Soils. Vertisols, extensive in the central and southern part of India, contribute 27 and 29% of the total SOC in upper 30 and 150cm depths, respectively. Aridisols are in general poor in organic carbon due to their high rate of decomposition, low rate of plant growth and contribution to SOC (8 and 7%). The Indian Mollisols contribute nearly 1 and 2% of the total SOC stocks due to the fact that only a small portion of geographical area of the country is covered by these soils. Most of Alfisols occur in sub-humid to humid regions of the country and contribute about 33 and 32% of the total SOC stocks in 0-30 and 0-150cm depths, respectively. Ultisols occupying small area contributed nearly 2% of the total SOC stock in both depths. Also poor accumulation of SOC in Oxisols is due to greater decomposition in tropical humid regions. The relative contribution of SOC and SIC stock to the total stock in 0-30 cm depth is 71 and 29% respectively. However, in the 0-150 cm soil depth, the contribution of SOC is 47 and 53%, respectively (Bhattacharyya et al. 2000).

Maximum amount of SOC stocks is in surface of hot arid to semiarid regions covering agro-ecoregions of 2, 4, 6, 5, 7, and 8 followed by cold arid agro-ecoregions (1 and 3), and hot sub humid regions 9 to 15 (Table 2). The SOC stock in agro-ecoregions of 16 to 20 is comparatively less than those of arid and semiarid regions. Aridisols are in general poor in organic carbon due to their high rate of decomposition, low rate of plant growth and contribution to SOC. However, a few arid soils belonging to cold (Typic Camorthids) as well as hot (Typic Camorthids/ Natragids/Calciorthids) and arid ecosystem contribute substantially to the total SOC stock mainly because of large areas occupied by them (Bhattacharyya et al. 2000).

Carbon sequestration potential of Indian soil

SOC stocks in different agro-regions of the country may not help in identifying areas for C sequestration

Table 1. Carbon stock distribution in Indian soils

Soil order	Soil depth	Carbon stock (Pg = 1015 g)		
		SOC	SIC	TC
Entisols	0-30	0.62 (6)	0.89 (21)	1.51 (11)a
	0-150	2.56 (8)	2.86 (8)	5.42 (8)
Vertisols	0-30	2.59 (27)	1.07 (26)	3.66 (27)
	0-150	8.77 (29)	6.14 (18)	14.90 (23)
Inceptisols	0-30	2.17 (23)	0.62 (15)	2.79 (20)
	0-150	5.81 (19)	7.04 (21)	12.85 (20)
Aridisols	0-30	0.74 (8)	1.40 (34)	2.14 (16)
	0-150	2.02 (7)	13.40 (39)	15.42 (24)
Mollisols	0-30	0.09 (1)	0.00	0.09 (1)
	0-150	0.49 (2)	0.07 (0.2)	0.56 (1)
Alfisols	0-30	3.14 (33)	0.16 (4)	3.30 (24)
	0-150	9.72 (32)	4.48 (13)	14.20 (22)
Ultisols	0-30	0.20 (2)	0.00	0.20 (1)
	0-150	0.55 (2)	0.00	0.55 (1)
Total	0-30	9.55	4.14	13.69
	0-150	29.92	33.98	63.90

Source: Pal et al. (2014)

without considering other factors like a real extent of the soil type, C content in soil profile, depth and bulk density of soils. Even with a relatively small SOC content (0.2-0.3%), the SOC stock of arid and semi-arid soils indicates a high value due to large area under dry regions (Pal et al., 2014). Bhattacharyya et al. (2008) observed that vast areas of lands in arid (AESRs), semi-arid and drier part of sub-humid (AESRs 4.1-4.4, 5.1-5.3, 6.4, 7.1-7.3, 8.1-8.3, 9.1-9.2, 10.1-10.4) of India are impoverished in SOC, but are high in SIC up to 30 cm depth. These specified areas are the prioritized ones for OC management in soil. These areas cover 155.8 m ha of which, arid areas cover 4.9, semi-arid 116.4 and dry sub-humid 34.5 m ha.

Long-term fertilizer experiments (LTFEs) provide opportunities for assessing long-term changes in SOC and estimating C sequestration potential (CSP) of agricultural lands (Powlson et al. 1986; Ladha et al. 2003). Using the data from these LTFEs, estimates of C sequestration were carried out by some researchers (Swarup et al. 2000; Lal 2004 (a & b).; Manna et al. 2005; Mandal et al. 2007, 2008). Very recently, Pathak et al. (2011) estimated C sequestration potential of Indian soils under different cropping systems using long-term experiments at different agro-ecoregions. The C sequestration was calculated only in terms of increase in C stocks in soil in NPK and NPK+FYM treatments in reference to unfertilized control (Table 3). Carbon sequestration potential (CSP), i.e., increase in soil C stock in a treatment compared of reference treatment in different scenarios varied in the order of CSP_FYM> CSP_INM>CSP_NPK. In the CSP_FYM scenario average CSP was 4.93 Mg C ha^{-1} followed by CSP_INM and CSP_NPK scenarios with CSP of 2.78 Mg C ha^{-1} and 2.15 Mg C ha^{-1}, respectively (Table 3). Carbon sequestration in CSP_NPK scenario denoted that even without any organic matter application soils could sequester organic carbon through balanced application of NPK. But application of FYM along with inorganic fertilizer led to an additional build up of SOC in soil. Average rate of sequestration was 0.33 Mg C ha^{-1} yr^{-1} in the NPK +FYM treatment whereas in the NPK treatment the rate was 0.16 Mg C ha^{-1} yr^{-1} (Pathak et al. 2011).

Lal (2004b) computed carbon sequestration potential of Indian soils by assuming converting degraded soils to restorative land use and estimated total potential of 39 to 49 (44 ± 5) Tg C yr^{-1}. According to him, Indian soils have considerable potential of terrestrial/soil carbon sequestration. He estimated the soil organic carbon (SOC) pool of 21 Pg to 30-cm depth and 63 Pg to 150-cm depth. The SOC concentration in most cultivated soils is less than 5 g kg^{-1} compared with 15 to 20 g kg^{-1} in uncultivated soils. Low SOC concentration in soil is attributed to plowing, removal of crop residue and other bio-solids, and mining of soil nutrients. Accelerated soil erosion by water leads to emission of 6 Tg C yr^{-1}. Important strategies of soil C sequestration include restoration of degraded soils, and adoption of recommended best management practices (BMPs) of agricultural and forestry soils. Potential of soil C sequestration in India is estimated at 7 to 10 Tg C yr^{-1} for restoration of degraded soils and ecosystems, 5 to 7 Tg C yr^{-1} for erosion control, 6 to 7 Tg C/y for adoption of BMPs on agricultural soils, and 22 to 26 Tg C yr^{-1} for secondary carbonates.

Strategies for soil carbon management

In general, any change in management that increases inputs and/or reduces losses should build SOC stocks

Table 2. Soil organic and inorganic carbon stock (0-30 cm) in different bioclimatic zones in India

Bio-climatic zone	Area coverage		SOC		SIC		TC		Stock per unit area ($Pg\ m^{-1}\ ha^{-1}$)	
	m ha	% of TGA	Stock (Pg)	% of SOC stock	Stock (Pg)	% of SIC stock	Stock (Pg)	% of TC stock	SOC	SIC
Cold arid	15.2	4.6	0.6	6	0.7	17	1.3	10	0.39	0.046
Hot arid	36.8	11.2	0.4	4	1.0	25	1.4	10	0.011	0.27
Semi-arid	116.4	35.4	2.8	30	2.0	47	4.8	35	0.025	0.016
Subhumid	105.0	31.9	2.4	26	0.33	8	2.73	20	0.024	0.003
Humid to perhumid	34.9	10.6	2.0	21	0.04	1	2.04	15	0.060	0.001
Coastal	20.4	6.2	1.3	13	0.07	2	1.37	10	0.064	0.033

Source: Pal et al. (2014)

especially in soils that have lost significant quantities of SOC relative to preclearing conditions. Management changes may be broadly classified into following categories: i) management for increased yields; ii) tillage and residue management; iii) crop rotation and crop cover; iv) pasture and grazing management; v) conversion of agricultural land; vi) offsite organic matter additions; and vii) alternative farming systems.

Long-term fertilizer experiments conducted over 30-35 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. However, 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. The nutrient removal was 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.

In a global meta-analysis of long-term agricultural experiments, West and Post (2002) found that the mean relative sequestration rate for conversion of conventional tillage (CT) to no-till (NT) was 0.57 ± 0.14 Mg C ha^{-1} yr^{-1} and a new equilibrium was reached in 15-20 years, with 75% of the studies showing increased SOC stocks. However, Baker et al. (2007) argued that sampling depth protocol has biased these tillage trial results. These researchers found that 37 of 45 studies with sampling depth <30 cm reported positive results in NT trials, while 35 of 51 studies with depths >30 cm reported losses. This issue underscores the need for accurate measurement of bulk density and sampling based on equivalent mass instead of similar depths (Dalal and Mayer 1986; Gifford and Roderick 2003; Wuest 2009)

Alternate land use systems, viz., agro-forestry, agro-horticulture, and agro-silviculture, are more remunerative for SOC restoration as compared to sole cropping system. In northeast hill states of India, where all the above three land use systems are existed that reduce soil erosion and SOC loss considerably. Lal (2008) enumerated some important points for improving carbon content of terrestrial soil (Table 4).

Future uncertainty in light of climate change and economic factors

The maximum feasible sequestration potential at any given location or agro-ecosystem most likely may never be

Table 3. Potential, rate and efficiency of soil C sequestration in long-term fertilizer experiments

Location	Soil type	Cropping System	C sequestration potential (Mg C ha^{-1})			Rate of C sequestration (Mg C ha^{-1} yr^{-1})			C sequestration efficiency (%)	
			CSP_NPK[a]	CSP_FYM[b]	CSP_INM[c]	CSP_NPK[a]	CSP_FYM[b]	CSP_INM[c]	CSP_FYM[b]	CSP_INM[c]
Palampur	Typic Hapludalf	Maize-Wheat	1.02	11.08	10.07	0.04	0.44	0.40	12.67	11.51
Barackpore	Typic Eutrochrept	Rice-Wheat-Jute	1.88	3.33	1.45	0.07	0.12	0.05	3.40	1.48
Pantnagar	Udic Fluvents	Rice-Wheat	1.46	1.87	0.41	0.10	0.13	0.03	6.05	1.34
Ludhiana	Typic Ustipsamment	Rice-Wheat	0.69	7.45	6.75	0.05	0.50	0.45	28.37	25.72
New Delhi	Typic Haplusept	Maize-Wheat-Cowpea (F)	1.77	11.08	9.30	0.06	0.37	0.31	7.03	5.91
Ranchi	Typic Haplusept	Soybean-Wheat	1.83	2.24	0.41	0.06	0.07	0.01	2.13	0.39
Jabalpur	Typic Haplusept	Soybean-Wheat-Maize (F)	0.43	3.82	3.40	0.02	0.14	0.12	2.60	2.31
Akola	Vertisol	Sorghum-Wheat	3.17	6.87	3.70	0.26	0.57	0.31	16.37	8.82
Coimbatore	Typic Hapludoll	Finger millet-Maize-Cowpea (F)	2.30	4.77	2.47	0.10	0.20	0.10	4.54	2.35
			2.15	4.93	2.78	0.16	0.33	0.17	12.24	6.53

Source: Pathak et al. (2011)
a CSP_NPK, NPK treatment compared to control treatment
b CSP_FYM, NPK + FYM treatment compared to control treatment
c CSP_INM NPK+FYM treatment compared to NPK treatment

realized due to a series of biological, physical, economic, social, and political constraints (Smith et al. 2005). In the absence of best management practices (BMPs) active management, most soils are believed to become net sources of CO_2 to atmosphere primarily due to rising temperatures (Cox et al. 2000; Torn and Harte 2006). The degree to which SOC is lost with rising temperatures will depend on a host of factors and likely vary with agricultural management, but, at a minimum, this will add additional uncertainty into projected soil carbon storage potentials and in the permanence of sequestered soil C. Predicted shifts in regional precipitation patterns (Chiew et al. 1995; Groisman et al. 1999), while less certain than projected temperature changes, will create even more uncertainty in predicting sequestration rates in the future.

Agriculture is a free market enterprise, and if a farmer decides that the current management practices are not maximizing profits or commodity prices significantly change, then he may very well change management which may have significant deleterious effects on newly stored carbon. Richardson et al. (2014) concluded that inorganic nutrients were a 'hidden cost' for sequestration C in SOM and highlight the significant 'hidden nutrient cost' in the long-term sequestering of carbon in SOM through the use of carbon rich crop residues. The 'cost' of these nutrients should therefore ideally be considered in programs aimed at increasing soil carbon content in terrestrial ecosystems and, where possible, be accounted for in various carbon-trading schemes that are being developed across the globe.

Increasing carbon content in the soil, through better management practices, produce a number of benefits in terms of soil biodiversity, soil fertility and soil water storage capacity and hence productivity. Soil carbon sequestration through the restoration of soil organic matter can further reverse land degradation and restore soil "health" through restoring soil biota and the array of associated ecological processes. In particular, through improved soil water storage and nutrient cycling, land use practices that sequester carbon will also contribute to stabilizing or enhancing food production and optimizing the use of synthetic fertilizer inputs, thereby reducing emissions of GHGs from agricultural land. Vast areas of land in arid, semi-arid and drier part of sub-humid eco-regions of the country are considered to be the prioritized areas for SOC management and restoration.

Long-term fertilizer experiments at different agro-ecoregions and other long-term studies have amply proved that balanced fertilization (NPK) and integrated nutrient management (NPK+FYM) have good potential in SOC accumulate C in upper soil layers and sequestration in Indian soils. Conservation agriculture and conservation tillage practices also reduce significantly the use of fuel and hence gaseous emissions, and thus help in C sequestration. Soil carbon sequestration is thus very cost effective and can take effect very quickly. It also constitutes a valuable win-win approach combining mitigation and adaptation, through both increased agro-ecosystem resilience to climate variability, and more reliable and better yields.

Table 4. Terrestrial carbon management options

Management of terrestrial C pool	Sequestration of C in terrestrial pool
Reducing emissions	Sequestering emissions as SOC
* eliminating ploughing	* increasing humification efficiency
* conserving water and decreasing irrigation need	* deep incorporation of SOC through establishing deep rooted plants, promoting bioturbation and transfer of DOC into the ground water
* using integrated pest management to minimize the use of pesticides	
* biological nitrogen fixation to reduce fertilizer use	
Offsetting emissions	Sequestering emissions as SIC
* establishing biofuel plantations	* forming secondary carbonates through biogenic processes
* biodigestion to produce CH4 gas	
* bio-diesel and bioethanol production	
* leaching of biocarbonates into the ground water	
Enhancing use efficiency	
* precision farming	
* fertilizer placement and formulations	
* drip, sub-irrigation or furrow irrigation	

Source: Lal (2008)

Any management practice which results in greater C return to the soil, increased stabilization of soil C, or a reduction in losses should lead to positive SOC sequestration. If the agricultural sector is to be issued credits for sequestering C in the soil as SOC, then a full accounting of all GHG emissions should be required. A full lifecycle analysis will be needed for management practices that involve significant use of offsite additions. However, due to the complex web of factors that govern the C balance of any particular soil, quantitative predictions of SOC sequestration rates will likely always entail a large degree of uncertainty. Given that many mitigation options in the agricultural sector have numerous co-benefits in terms of food security, environmental sustainability and farm profitability, governmental policies that promote adoption of the best management practices should be pursued regardless of the final status of agricultural soils in any carbon pollution reduction scheme.

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Crop residue management: A potential source for plant nutrients

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Abstract

Crop residues generated in India are around 502 million tonne (Mt) out of which 141 Mt residues are available in surplus. The nutrient potential (N, P_2O_5, K_2O) of these crop residues is about 36.89 Mt. But, instead of using it as potential source of plant nutrients, a large portion of the residues (approximately 80-90 Mt) is burnt annually in field mainly to clear the field from straw and stubble after the harvest of the preceding crop. Burning leads to loss of nutrients and green house gas emission, etc. Thus, there is an urgent need of management of crop residues both on-farm as well as off-farm. On-farm management includes conservation agriculture whereas off-farm management points out the importance of composting. The exhaustive review of the crop residues as the potential source for improving soil health vis-a-vis carbon sequestration is presented here.

Keywords: Plant nutrient, Crop residue

Crop residues (CR) have been referred to as "wastes" but also considered to be "potential black gold" as a natural and valuable resource. Soil organic matter (SOM) is one of the primary contributors to soil quality and CR are precursors to SOM. The stems, leaves, chaff and husks that remain in the fields after crops are harvested for grain, seed or fibre, play a critical role in soil quality and environmental issues since they are primary inputs of elemental carbon (C) into soil systems (Fig.1). Crop residue management is a widely used crop land conservation practice as it provides significant quantities of nutrients for crop production. In addition to affecting soil physical, chemical and biological functions and properties, crop residues can also affect water movement, infiltration, runoff and quality. Crop management for maximum residue production requires basic scientific research information regarding site-specific soils, crops and climate. Therefore, the availability of CR in India, major types and their use pattern, adverse effects of CR burning, nutrient potential and its cycling, on-farm and off-farm management of CR, effect of CR on soil health and C sequestration have been dealt herewith and future research needs for efficient residue management.

Availability of CR in India

A huge amount of agricultural residues in produced every year (MNRE, 2009) (Table 1). Among different crops, cereals generate 352 Mt residue followed by fibres (66 Mt), oilseed (29 Mt), pulses (13 Mt) and sugarcane (12 Mt). The cereal crops (rice, wheat, maize, millets) contribute 70% out of which rice crop alone contributes 34% of CR. Wheat ranks second contributing 22% of total residues whereas fibre crops contribute 13% of residues generated from all crops. Among fibres, cotton generates maximum 53 Mt of CR sharing 11% of total

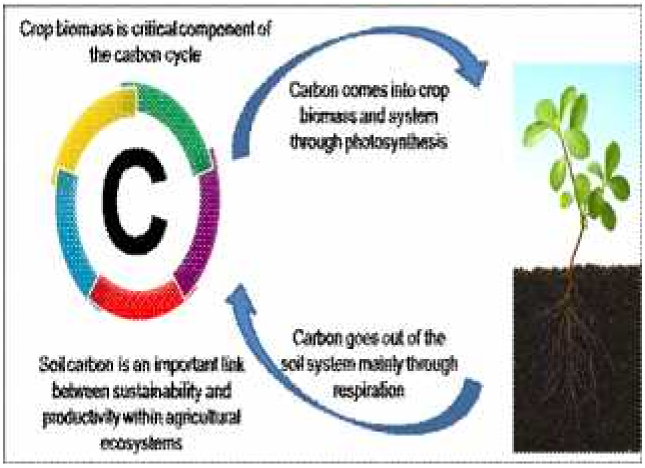

Fig 1. Role of crop biomass in the agricultural ecosystem carbon cycle (Adapted and modified from Reicosky and Wilts 2005)

CRs. Coconut ranks second among fibre crops with 12 Mt of residue generation. Sugarcane residues (tops and leaves) account for 12 Mt i.e., 2% of CRs in India. Highest residue is generated from Uttar Pradesh (53 Mt) followed by Punjab (44 Mt) and West Bengal (33 Mt). Maharashtra stood first in pulse residue generation (3 Mt) whereas Andhra Pradesh is dominant in fibre crop residues (14 Mt). Gujarat and Rajasthan generate about 6 Mt each of residues from oilseed crops.

Major residue types and their use pattern in India

Contribution of various crops in residue generation is given in Fig. 2. Rice gives two types of residue, straw and husk. Rice straw is major portion of the rice crop residue and is used as fodder mainly for cattle in southern and eastern India and for roof thatching all over the country. Husk is a by-product of rice milling and is the second largest agro industrial residue after bagasse produced in the country, upto 43% of which is consumed in rice mills (Meshram 2002). Due to high silica content, only 5% of husk is used as cattle feed, but the major share of husk goes as fuel in parboiling rice mills followed by applications like domestic fuel, bedding for animals especially poultry and also for oil extraction (Tyagi 1989; TIFAC 1991). Wheat straw is produced in large quantity and the major share goes into cattle feeding, domestic fuel, paperboard making and oil extraction. Cotton stalk, hull and ball, almost all is used primarily as household fuel. Some of cotton stalk find its use in fencing, thatching and wall construction and rest is left in field. Sugarcane produces three types

Table 1. Generation and surplus of CR (in Mt yr^{-1}) in various states of India

States	Residue generation[a]	Residue surplus[a]	Residue burned[b]	Residue burnt[c]
Andhra Pradesh	43.89	6.96	5.73	2.73
Arunachal Pradesh	0.4	0.07	0.06	0.04
Assam	11.43	2.34	1.42	0.73
Bihar	25.29	5.08	3.77	3.19
Chhattisgarh	11.25	2.12	1.84	0.83
Goa	0.57	0.14	0.08	0.04
Gujarat	28.73	8.9	6.69	3.81
Haryana	27.83	11.22	5.45	9.06
Himachal Pradesh	2.85	1.03	0.20	0.41
Jammu and Kashmir	1.59	0.28	0.35	0.89
Jharkhand	3.61	0.89	1.11	1.10
Karnataka	33.94	8.98	2.85	5.66
Kerala	9.74	5.07	0.40	0.22
Madhya Pradesh	33.18	10.22	3.46	1.91
Maharashtra	46.45	14.67	6.27	7.41
Manipur	0.9	0.11	0.14	0.07
Meghalaya	0.51	0.09	0.10	0.05
Mizoram	0.06	0.01	0.01	0.01
Nagaland	0.49	0.09	0.11	0.08
Orissa	20.07	3.68	2.57	1.34
Punjab	50.75	24.83	8.94	19.62
Rajasthan	29.32	8.52	3.58	1.78
Sikkim	0.15	0.02	0.01	0.01
Tamil Nadu	19.93	7.05	3.55	4.08
Tripura	0.04	0.02	0.22	0.11
Uttarakhand	2.86	0.63	13.34	21.92
Uttar Pradesh	59.97	13.53	0.58	0.78
West Bengal	35.93	4.29	10.82	4.96
India	501.76	140.84	83.66	92.81

Source: a. MNRE 2009, b. Based on IPCC coefficients, c. Pathak et al. 2010 of residues viz. trash, tops and bagasse. Trash is mainly used as fuel in gur making and to some extent as cattle feed. Bagasse produced from cane juice extraction is almost completely used up as captive fuel in sugar industry. Maize produces two types of residues viz. sticks/straw and cobs. Sticks/straw is mainly used as fodder and rural domestic fuel. Maize cobs, being hard, are not

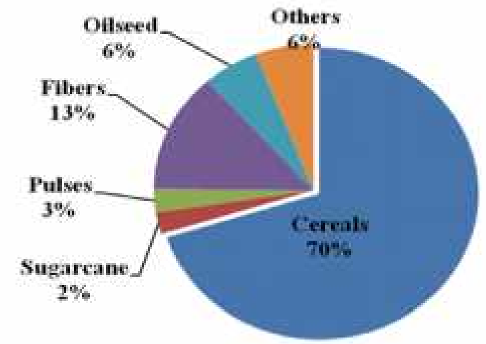

Fig 2. Contribution of various crops in residue generation in India

consumed in significant quantities by livestock as fodder. Millets stalk and stick are used as fodder and as domestic fuel (TIFAC 1991; Meshram 2002). Groundnut stem is used almost completely as domestic fuel and shells end up as industrial fuel (Tyagi 1989; Meshram 2002). Haulms are used as household fuel. Jute produces two types of residues viz. straw/sticks and dust. Straw/sticks is partly used as fuel in households and tobacco leaves processing. Jute dust is used mainly as fuel in boilers and rest is either thrown or collected for household use. Rapeseed and mustard stalk is widely burnt in rural domestic chulhas (Tyagi 1989).

Surplus residues

The surplus residues i.e., total residues generated minus residues used for various purposes, are primarily burned

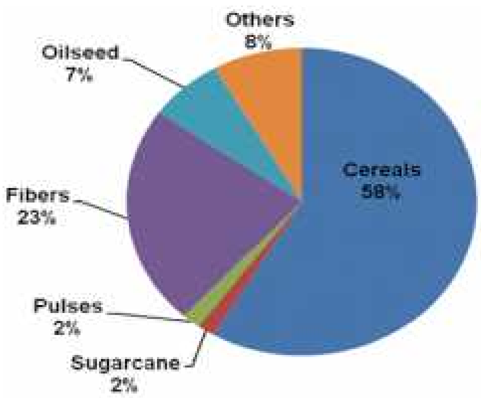

Fig. 3. Surplus of various crops residues in India

in the field or used as fuel for household purpose by farmers. The total surplus crop residue in India is estimated to be 84-141 Mt yr^{-1} where cereals and fibre crops contribute 58% and 23%, respectively (Fig. 3). Remaining 19% is contributed by sugarcane, pulses, oilseeds and other crops. Out of 82 Mt surplus residues from the cereal crops, 44 Mt and 24.5 Mt from rice and wheat respectively are burnt in fields. Out of 33 Mt of surplus residue from fibre crops approximately 80% from cotton, is subjected to burning.

Crop residue burning and its adverse effect

Although, CR are having tremendous value to farmers, a large portion of the residues, approximately 90-140 Mt, is burnt in field mainly to clear the field from straw and stubble after the harvest of the preceding crop. It could be ascribed to unavailability of labour, high cost in removing the residues, lack of requisite machinery to incorporate CR in soil and use of combine harvesters in rice-wheat cropping system. Primary crop types whose residues are typically burnt include rice, wheat, cotton, maize, millet, sugarcane, jute, rapeseed-mustard and groundnut. About 82% of rice residue is burnt in the field, however most of the wheat residues are preferred as animal fodder. In North West India the time gap between rice harvesting and wheat sowing is only 15-20 days. Therefore, farmers burn the rice stalk in the field instead of incorporating it into the soil owing to slow rate of decomposition due to its high silica content (Singh and Sidhu 2014). Burning of CR leads to plethora of problems such as:

Loss of nutrient

In addition to loss of entire amount of C, 80% of N, 25% of P, 50% of S and 20% of K present in straw is lost due to burning and pollutes the atmosphere. If the CRs are incorporated or retained, the soil will be enriched, particularly with organic carbon and N.

Impact on soil properties

Heat from burning residues abruptly increases soil temperature causing death of microbial populations. However, the death is temporary as the microbes regenerate after few days. Nevertheless, repeated burning may cause permanent reduction in microbial population. Though, burning immediately increases the exchangeable NH_4^+-N and bicarbonate extractable P content, no build-up of nutrients in the profile is found. Long-term burning decreases total N, C and potentially mineralized N in the 0-15 cm soil layer.

Emission of greenhouse gases

Burning of residues emits a significant amount of Green House Gases(GHGs) . It is estimated that 70, 7 and 0.66% of C present in rice straw is emitted as CO_2, CO and CH_4, respectively, while 2.09% of N in straw is emitted as N_2O upon burning. Residue burning has been reported to cause emission of 379 pentagram carbon equivalents for India and 14 Gg C equivalents for Madhya Pradesh.

Emission of other gases and aerosol

Burning of agricultural generates trace gases and aerosols such as CH_4, CO, N_2O, NOX and other hydrocarbons which cause radiative forcing to the atmosphere affecting the atmospheric composition and in turn radiation balance. It also emits large amount of particulates that are composed of wide variety of organic and inorganic species. One tonne straw on burning releases 3 kg particulate matter, 60 kg CO, 1460 kg CO_2, 199 kg ash and 2 kg SO_2. Besides other light hydrocarbons, volatile organic compounds (VOCs) and semi-volatile organic compounds (SVOCs) including polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs) and SOx, NOx are also emitted. These gases are important for their global impact and may lead to a regional increase in the levels of aerosols, acid deposition, increase in tropospheric ozone and depletion of the stratospheric ozone layer. They may subsequently undergo trans-boundary migration depending upon the wind speed/direction, reactions with oxidants like OH- leading to physico-chemical transformation and wash out by precipitation. Many of the pollutants found in large quantities in biomass smoke are known or suspected carcinogens and could be a major cause of concern leading to various air borne/lung diseases.

Nutrient potential of CR and its recycling

Crop residues are potential source of plant nutrients and their beneficial effect on soil fertility and productivity could be harnessed by recycling them in to the soil (Table 2). Estimates showed that 30-35% of applied N & P and 70-80% of K accumulated in the CRs of food crops. Moreover, CRs are the primary source of organic matter (as C constitutes about 40% of the total dry biomass) which is indispensable for sustainability of agricultural ecosystems. About 40% of the N, 30-35% of the P, 80-85% of the K, and 40-50% of the S taken up by rice remain in the vegetative parts at maturity (Dobermann and Fairhurst 2002). Similarly about 25-30% of N and P, 35-40% of S, and 70-75% of K uptake are retained in wheat residue. Dobermann and Witt, (2000) estimated the typical amounts of nutrients in rice straw at harvest are 5-8 kg N, 0.7-1.2 kg P, 12-17 kg K, 0.5-1 kg S, 3-4 kg Ca, 1-3 kg Mg, and 40-70 kg Si per ton of straw on a dry weight basis. Similarly, Singh and Sidhu (2014) reported that one ton of wheat residue contains 4-5 kg N, 0.7-0.9 kg P,

Table 2. Nutrient potential of different crop residues in India

	N (%)	P_2O_5 (%)	K_2O (%)	Total	Tonne / Tonne residue
Rice	0.61	0.18	1.38	2.17	0.0217
Wheat	0.48	0.16	1.18	1.82	0.0182
Sorghum	0.52	0.23	1.34	2.09	0.0209
Maize	0.52	0.18	1.35	2.05	0.0205
Pearl millet	0.45	0.16	1.14	1.75	0.0175
Barley	0.52	0.18	1.30	2.00	0.0200
Finger millet	1.00	0.20	1.00	2.20	0.0220
Pulses	1.29	0.36	1.64	3.29	0.0329
Oilseeds	0.80	0.21	0.93	1.94	0.0194
Groundnut	1.60	0.23	1.37	3.20	0.0320
Sugarcane	0.40	0.18	1.28	1.86	0.0186
Potato tuber	0.52	0.21	1.06	1.79	0.0179
Total	8.71	2.48	14.67	26.16	0.2616

Source: Tandon (2003)

and 9 -11 kg K. It is important to mention here that K concentration is generally higher (upto 25 kg per tonne) in rice straw of North West Indo Gangetic Plain than that from other regions of the India or other countries. However, soil conditions, crop management, variety, season determines the nutrient concentration in CRs. The amount of NPK contained in rice and wheat residues produced (197 Mt) is about 4.1 x 106 Mt in India. Besides NPK, one ton of rice and wheat residues contain about 9-11 kg S, 100 g Zn, 777 g Fe and 745g Mn. Thus, CRs play an important role in the cycling of nutrients in addition to the role of chemical fertilizers in crop production and its continuous removal and burning can lead to net losses of nutrients which ultimately will lead to higher nutrient cost input in the short term and reduction in soil quality and productivity in the long term.

The annual nutrient cycling in the plant-soil ecosystem is essential in maintaining a productive agricultural system. The CR management has important implications for the total amounts of nutrients removed from and returned to the soil. The dynamics and bio-availability of main plant nutrient elements are also improved by SOM. The soil, water and air also contain various inorganic chemicals necessary for plant growth. Soil organic matter is the main determinant of biological activity because it is the primary energy source. The amount, diversity and activity of soil fauna and microorganisms are directly related to SOM content and quality. Each plant nutrient has its own C-dependent cycle (Fig.4) that controls its availability to the next generation of plants. Carbon compounds in the residue are the fuel or energy sources for the soil microbes and fauna

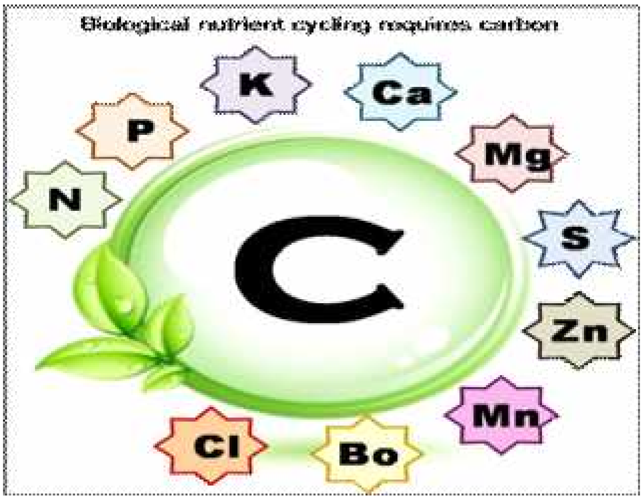

Fig 4. Soil carbon plays critical role in biological nutrient cycling (Adapted and modified from Reicosky and Wilts, 2005)

responsible for biological recycling of these inorganic plant nutrients. During microbial decomposition of crop residues, chemical elements are released into the immediate environment that may be utilized by living plants or organisms. This constitutes the basic framework of biological nutrient cycling in agricultural production systems. Carbon-enriched crop biomass becomes the primary food source for soil microorganisms and fauna and as a result "nurtures" nutrient cycling. Plant availability of nutrients in crop residues is regulated largely by soil water, soil temperature, other soil properties and soil and crop management practices. For nitrogen (N), activity of soil microorganisms is usually most important in determining the cycling and potential availability from crop residues. For phosphorus (P), both microbial activity and soil mineralogy are involved. For potassium (K), mineralogy and soil water movement are important parameters. Management practices such as fertilization and the amount of residue remaining after harvest determine the extent of cycling and plant availability of nutrients from crop residues. The shift from conventional to conservation tillage systems necessitates new research to determine the rate of cycling and plant nutrient availability.

On-farm management of CR

Crop residue mulching

Crop residue mulching (CRM) can be defined as a technology whereby at the time of crop emergence at least 30% of the soil surface is covered by organic residue of the previous crop. The timing aspect relates to the limited crop cover at the onset of the season and the correspondingly high erodibility of the soil. The 30% threshold originated in the USA (Allmaras and Dowdy 1985) however, arbitrary and higher levels of soil cover may leads to greater reductions of soil erosion. A crop residue mulch arrests soil erosion efficiently by providing a protective layer to the soil surface, enhancing soil surface aggregate stability and permeability through its combined physical and biological effects (Lal et al. 1990; Stocking 1994), increasing resistance against overland flow in both tropical and temperate climates. The presence of crop residue mulch at the pedosphere alters the entire soil ecology (Carsky et al. 1998) attributing to profound water conserving effect. CRM also promotes the activity of soil biota by providing a readily available food source and a more favourable niche (Mando 1997). Moreover water conservation effect can produce a tangible yield benefits particularly in dry land areas where drought stress is an issue (Pierce and Lal 1994). CRM also aids buffering of soil temperature fluctuation.

Conservation Agriculture

Conservation Agriculture (CA) revolves around three main principles: minimum soil disturbance; permanent soil cover, primarily by retaining CRs as mulch; and crop rotation, especially with legumes. With the rising concerns over the natural resource degradation and surging production cost, no-tillage with residue retention and judicious crop rotation are gaining more attention in recent years (Ladha et al. 2009, Saharawat et al. 2012). Moreover, intensive tillage systems diminishes soil organic matter due to accelerated oxidation of organic matter and ultimately degradation of soil properties (Biamah et al. 2000, Gathala et al. 2011). However, the main back drop of CA is sowing a crop in the presence of residues of preceding crop. To address this problem new variants of zero-till seed-cum-fertilizer drill/planters such as Happy Seeder, Turbo Seeder and rotary-disc drill have been invented for direct drilling of seeds even in the presence of surface residues (loose and anchored up to 10 t ha^{-1}). These machines are very useful for managing CRs for conserving moisture and nutrients as well as controlling weeds in addition to moderating soil temperature. Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad, has shown that in dry land ecosystems, where only a single crop is grown in a year, it is possible to raise a second crop with residual soil moisture by covering soil with CRs. In addition Gathala et al. (2013) also demonstrated the positive effects of managing wheat straw in direct seeded rice and the rice straw in wheat on system productivity and water use efficiency in the rice-wheat system under permanent zero-till system. Nevertheless, environmental contamination due to excessive use of herbicide for weed control, complex nutrient management and pest infestations are major challenges for proper implementation of his technology.

Off-farm management of CR

Composting

The potential of composting to turn on-farm waste materials into a farm resource makes it an attractive proposition. Composting is a microbiological and non-polluting safe method for disposal and recycling of these wastes by converting them into organic fertilizer. It is also known that the composts produce in India is of nutritionally low-grade quality. Thus, a sound technology is required to improve the quality of compost in the shortest possible time, where farmers can prepare the compost easily and improve its nutritional quality by the addition of cheap amendments such as rock phosphate and pyrites. During composting rice straw can be fortified with P using indigenous cheap source of low grade rock phosphates to make it value added compost with 1.5% N, 2.3% P_2O_5 and 2.5% K_2O (Sidhu and Beri 2005).

Biochar

The detrimental effects of crop residue burning call for an effective crop residue management (CRM) system for attaining agricultural sustainability. Thermo-chemical conversion (pyrolysis) of lingo-cellulosic biomass of crop residues in absence of oxygen to produce solid biochar has been suggested to avert open residue burning. Biochar production provides great opportunities as resource conservation technologies for sustainable agro-ecosystem services leading to evergreen revolution against the existing one (Tillman 1998; Conway 1999) because biomass C to biochar C conversion facilitates more C retention to soil. Biohar system retains about 50% (for long time) of parent C compared to traditional agriculture systems i.e., burning (only 3%, rest releases instantly to atmosphere) and microbial degradation following incorporation (10-20% for 5-10 years) (Lehmann and Rondon 2006). CRs have been regarded as potential feedstock for biochar production (Lehmann 2007 a, b). Biochar production from CR is cost-effective, thus, it could be explored as a promising soil ameliorant (Beesley et al. 2011). Crop residue biochar (CRB) is more suitable for soil amelioration due to easy availability, whereas wood biochar will pose extra pressure on forest resources (Cornelissen et al. 2013). CRB has also reported to produce positive impact on broad level ecosystem services like enhanced soil microbial dynamics, suppression of plant diseases, reduced GHG emission, reduced nutrient leaching, ameliorating soil acidity and improving soil quality and plant growth (Sohi et al. 2009, Woolf et al. 2010). Nevertheless, higher salt concentration of CRB may restrict its potential as soil ameliorant. But recently Singh et al. (2015) has recommended that CRB integrated approach as a partial retention and partial removal with closed loop model of reversion can be considered as a better option under conservation agriculture scenario as biochar get concentrated under rhizospheric zones.

Bio-energy and bio-fuel

Biomass based energy generation is one of the major focus areas of renewable energy programs in India. The strength of India's biomass resources mostly lies in huge amount of CRs. Although accesses to electricity and LPG have been improved in India compared to the last few decades, consumption of biomass as traditional fuel also increases in parallel and it dominates the fuel mix of rural households. The main biofuel option for CRs is cellulosic ethanol production, which involves enzymatically breaking down the cellulose in the straw into its component sugars, which can then be fermented to ethanol. In September 2007, the Cabinet Committee on Economic Affairs (CCEA) implemented 5 percent ethanol blending across the country and recommended 10 percent ethanol blending where feasible, effective October 2007 (CCEA 2007). Subsequently, the "National Biofuel Policy" formulated by the Ministry of new and Renewable Energy (MNRE) was approved in September 2008 and finally released in December 2009. This policy foresees biofuels as a potential means to stimulate rural development and generate employment opportunities and aspires to reap environmental and economic benefits arising out of their large-scale use. Various crops, such as sugarcane, sweet sorghum, cassava, maize are considered potential crop under biofuel policy.

However, the potential bioenergy generation have three serious implications for crop residue management if it is widely adopted: (1) residue would be removed rather than returned to the soil, (2) harvesting and threshing techniques would need to be considerably modified to make it feasible to collect the residue for transportation, and (3) it would become important to grow varieties with desirable straw characteristics. (Singh et al. 2008). Lately, rice straw utilization potential for bioenergy production may not be more than 10% of the total residues produced. Moreover, retention of residue instead of removal for bioenergy production is more crucial for the sustainability of rice-wheat cropping system. The partial removal of residue in rice-wheat system might be feasible without jeopardizing sustainability provided inputs of K, S, and other nutrients are suitably adjusted to compensate for those removed with residue.

Value addition

Bioconversion of CRs for the production of food and fodder is an area which needs much attention especially in India. Solid state fermentation is the most appropriate technology to produce protein rich feed and fodder. Mushroom cultivation using CRs as substrate has also commercial viability. Sugarcane bagasse, a lingo-cellulosic fibrous residue of cane stalks left over after crushing and extraction of the juice is almost completely used as fuel for the boiler in sugar industry. Because of its low ash content, it provides numerous advantages as compared to rice and wheat straw which contain 17.5 and 11.0 % ash respectively. However, the most important bioconversion product is protein rich (single cell protein) animal feed and cellulose enzyme (Pandey and Soccol 2002).

Effect of CR on soil health and C sequestration

The residue derived from crops is considered "the greatest source of soil organic matter" (Tisdale et al. 1985) for agricultural soils. Crop residue returns organic matter to the soil where it is retained through a combination of physical, chemical, and biological activities that interact and affect soil quality, including nutrient cycling (Fig. 5). Nutrient availability and carbon storage depend on soil organic matter (SOM) content. Crop residue retention is very crucial for increasing and/or maintaining soil organic carbon (SOC) levels; however, its effect may be controlled by soil type, climate and management factors (Govaerts et al. 2009). Climatic factors influence decomposition rates and in turn control SOC accumulation with residue surface retention vs. incorporation. In a similar study, in Varanasi, India, with high temperatures and decomposition rates, SOC and total N were highest under minimum tillage with residue retained on the surface compared to incorporation (Kushwaha et al. 2001). Residue retention at surface enhances SOM content, eventually increases the soil's pH dependent CEC. Both residue retention on the surface or incorporation have been reported to increase CEC (Govaerts et al. 2007; Lal 1997). Recycling of CRs can influence the availability of nitrogen to the crop. C/N ratio of CRs dictates the N mineralization-immobilization dynamics. Application of legume residues with a low C/N ratio can result in N mineralization, whereas cereal residues with a high C/N composition can temporarily immobilize N during the decomposition process (Govaerts et al. 2006; Aulakh et al. 1991) in soil. Denitrification losses of mineral nitrogen fertilizer can also be greater when residues are left on the surface due to higher soil moisture content and if fertilizers are not properly incorporated (Aulakh et al. 1984).

Apart from nitrogen, addition of residues can indirectly increase the availability of phosphorus in strongly weathered soils. Humic molecules and low molecular weight aliphatic acids released during the decomposition of CR can block Al-oxide adsorption sites and reduce overall adsorption of P and P availability (Haynes and Mokolobate, 2001). However, this effect is dependent on the quality as well as decomposition rate of CRs (Nziguheba et al. 1998). Moreover, surface residue retention plays an important role in protecting soil aggregates from raindrop impact. According to Panachuki et al. (2011) residue cover dissipates kinetic energy of rainfall and prevents soil aggregates from breaking down.

Retaining crop residue can improve soil structure through various mechanisms: (1) increasing soil aggregation through adding organic matter to the top soil, (2) protecting soil aggregates from raindrop impact, and (3) protecting soil from compaction caused by raindrop impact (Six et al. 2006; Jacobs et al. 2009; Verhulst et al. 2010).

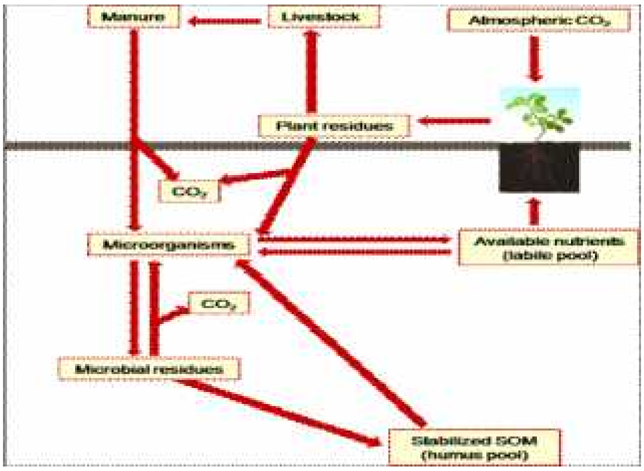

Fig 5. Simplified model of plant residue inputs transformed by soil microorganisms

Results from the Indian Himalayas show that leaving CR on the surface may be important in improving topsoil aggregate stability in areas with hilly terrains, heavy rainfall and highly eroded soils. Comparison between continuous NT and seasonal NT-CT practices that keep residue on the surface revealed that seasonal NT-CT practices are instrumental for maintaining SOC and aggregate stability in soils highly susceptible to erosion (Bhattacharyya et al. 2012). In tropical and subtropical areas with high temperatures and rainfall, no-till and surface crop residue have been observed to increase SOC content in surface soils compared to incorporation (Corazza et al. 1999; Bayer et al. 2000). This is due to less contact between surface residue and microorganisms in no-till systems, as described earlier, suggesting the importance of retaining residue on the surface rather than incorporating residues in sub-humid temperate to sub-humid tropical regions where decomposition rates are high. In addition, residue retention is an important factor in stimulating SMB and microbial activity. Lou et al. (2011), in comparing treatments with straw retained and straw removed in Northeast China, found significantly higher microbial biomass C levels when straw was retained because of improved C and N contents, soil moisture content and porosity and decreased soil temperature caused by the residue cover Earthworms have been observed to respond positively to crop residue retention and minimum soil disturbance. The cooler soil temperature, improved soil structure, and food resource provided by crop residue retained on the surface can lead to increases in earthworm number and biomass (Chan and Heenan 2006).

Future Research

Management of CRs in conservation agriculture is crucial for long-term sustainability of Indian agriculture. Instead of burning, residues must diverted to CA for improving soil health and reducing environment pollution. Even in regions where CRs are used for animal feed and other useful purposes, some amount of residues must be recycled to soil. Several technologies are available, however, they need refinement as well as awareness for adoption by resource poor, low skilled farmers. Moreover quantification of the benefits of CA-based practices under short and long-term situations in terms of economic, social and environmental benefits need to be done. These can then form a basis for policy level issues in relation to C-sequestration, erosion control, fertilizer use efficiency, incentives to retain residues etc. Some of the areas where research activities could be taken up include the following.

- Developing inventory of amount of residues generated in different crops in different regions of the country.
- Identifying the major uses of CRs and comparative assessment of their competing uses. Use of satellite imageries could be the best way to estimate the amount of residues burnt in the field.
- Quantifying the permissible amount of residues of different crops which can be incorporated/retained depending on cropping systems, soil, and climate without creating operational problems for the next crop or chemical and biological imbalance.
- Analysing the benefit:cost ratio and socio-economic impacts of residue retention/incorporation in CA vis-à-vis residue burning for both short and long-term time scale.
- Assessing the quality of CR and their suitability for various purposes.
- Development of appropriate farm machinery to facilitate the application of residues, and successful planting of a crop in the rotation under a layer of residues on soil surface.
- Modifying combine harvester to collect and remove residues from field.

Crop residues through best site-specific management systems can improve soil productivity and crop production by maintaining SOM levels and enhance nutrient cycling and retention. Greater microbial biomass and activity near the soil surface acts as a reservoir for nutrients needed in crop production and increases structural stability for increased infilteration. In addition to the altered nutrient distribution within the soil profile, changes also occur in the chemical and physical properties of the soil. Improved soil C sequestration through enhanced CR management is a cost effective option for minimizing agricultural impact on the environment.

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Visual soil quality assessment

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Abstract

Many physical, biological and, to a lesser degree, chemical soil properties show up as visual characteristics. Changes in land use or land management can markedly alter these. Research shows that many visual indicators like color, structure, aggregation, texture, moisture conditions, earthworm casts are closely related to key quantitative (measurement-based) indicators of soil quality. As indigenous people have done before, soil science and soil advisory services utilize the same common field diagnostic criteria within defined frameworks and check their validity over larger scales. Conventional methods for assessing soil quality under different management practices require considerable time and knowledge. Visual techniques of soil examination and evaluation are of immense value for soil management, particularly methods associated with the rapid assessment of soil. They complement newly developed techniques for soil assessment such as remote sensing and soil-landscape modeling, and well established procedures such as laboratory analysis of soil samples.

Keywords: Soil properties, visual indicator, conventional methods of diagnosis of soil characters

The need to increase agricultural production with less impact on the environment has renewed interest in assessing how land use systems and management influence soil properties (Batey and McKenzie 2006). Soil and crop management practices can enhance or reduce soil quality, which in turn can be associated with an increase or decrease in soil productivity (Pankhurst et al. 2003; Ogle et al. 2012). Conventional methods for measuring soil properties and evaluating soil quality require varied methodological knowledge, resource infrastructure (equipment and laboratories) and considerable time and money (Guimaraes et al. 2011). Therefore a reliable, rapid method to quantify soil structural quality that is sensitive to the effects of management on soil quality would be useful for both scientists and farmers. Visual techniques for assessing soil quality in the field are useful to diagnose and control erosion, soil compaction and decisions about systems of tillage (Shepherd 2000; Ball and Douglas 2003; McKenzie 2001(a & b) and Mueller et al. 2009, 2010). Visual assessment of soil structure, root growth, organic matter, colour and surface condition offers a holistic means of assessing soil physical condition. Kerebel and Holden (2013) used slope gradient; landscape position, soil roughness, weed abundance, grittiness and hydromorphism (eg., soil mottling, red channels) as visual indicators of soil quality. Such assessment also enables evaluation of current soil management by pinpointing specific problems such as compaction, impeded drainage, erosion and restrictions to roots.

The visual assessment of soil is a low cost method for semiquantitative assessment of soil quality (Shepherd 2000) for use in extension and monitoring (Shepherd 2000; McKenzie 2001) or even modeling (Roger-Estrade et al. 2004). Visual assessment methods should be simple, inexpensive, reliable, highly accurate, produce results fast and be understood by researchers, technical advisors and farmers (Shepherd 2003). Visual methods for objectively and reproducibly evaluating soil quality based on field assessment and measurements have been developed (Shepherd 2000, 2009; Ball and Douglas 2003; Ball et al. 2007), tested (Mueller et al. 2009a,b) and modified (Guimaraes et al. 2011; Murphy et al. 2013). These methods range from easily understood and quick tests to more complex multifaceted assessments, but all are designed to help land managers make better decisions as part of their soil management system, and scientists to acquire low-cost, objective, reproducible data on soil structure over large areas with high sampling frequency. The simpler methods such as Shepherd (2000) and Guimaraes et al. (2011) do not require particular knowledge and specific equipment yet provide a rapid and meaningful result (Giarola et al. 2010)

Visual assessment scores are correlated with measured data of physical soil quality (Murphy et al. 2013; Kerebel and Holden, 2013; Giarola et al. 2013; Guimaraes, 2013; Lin et al. 2005), chemical soil quality (Murphy et al. 2013) and crop yield (Mueller et al. 2009; Mueller et al. 2013; Giarola et al. 2013; Munkholm et al. 2013). However, clearly defined rules and scoring methods are necessary to minimize subjective errors. Visual methods based on, or supplemented by illustrations, have clear advantages for the reliable assignment of a rating score based on visual diagnostic criteria.

Methods for visual assessment of soil quality

Several methods have been developed over the past five decades. One of the oldest but most accepted methods is that of Peerlkamp (1967). The traditional French method "Le profil cultural" (Roger-Estrade et al. 2004) belongs to a group of more sophisticated methods providing detailed information on the total soil profile. A quantitative comparison of some methods and their correlations with measured physical parameters after standardizing data revealed that most methods provided similar results (Mueller et al. 2009). Types and sizes of aggregates and abundance of biological macropores were the most reliable criteria as related to measurement data and crop yields. Differences in soil management could be recognized by visual structure criteria (Mueller et al. 2009). Unfavourable visual structure was associated with increased dry bulk density, higher soil strength and lower infiltration rate but correlations were site-specific. Effects of compaction may be detected by visual examination of the soil (Batey and Mc Kenzie 2006). Also, the New Zealand Visual Soil Assessment (VSA), (Shepherd 2000, 2009) as an illustrated multi-criteria method enables reliable assessments of the soil structure status. These are feasible tools for structure monitoring and management recommendations. However, they may explain only part of crop yield variability, as the influence of inherent soil properties and climate on crop yield is dominant, particularly over larger regions.

In France, agronomists have studied the effects of cropping systems on soil structure using a field method based on a morphological description of soil structure. In this method, called "Le profil cultural" or soil profile in the soil structure of the tilled layer is observed on a vertical face of a pit. Herrick et al. (2001) described a stability kit which can be inexpensively and easily assembled with minimal tools. It permits up to 18 samples to be evaluated in less than 10 min and eliminates the need for transportation, minimizing damage to soil structure. Among all these methods, two main types can be distinguished: (i) methods based on the topsoil examination with VSEE (Ball et al. 2007), or the VSA drop test (Shepherd 2000) and (ii) those based on soil profile evaluation like SoilPAK and Le Profil Cultural Method (Roger-Estrade et al. 2004; McKenzie, 2001a,b; Batey and McKenzie, 2006).

VSEE (Visual Soil Examination and Evaluation)

The Peerlkamp method

The Peerlkamp method involves digging a hole that is slightly wider and deeper than the spade. Then a spadeful of soil is removed and laid on the ground and recognizable or pre-determined layers or horizons separated. The key criterion is to assess the total soil block or the separated layers for its potential as a medium for rooting. Beginning with the top layer the soil is gently broken apart into aggregates and placed on the soil surface or a sheet of paper. A score number is assigned according to the scale description given by Peerlkamp (1967). The scale for clay and loam soils is:

1-2 "Plough layer consists entirely of big clods, smooth dense crack faces, roots only in cracks",

3-4 "Plough layer big dense aggregates, smooth crack faces, roots between aggregates",

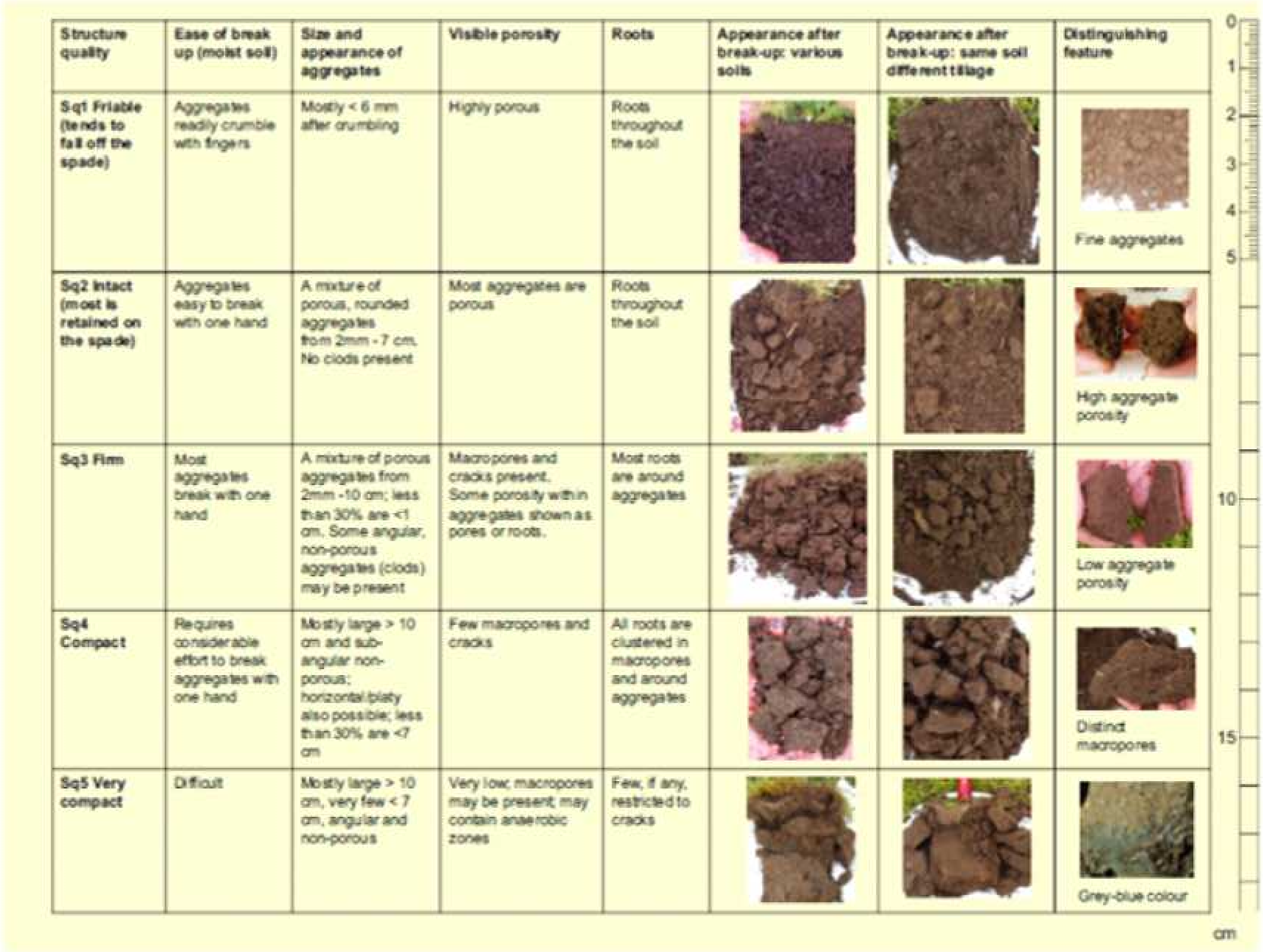
5-6 "Plough layer big porous aggregates, rather smooth crack faces",

7-8 "Plough layer mostly porous crumbs partly combined as porous aggregate. Occasional denser clods",

9-10 "Plough layer all porous crumbs, very few dense aggregates".

The latest development of the Peerlkamp method provided by Ball et al. (2007) is well illustrated (Fig. 1).

The main advantages of this method are speed and minor soil disturbance, providing comparative statistical analyses both in large fields and also in small plots of long-term trials. However, the scoring frame has potential for subjective errors. Some methods like that of Peerlkamp (1967) and its revised version by Batey and Ball (2005) and Ball et al. (2007) or the structure score of Diez and Weigelt (1997) could be characterized as Peerlkamp type methods as they are based on a single scale of conjoint parameters. In case of disagreement between single parameters from the description or sample photograph, the scoring person has to find a compromise. For example, the method of Peerlkamp, modified by Batey and Ball (2005) combines in the highest (best) class: "Friably, crumbling aggregates, low size after crumbling,



Structure quality	Ease of break up (moist soil)	Size and appearance of aggregates	Visible porosity	Roots	Appearance after break-up: various soils	Appearance after break-up: same soil different tillage	Distinguishing feature
Sq1 Friable (tends to fall off the spade)	Aggregates readily crumble with fingers	Mostly < 6 mm after crumbling	Highly porous	Roots throughout the soil			Fine aggregates
Sq2 Intact (most is retained on the spade)	Aggregates easy to break with one hand	A mixture of porous, rounded aggregates from 2mm - 7 cm. No clods present	Most aggregates are porous	Roots throughout the soil			High aggregate porosity
Sq3 Firm	Most aggregates break with one hand	A mixture of porous aggregates from 2mm -10 cm; less than 30% are <1 cm. Some angular, non-porous aggregates (clods) may be present	Macropores and cracks present. Some porosity within aggregates shown as pores or roots.	Most roots are around aggregates			Low aggregate porosity
Sq4 Compact	Requires considerable effort to break aggregates with one hand	Mostly large > 10 cm and sub-angular non-porous; horizontal/platy also possible; less than 30% are <7 cm	Few macropores and cracks	All roots are clustered in macropores and around aggregates			Distinct macropores
Sq5 Very compact	Difficult	Mostly large > 10 cm, very few < 7 cm, angular and non-porous	Very low; macropores may be present; may contain anaerobic zones	Few, if any, restricted to cracks			Grey-blue colour

Fig 1. Revised Peerlkamp scale as an example of soil structure evaluation (Ball et al. 2007)

highly porous, roots throughout aggregates". This makes methods of the Peerlkamp type very fast in handling but sensitive to subjective scorings. If one or more features are not present for this description (e.g. absence of roots, difficulties with break-up caused by drought) the operator can underestimate structural quality. Separate assessments of several parameters as in the methods of Werner and Thaemert (1989), or Munkholm et al. (2005) provide more reliable single scorings but this is more time consuming, the total assessment is difficult and a total numerical score, though desirable, may not be part of the test.

Werner method

An alternative to the Peerlkamp type of measurement is a multi parameter technique such as the Werner method (Werner and Thaemert 1989). Soil handling prior to scoring is similar to that of the Peerlkamp test but separate scoring of different soil layers of the topsoil and subsoil (down to about 50 cm depth) is recommended. Scorings are separately performed for five different criteria:

Aggregate size, given classes are 1 fine (<5 mm), 2 medium (5- 20 mm), 3 large (20-50 mm) 4 very large (>50 mm) 5 structureless.

Aggregate type, given classes are 1 rounded, 2 edgeless-rough planes, 3 sharp edged-smooth planes, 4 unseparated, massive.

Shape of intra-aggregate voids, given classes are 1 rough cavities, 2 rough fissures, 3 smooth cavities, 4 smooth fissures, 5 unseparated.

Width of aggregate interfaces, given classes are 1 open, 2 halfopen, 3 closed, 4 no interfaces.

Proportion of biogenic macropores (>1 mm), given classes are 1 very high, 2 high, 3 medium, 4 low.

This last criterion is scored not from soil broken-up by hand but by careful vertical removal of soil layers and counting of macropores at the bottom of each layer. Classes are characterized by a specific table (in: Werner and Thaemert 1989) containing numbers for different pore classes. The result of the Werner method is a five digit number of the dominating class of each criterion. A soil of very best structure would have the theoretical optimum number of 11,111. But common numbers have mixed digits (for example 12,224 or 32,222) and are thus not numbers but strings, e.g. nominally scaled data, which are difficult to handle. Development of a method of weighted averaging would remove this difficulty.

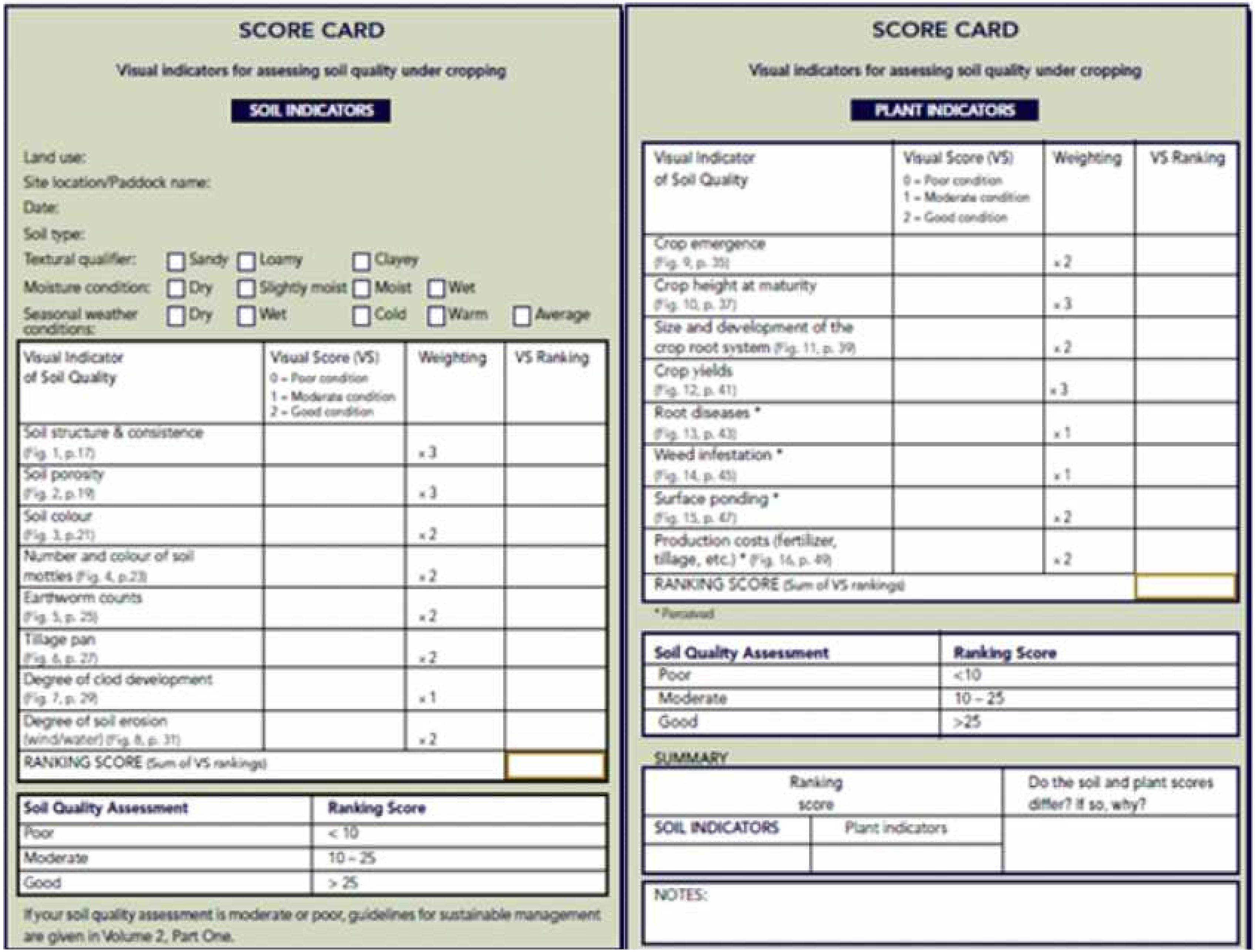
Visual soil ssessment

VSA is based on the visual assessment of key soil 'state' and plant 'performance' indicators of soil quality, presented on a score card (Fig 2). Soil quality is ranked by assessment of the soil indicators alone. It does not require knowledge of paddock history. Plant indicators, however, require knowledge of immediate crop and paddock history. Because of this, only those who have this information will be able to complete the plant indicator score card satisfactorily. Plant indicators extend or qualify the soil quality assessment to allow you to make cause and affect links between management practices and soil characteristics. By looking at both soil indicators and plant indicators, VSA links the natural resource (soil) with plant performance and farm enterprise profitability. Because of this, the soil quality assessment is not a combination of the 'soil' and 'plant' scores. Rather, the scores should be looked at separately, and compared.

Each indicator is given a visual score (VS) of 0 (poor), 1 (moderate), or 2 (good), based on the soil quality observed when comparing the paddock sample with three photographs in the field guide manual. The scoring is flexible, so if the sample you are assessing does not clearly align with any one of the photographs but sits between two, a score in between can be given, for example 0.5 or 1.5. An explanation of the scoring criteria accompanies each set of photographs. Because some soil factors or indicators are relatively more important for soil quality than others, VSA provides a weighting factor of 1, 2 or 3. For example, soil structure is a more important indicator (a factor of 3) than clod development (a factor of 1). The score you give each indicator is multiplied by the weighting factor to give a VS ranking. The total of the VS rankings gives the overall ranking score for the sample you are assessing. Compare this with the score ranges at the bottom of the page to determine whether your soil has good, moderate, or poor soil quality.

Drop Shatter Test

The drop shatter test requires the block of soil (200 mm _ 200 mm _ 50 mm) to be dropped three times from a height of one meter onto a firm surface (a tray or board). The soil is then teased apart into the aggregate using only "very gentle pressure". The object is to break the clods by hand along exposed cracks or fissures. If clods are not easily separated the cracks or fissures are not continuous and so are not available to readily transport air or water within the soil. The aggregates or fragments formed by this dropping process are then graded with the larger fragments or aggregates being moved to one end of the tray and the



SCORE CARD

Visual indicators for assessing soil quality under cropping

SOIL INDICATORS

Land use:

Site location/Paddock name:

Date:

Soil type:

Textural qualifier: ☐ Sandy ☐ Loamy ☐ Clayey

Moisture condition: ☐ Dry ☐ Slightly moist ☐ Moist ☐ Wet

Seasonal weather conditions: ☐ Dry ☐ Wet ☐ Cold ☐ Warm ☐ Average

Visual Indicator of Soil Quality	Visual Score (VS) 0 = Poor condition 1 = Moderate condition 2 = Good condition	Weighting	VS Ranking
Soil structure & consistence (Fig. 1, p.17)		x 3	
Soil porosity (Fig. 2, p.19)		x 3	
Soil colour (Fig. 3, p.21)		x 2	
Number and colour of soil mottles (Fig. 4, p.23)		x 2	
Earthworm counts (Fig. 5, p. 25)		x 2	
Tillage pan (Fig. 6, p. 27)		x 2	
Degree of clod development (Fig. 7, p. 29)		x 1	
Degree of soil erosion (wind/water) (Fig. 8, p. 31)		x 2	
RANKING SCORE (Sum of VS rankings)			

Soil Quality Assessment	Ranking Score
Poor	< 10
Moderate	10 – 25
Good	> 25

If your soil quality assessment is moderate or poor, guidelines for sustainable management are given in Volume 2, Part One.

SCORE CARD

Visual indicators for assessing soil quality under cropping

PLANT INDICATORS

Visual Indicator of Soil Quality	Visual Score (VS) 0 = Poor condition 1 = Moderate condition 2 = Good condition	Weighting	VS Ranking
Crop emergence (Fig. 9, p. 35)		x 2	
Crop height at maturity (Fig. 10, p. 37)		x 3	
Size and development of the crop root system (Fig. 11, p. 39)		x 2	
Crop yields (Fig. 12, p. 41)		x 3	
Root diseases * (Fig. 13, p. 43)		x 1	
Weed infestation * (Fig. 14, p. 45)		x 1	
Surface ponding * (Fig. 15, p. 47)		x 2	
Production costs (fertilizer, tillage, etc.) * (Fig. 16, p. 49)		x 2	
RANKING SCORE (Sum of VS rankings)			

* Perceived

Soil Quality Assessment	Ranking Score
Poor	<10
Moderate	10 – 25
Good	>25

SUMMARY

Ranking score		Do the soil and plant scores differ? If so, why?
SOIL INDICATORS	Plant indicators	

NOTES:

Fig 2. Source: Shepherd (2000)

finest to the other end. This procedure produces a graded display or sample of fragment and aggregate sizes (Fig. 3). The Drop Test Friability or DT Friability is calculated as (Murphy et al. 2013):

SOILpak scheme

The SOILpak score (McKenzie 2001a) used visual assessment of the soil structural form to derive an overall score. The 'SOILpak scoring procedure' has been developed within the Australian cotton industry to allow semi-quantitative assessment of soil structural form. It allows compaction severity in Vertisols to be separated into as many as 20 categories on a scale of 0.0 (severely compacted) to 2.0 (excellent structure for root growth). The procedure is based upon visual assessment of soil samples in the field as they are pulled apart by hand. The SOILpak scoring system is well accepted by advisory staff because of its speed and simplicity. However, there have been some problems with operator bias, and an inability to deal with continuity of vertical macropores, degree of encroachment of under-furrow compaction into the ridges where cotton is planted, and the presence of thin smeared layers. The SOILpak test is done first on the 0-50 mm layer and then the 50-100 mm layer. The scores are based on the size of primary clods, ease of breakage of the soil into clods, behaviour of fresh roots, shape of clods, amount of compound clods, internal porosity, and internal color of clods. Each of the factors is given a value between 0 and 2, with 0 being the worst condition and 2 the best. The final score is calculated after applying a weighting to the different factors and a normalizing factor of 36, which gives a final overall score between 0 and 2.

$$\text{DT Friability} = \frac{\text{length of aggregates of size} < 20\,\text{mm}}{\text{total length of aggregate display}}$$

Fig 3. Example of drop/shatter test (Source: Murphy et al. (2013)

"Le Profil Cultural" Method

In France, agronomists have studied the effects of cropping systems on soil structure using a field method based on a morphological description of soil structure. In this method, called "Le profil cultural" or soil profile in English, the soil structure of the tilled layer is observed on a vertical face of a pit. As the profil cultural method was first devised to evaluate the effect of agricultural operations in ploughed tillage systems, the focus was initially on topsoil. But the profil cultural method also allows us to examine the subsoil (Gautronneau and Manichon 1987). Peigne et al. 2013 presented the profil cultural method in detail, along with the improvements made to quantify the ability of roots to penetrate compacted zones in the transition layer. They proposed two indicators: (i) number of earthworm burrows per m2 counted on a horizontal surface at the bottom of the transition layer in the soil pit (ii) cracking quantified by taking a 50-mm x 50-mm x 100-mm sample of soil from the transition layer and examining the number of cracks.

Field soil aggregate stability kit

Filed soil aggregate stability kit (Herrick et al. 2001) is an inexpensive and easy to assemble tool for assessing soil quality based on aggregate stability. It permits up to 18 samples to be evaluated in less than 10 minutes and eliminates the need for transportation, minimizing damage to soil structure. The kit consists of two 21x10.5x3.5 cm plastic boxes divided into eighteen 3.5x3.5 cm sections, eighteen 2.5-cm diameter sieves with 1.5-mm distance openings and a small spatula used for soil sampling. Soil samples are rated on a scale from one to six based on a combination of ocular observations of slaking during the first 5 min following immersion in distilled water, and the percent remaining on a 1.5-mm sieve after five dipping cycles at the end of the 5-min period. A laboratory comparison yielded a correlation between the stability class and percent aggregate stability based on oven dry weight remaining after treatment using a mechanical sieve. The methods has been applied in a wide variety of agricultural and natural ecosystems throughout western North America, including northern Mexico, and been found highly sensitive to differences in management and plant community composition (Herrick et al. 2001). Although the field kit cannot replace the careful laboratory-based measurements of soil aggregate stability, it can clearly provide valuable information when these more intensive procedures are not possible (Herrick et al. 2001).

Correlation of visual scores with soil properties

Visual assessment scores are correlated with measured data of physical soil quality (Murphy et al. 2013; Kerebel and Holden, 2013; Giarola et al. 2013; Guimaraes, 2013; Lin et al. 2005), chemical soil qulity (Murphy et al. 2013) and crop yield (Mueller et al. 2009; Mueller et al. 2013; Giarola et al. 2013; Munkholm et al. 2013). Murphy et al (2013) compared three tests namely VSA scores, SoilPak scores and DT Friability and correlated with ESP (exchangeable sodium percentage), ESI (electrochemical stability index), MOR (modulus of rupture) and SOC (soil organic carbon). ESP, ESI and MOR were found well correlated with those scores whereas SOC was poorly correlated and non significant in some cases. Giarola et al. (2013) assessed Oxisols of Ponta Grossa in the central-southern part of Parana State, southern Brazil with VESS and VSA scores. The relationship between Sq index based on VESS and clay content was not significant ($p < 0.26$), whereas the relationship between VS index and clay content was highly significant ($p < 0.0002$). The Sq obtained by the method of Ball et al. (2007) ranged from 3.0 to 4.2, with a mean of 3.68 ± 0.38, while that VS obtained through the method of Shepherd (2009) ranged from 0.5 to 1.5, with a mean of 1.11 ± 0.32. Munkholm et al. (2013) reported weaker correlations of VESS scores with the quantitative soil physical properties. Guimaraes et al. (2013) reported a positive relationship between VESS score and bulk density with $r^2 = 0.51$ for the clayey soil and 0.62 for the sandy loam soil. A strong significantly positive correlation was shown between VESS score and resistance to penetration only under native forest in both soils, with $R^2 = 0.65$ for the clay soil and 0.72 for the sandy loam soil. Soil air permeability showed a weak negative correlation with VESS. Peerlkamp score and relative bulk density shown significant linear negative correlations ($P < 0.05$) with large scatter around regression line (Mueller et al (2009). Strong and significant correlation were found between VESS scores and tensile strength and visible porosity of five soils with clay content ranging from 13.9 to 78 percent (Guimaraes et al. 2011).

The relationship between VESS score and crop yield was significant only at the 10% level probably because the ranges of scores and yields were narrow, despite the wide range in soil texture along of transect Giarola et al (2013). Munkholm el at (2013) indicated with experimental results a rather good correlation between topsoil structure and crop yield. Corn yields decreased linearly with increasing VESS Sq values ($R^2 = 0.35^{**}$). The correlation between Peerlkamp score and grain yield of cereals was significant and $P = 0.06$ and thus very close to the common significance level of $P = 0.05$ (Mueller et al (2009).

Comparison of different visual assessment methods

Murphy et al. (2013) found DT Friability well and significantly correlated with VSA score and SOILPak scores, whereas, the correlation between VSA and SOILPak scores were found weak due to non -similar ranges (0.5 to 1.5 for SOILPak and 10 to 40 for VSA). Although the range between the two indices is similar, the VSA and VESS scores were not significantly related ($p < 0.178$) (Giarola et al. 2013).

Conclusion

The use of techniques of visual evaluation is now well established and proving valuable in explaining differences in crop performance and yield due to soil management and type. The tests are particularly helpful in conveying the importance of soil structure to farmers and in fostering the exchange of soil knowledge. Visual evaluation has also moved beyond soil structure to include other soil properties and crop and topographic conditions.

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Heavy metal polluted Soils in India: status and countermeasures

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Abstract

Contamination of soil environment by heavy metals is becoming a rife across the globe. The rapid industrialization and poor management of industrial effluent is creating a more chance of heavy metal pollution. Even at their exposure at minute level, heavy metals can have carcinogenic effect on human, animals and negative effect on soil microorganisms & crop plants. Excessive concentration of heavy metals viz., Cr, Cd, As, Ni, Se and Pb have been found in soils of agricultural land nearby cities, mines and industrial areas around the world. Although geogenic source of pollution has been observed for some trace elements in different parts of the world including India, the secondary sources of anthropogenic pollution are more dominant, localized and causing higher magnitude soil pollution. Use of contaminated water for agricultural purpose has affected the soil health and reduced the crop productivity in the long run. Remediation of heavy metal contaminated soil is a necessity in order to have a safe and healthy environment, which will sustain our life on the beautiful earth planet. This paper describes the heavy meal sources, type and status in India; remediation techniques and safety measures for safe use of industrial contaminated water.

Keywords: Heavy metals, Remediation, Soil microorganisms, Wastewater

"Heavy metals" is a general collective term, which applies to the group of metals and metalloids with atomic density greater than 5 g cm^{-3}, or 5 times or more, greater than water (Nriagu and Pacyna 1988; Hawkes 1997). In other words the term "heavy metals" refers to any metallic element that has a relatively high density and is toxic or poisonous even at low concentration. Important metal and metalloids of environmental concern are arsenic (As), cadmium (Cd), chromium (Cr), nickel (Ni), lead (Pb), mercury (Hg), selenium (Se), etc. While heavy metals are ubiquitous in the environment and some are essential micronutrients, all are toxic to biota above some threshold concentration (Knox et al. 1999). Soil pollution by heavy metals is a significant environmental problem worldwide (Alloway 1995). In particular, heavy metal pollution of surface soils due to intense industrialization and urbanization has become a serious concern in many developing countries (Mireles et al. 2012; Wei and Yang 2010; Yaylali and Abanuz 2011). Heavy metal pollution in the soil can be caused by many anthropogenic activities like mining, improper disposal of industrial and urban waste, transportation and unscientific agricultural activities. The chemical composition of soil, particularly its metal content is environmentally important, because the presence of these metals in the soil affects the environment in several ways: contamination of food because of the plants grown in polluted soil, as well as a decrease in crop productivity (Rooney et al. 2007) and soil microbial activity (Brookes and McGrath 1984; Chaudri et al. 1993; Akerblom et al. 2007). Because of its environmental significance, many studies to determine risk caused by metal levels in soil on human health and forest ecosystem have attracted attention in recent years (Denti et al. 1998; Sandaa et al. 1999; Krzyztof et al. 2004). Extent of soil pollution with heavy metals from various anthropogenic sources and subsequent uptake by crops depend upon several factors such as source, soil type, frequency of application, organic matter content, seasonal variations, major and minor nutrients and load of chemical pollutants. However, pollution of soil by heavy metals is an irreversible process and it is hard to manage and reclaim these kinds of metal polluted soils.

In India, information on extent of soil pollution, its impacts on other functional area, plant and human health is not complete. The data given by different agencies on soil degradation mainly focus on physical aspects of soil deterioration like erosion, waterlogging etc. and not much attention was given in case of chemical degradation except for soil salinity problems. Information about the impact of different developmental activities like mining, industries, urbanization, transportation and others, on soil environment like heavy metal buildup and persistent organic pollutants, toxic substances, etc. are very meager and should be addressed. In recent years, contamination of large areas of land by heavy metals has become a major concern. In India, many urban and dense cities with significant industrial waste generation have been found to have contaminated soil in and surrounding areas. We should not forget that though estimated land area affected with pollution is smaller as compared to other types of degraded land, these are generally situated in more fertile area nearby cities and also, reclamation of such land is generally very costly (many a times with lower degree of success) as compared to the other types of degraded land. In order to develop an action plan for remediation of such area, we need to have first hand information on the status of soil pollution in the country. Unlike in India, in many developed countries like in North America and Western Europe, the extent of contaminated land is best known, with many of the countries in these areas having a legal framework to identify and deal with this environmental problem. Developing countries tend to be less tightly regulated despite some of them having undergone significant industrialization. Hence, soil pollution regulations, guidelines and policy are the need of the hour. The extent of soil pollution, its diversity and impact in the country is not well documented. Therefore, this article mainly focuses on heavy metal contaminated soils in the context of sources of heavy metals and its impact to soil environment and current situation and extent of heavy metal polluted soils in the country and remediation and sustainable management of heavy metal contaminated soils.

Sources of Heavy Metal Contamination in Soils

Excess heavy metals in the soil originate from many sources, which include atmospheric deposition, sewage irrigation, improper stacking of the industrial solid waste, mining activities and the use of pesticides and fertilizers (Zhang et al. 2011) as presented in Table 1.

Large areas of land can be contaminated by heavy metals released from smelters, waste incinerators, industrial wastewater, and from the application of sludge or municipal compost, pesticides, and fertilizers. Irrespective of their sources in the soil, accumulation of heavy metals can degrade soil quality, reduce crop yield and the quality of agricultural products, and thus negatively impact the health of human, animals, and the ecosystem (Nagajyoti et al. 2010). It is important to identify the sources of heavy metals, besides quantifying their concentrations and spatial variability in the soils.

Geogenic sources of heavy metals

The parent material largely influences the heavy metal content in many soil types, with concentration sometimes exceeding the critical values (Palumbo et al. 2000). Several heavy metals, such as Ni, Cr and Mn, are contained as trace elements in some rock types of volcanic and metamorphic origin (Alloway 1995). During weathering processes the primary crystalline structures of some rock minerals are completely broken and relevant chemical elements are thus either adsorbed in the topsoil or transported towards surface water or groundwater targets. Natural sources are: seepage from rocks into water, volcanic activity, forest fires, etc. In India, As, F, Fe and Se are reported to be of geogenic origin but their release into the environment is further aggravated due to

Table 1. Sources of hazardous metals in India (CPCB 2009)

Metal	Industry
Chromium (Cr)	Mining, industrial coolants, chromium salts manufacturing, leather tanning
Lead (Pb)	lead acid batteries, paints, e-waste, smelting operations, coal- based thermal power plants, ceramics, bangle industry
Mercury (Hg)	Chlor-alkali plants, thermal power plants, fluorescent lamps, hospital waste (damaged thermometers, barometers, sphygmomanometers), electrical appliances etc.
Arsenic (As)	Geogenic/natural processes, smelting operations, thermal power plants, fuel burning
Copper (Cu)	Mining, electroplating, smelting operations, vanadium Spent catalyst, sulphuric acid plant
Nickel (Ni)	Smelting operations, thermal power plants, battery industry
Cadmium (Cd)	Zinc smelting, waste batteries, e-waste, paint sludge, incinerations & fuel Combustion
Zinc (Zn)	Smelting, electroplating

anthropogenic activities that include disposal of untreated wastes, indiscriminate use of agrochemicals and agricultural inputs, unscientific mining, dumping industrial wastes, outdated technology, inadequate treatment and safe storage/management/disposal of chemicals and waste, and lack of designed engineered landfills.

Urbanization, inadequate treatment capacity and disposal of untreated wastes

Around 38254 MLD of sewage water and more than 25000 MLD of industrial wastewater generated from cities and towns of India (Table 2) are discharged in the surface water bodies (mostly without treatment) causing deterioration of river water quality near several cities (CPCB 2009). Use of such wastewater loaded surface water as irrigation has resulted significant build-up of heavy metals in soils of agricultural land near several cities and towns of India (Saha and Panwar 2013). With increased industrialization in residential areas, different materials are discharged into sewage which leads to environmental pollution. Large numbers of open and covered channels carry a mixture of waste water as generated by domestic, municipal and industrial activities (CPCB, 2009). The projected waste water generation estimates of 122,000 MLD for the country by 2050 (Bhardwaj 2005). Cities around the Ganga basin are generating 2637.7 MLD of sewage, but are in a position to treat 1174.4 MLD i.e., 44.2% only. The remaining sewage goes off without any treatment, pollutes the river Ganga. The treatment capacity existing is also not effectively utilized due to operation and maintenance problem. Apart from domestic sewage, about 13468 MLD of WW is generated by industries (mostly large scale) of which only 60% is treated (Kaur et al. 2012). Although untreated sewage is being used by farmers to grow crops on urban peripheral lands due to its high nutrient contents, it's use for longer periods is a matter of great concern (Saha et al. 2010). Urban sewage containing industrial effluents was found to relatively carry relatively high amounts of heavy metals such as Ni, Cr, Pb, Cd, Zn and salt load causing salinity alkalinity hazards. India generates about 50 million tonnes of municipal solid wastes (MSW) every year from cities (CPCB 2000) containing significant heavy metals. About 9-10% of these wastes find a way into agricultural land in the form of compost contaminating with heavy metals.

Use of contaminated ground and sewage water for irrigation

It has been estimated that in India sewage water can annually irrigate about 1.0 Mha to 1.5 Mha of land area (Sengupta 2008). In peri-urban areas, farmers usually adopt year round, intensive vegetable production systems (300-400% cropping intensity) or other perishable commodity like fodder and earn upto 4 times more from a unit land area compared to freshwater (Minhas and Samra 2004). However, studies have shown the buildup of heavy-metals in the soils to a varying extent (Brar et al. 2002; Rattan et al. 2005) after repeated use of WW for irrigation of crops. Sewage irrigation for consecutive 20 years has resulted in a significant build-up of DTPA-extractable Zn (208%), Cu (170%), Fe (170%), Ni (63%) and Pb (29%) in soils over GW irrigated soils, whereas Mn content was depleted by 31% (Rattan et al. 2005). Soils irrigated with sewage water for 20 years resulted into a significant buildup of DTPA extractable Zn (2.1 times), Cu (1.7 times), Fe (1.7 times), Ni (63.1%) and Pb (29%) in sewage-irrigated soils over adjacent tube well water irrigated soils (Simmons et al. 2006). Similarly, Yadav et al. (2003) expressed that the sewage water discharged through all the districts of Haryana contained micronutrients like Zn, Fe and Co to the extent of 30.1, 178.8 and 4.3 mg L-1, respectively. The excessive accumulation of heavy metals in agricultural soils through WW irrigation, may not only result in soil contamination, but also lead to elevated heavy metal uptake by crops, and thus affect food quality and safety. This loading of heavy metals often leads to degradation of soil health and contamination of food chain mainly through the vegetables grown in such soils (Rattan et al. 2002).

Table 2. Wastewater treatment capacity in urban areas in India in 2008 (CPCB 2009)

Category	No. of cities	Total water supply	Wastewater generation (in MLD)	Treatment capacity
Class-I City	498	44,769.05	35,558.12	11,553.68 (32%)
Class-II town	410	3,324.83	2,696.7	233.7 (8%)
Total	908	48,093.88	38254.82	11787.38 (31%)

Indiscriminate use of agrochemicals and agricultural inputs

Agricultural practice is frequently a source of heavy metal contamination (Pendias 1995), usually as a result of impurities in the fertilizers used. Other sources include sewage sludge, when used as an organic amendment, manure and compost as well as airborne particulate transport (Alloway 1995; Forstner 1995). Some of the agricultural sources of trace elements that contaminate soils are given in Table 3. In India, though these materials are frequently applied and no such cases of heavy metal contamination from the fertilizer and agrochemicals are reported. However, periodic monitoring of soils treated with these materials is necessary to know the amount of accumulation of HMs in soil in the food chain and human health.

Heavy metal pollution of soils

Heavy metal accumulation in soil and plants due to anthropogenic activity has been reported from different areas of India (Sachan et al. 2007; Shanker et al. 2005; Deka and Bhattacharyya 2009). In Table 4, major heavy metal contaminated sites in India are listed and discussed further.

Arsenic

Arsenic frequently enters into the human body through crops growing on arsenic-contaminated soils or contaminated groundwater used for irrigation purpose. Occurrence of as in groundwater has been reported from different countries and the extent of As contamination in groundwater is consistently increasing with the addition of other countries/ areas to the existing list. Central Ground Water Board (CGWB 1999) reported that the higher incidence of arsenic in groundwater is restricted mainly within the upper Delta plain along the Bhagirathi and other rivers. Out of nineteen (19) districts in West Bengal, recently nine districts are arsenic-affected where cropping intensities are very high. For the agricultural crop production, particularly the Boro (summer) rice during the lean period (March to May), a huge amount of the ground water loaded with arsenic is used for irrigating agricultural crops. Majority of fertile alluvial soils covering districts of Malda, Dinajpur (North and South), Murshidabad, Nadia, Burdwan, 24 Parganas (North and part of the South), Hoogly is in the trap of arsenic contamination, with a gradual build-up from the use of arsenic loaded ground water as a source of irrigation affecting soil quality vis-à-

Table 3. Agricultural sources of trace element contamination in soils (mg kg^{-1}) (Pendias and Pendias 2000)

Element	Sewage sludge	Phosphate fertilizers	Limestone	Nitrogenous fertilizers	Manures	Pesticides
As	2-26	2-1200	0.1-24	2-120	3-150	22-60
Cd	2-1500	0.1-170	0.04-0.1	0.05-8.5	0.3-0.8	-
Cr	20-40600	66-245	10-15	3-19	5.2-55	-
Cu	50-3300	1-300	2-125	1-15	2-60	12-50
Hg	0.1-55	0.01-1.2	0.05	0.3-3	0.09-26	0.8-42
Mn	60-3900	40-2000	40-1200	-	30-550	-
Ni	16-5300	7-38	10-20	7-38	7.8-30	-
Pb	50-3000	7-225	20-1250	2-1450	6.6-15	60
Zn	700-49000	50-1450	10-450	1-42	15-250	1.3-25

Table 4. Major heavy metals contaminated sites in India (CPCB 2009)

Cr	Pb	Hg	As	Cu
Ranipet (TN)	Ratlam (MP)	Kodaikanal (TN)	Tuticorin (TN)	Tuticorin (TN)
Vadodara (Gujarat)	Bandalamottu Mines (AP)	Ganjam (Orissa) (Jharkhand)	Gangetic plain (WB)	Singbhum Mines
Talcher (Orissa)	Vadodara (Gujarat)	Singrauli (MP)	Balia and other districts (UP)	Malanjkhand (MP)
Kanpur (UP),	Korba (Chattisgarh)			

vis crop production. Progressive build up of arsenic might be due to the left over roots after harvest contributing substantially to the accumulation of arsenic in soils (Garai et al. 2000). The toxicity of As depends on forms or species of As in soil rather than the total As content per se, with Arsenite (III) with later being more toxic to animal and human.

Selenium

Distribution of selenium in soils greatly depends upon the composition of geological materials. Selenium is efficiently transferred through the soil - plant - animal - human system. Seleniferous soils have been identified mainly in north eastern parts of Punjab, India. In the seleniferous areas, the selenium content of surface (2.12 ± 1.13 mg kg^{-1}) and subsurface (1.16±0.51mg kg^{-1}) layers of soils was 4-5 times higher than that of non-seleniferous areas. Deposition of seleniferous materials transported by seasonal rivulets from the higher reaches of the Siwalik hills and use of underground water for frequently irrigating crops like lowland rice has been ascribed to the development of seleniferous pockets (Dhillon and Dhillon 2003). The dry land areas (with very low rainfall or having less irrigation water) in Rajasthan and southern parts of the Haryana state had above normal soil selenium levels. These soils were also found to be alkaline in reaction.

Chromium

Koelmel and Prasad (2013) quantified anthropogenic terrestrial and atmospheric emissions of Cr. Under one emission control scenario in 2008 the major atmospheric chromium emission sources in India were stainless steel (43%), ferric chrome industries (42%), coal (9%), cement (2%), crude steel (2%), and chromite mine (2%) operations. The major sources to soil and water bodies were chromite tailings (62%), ferric chrome slag and dust (28%), fly ash (5%) and tanning effluent (2%). Tanning industries situated in Tamil Nadu and UP are major sources of Cr contamination of agricultural lands through tannery effluents (Dotaniya et al. 2014a, b). There are several contaminated sites in Vellore, Erode and Dindigul districts in Tamil Nadu, where, more than 60% of Indian tanneries are located. Assessment of Cr in contaminated soils in Vellore district showed that the soils around tannery industries are severely contaminated with Cr, and in most places exceeded the maximum threshold limit prescribed in different countries. Similarly, in Kanpur (UP), Orichem (Orissa), Ranipet (TN) and Nibra (WB) also Cr contaminated sites were reported.

Mercury

Main contributors to Hg emissions in India are caustic-chlorine industry, steel industry; coal based thermal power plants, cement industry, thermometer factory paper industry, pharmaceuticals, pesticides, hospital and municipal solid wastes. Singrauli of Madhya Pradesh and Sonbhadra district of Uttar Pradesh (a major site of Thermal Power Generation in India), and Kodaikanal, Tamil Nadu (Thermometer factory) are reported to be highly contaminated with Hg. Mercury in dust fallout from a steel plant near Raipur showed that the fallout of elemental mercury over the soil horizon was in the range from 60.36 to 836.18 g $km^{-1}month^{-1}$ depending on the distance, wind direction and location of the area with respect to the domestic environment in the vicinity of a steel plant contained mercury in the large of 2.3 to 56.8 mg kg^{-1}. Comparative study of the presence of mercury in the air dust particulates from paper mill of two metropolitan cities of India revealed that mercury in the ambient air dust in the paper mill was 20.5 +0.8 µg g^{-1} compared to 0.08 to 0.91 µg g^{-1} in cities. Mercury emission and ambient mercury levels were observed in the range of 1.13-4.00 µg m^{-3} and 0.055-6.17 µg m^{-3}, respectively. Mercury contamination in water in India is verging on the alarming situation due to discharge of industrial effluents containing mercury ranging from (0.058-0.268 mg l^{-1}) against 0.001 mg l^{-1}. as per WHO and Indian standards. Mercury levels in water near caustic chlorine industry have been reported as high as 0.176 ± 0.0003 mg l^{-1}. in water and 596.67 ± 25.17 mg kg^{-1} dry wt. soil against the prescribed limit of 0.001 mg l^{-1}. in water and 0.05 mg kg^{-1} in soil (Srivastava 2002).

Impact of Heavy Metal Contamination of Soils

Impact on soil microorganisms and enzymatic activity

Microbial activity and enzymatic activity in the soil can sensitively reflect the quality of the soil (Lee et al. 1996). Aceves et al. (1999) held that microbial biomass of the soil was an important indicator of determining the extent of soil contamination. Microbial activity is inhibited significantly in the heavy metal contaminated soil. Kandeler et al. (1997) indicated that the microbial biomass in the soil contaminated by Cu, Zn, Pb and other heavy metals were inhibited severely. The soil's microbial biomass near the mine was significantly lower than that far away from the mine. The effects of different concentrations of heavy metals and different heavy metals on soil microbial biomass were different. Chander et al. (1995) studied the effect of different concentrations of heavy metals on soil microbial biomass, and found that only if the concentration of heavy metals in the soil was three times above the environmental standard, established by the European Union, it could inhibit microbial biomass. Fliepbach et al. (1994) found that low concentrations of heavy metals could stimulate microbial growth and increase microbial biomass; while high concentrations could decrease soil microbial biomass significantly. Enzymes in the soil play an important role in the process of organic matter decomposition and nutrient cycling. Studies have shown that the activities of enzymes in the soil are related to the heavy metal contamination. Saha et al. (2013) found that the activities of almost all enzymes in the soil were significantly reduced with the increase of the concentration of heavy metals.

The impact of heavy metals on plant, animal and human health is depicted in Table 5.

Heavy metal polluted areas in India

Although India's economic growth is aided by higher levels of industrialization, there is also a huge concern for the environmental degradation that has followed. Researchers identified critically polluted industrial areas and clusters or potential impact zone based on its Comprehensive Environmental Pollution Index (CEPI) rating. There are 43 critically polluted zones that were reported in the 16 states, which has CEPI rating more than 70. Among the 43 sites, 21 sites prevailing in only 4 states, namely Gujarat, Uttar Pradesh, Maharashtra and Tamil Nadu. Some of the severely polluted industrial clusters of India are discussed.

Ratlam and Nagda Industrial Area, Madhya Pradesh

In Ratlam the groundwater at about 60 - 80 m depth in several villages has been polluted with salts due to contamination with percolating industrial effluent and is

Table 5. Impact of heavy metals on plant and animal/human health (Gupta and Gupta 1998, Rattan et al. 2002)

Pollutant	Impact on: Plant	Impact on: Animal/human health
As	Red brown necrotic spots on old leaves, yellow browning of roots, growth reduction	Gastrointestinal problem, cardio vascular problem, Diarrhea, Colic pain, weak pulse, skin pigmentation renal dysfunction
Cd	Brown margin to leaves, chlorosis, necrosis, cubbed leaves, brown stunted roots, reddish veins and petioles, reduction in growth, purple coloration	Renal dysfunction, increased uric acid, Liver cirrhosis, lung cancer Vomiting, Itai-itai
Cr	Affect seed emergence, stunted plant growth and decrease dry matter production	Damages the kidneys, the liver and blood cells, Ulceration of the skin, premature dementia, cancer.
Pb	Dark green leaves, stunted foliage, increased amount of shoots	Reduces synthesis of haemoglobin affect the central nervous system Renal dusfunction, loss of weight and loss of teeth, Vomiting and reduced immune
Ni	Chlorosis, necrosis, stunting, inhibition of root growth, decrease in leaf area	Nausea, vomiting, insomnia, irritability, tightness of the chest, non-productive, cough, dyspnoea, cyanosis, tachycardia, palpitations, cardiac arrest
Hg	Severe stunting of seedlings and roots, chlorosis, browning of leaf tips, reduction in growth	Affect the central nervous system Renal dysfunction, mental deterioration, Vomiting, insomnia and loss of smell sense
Cu	Chlorosis, yellow coloration, purple colouration of the lower side of the midrib, less branched roots, inhibition of root growth	Wilson's disease - heaglobinuria, Jaundice Enlargement of Kidney, liver and spleen Hypertension, Neurological problem, paralysis and abdominal pain
Se	Interveinal chlorosis, black spots, bleaching and yellowing of young leaves, pink spots on root	Nervousness, drowsiness, rapid and weak pulse, Colic pain, respiratory failure, paralysis, Enlarge spleen, loss of appetite, loss of hair and nails, loss of fertility, heart problem, cirrhosis

being used for irrigation to winter crops (Saha 2005). While mean EC values of ground water of unaffected villages were in the range of 0.85-0.92 dS m^{-1}, the same in affected villages ranged from 1.49 to 4.50 dS m^{-1} with an overall mean of 2.84 dS m^{-1}. Contents of sodium, sulphate and chloride in groundwater of affected villages were, respectively, 348%, 288% and 364% more than the similar values obtained in groundwater samples of unaffected villages. About 40% of the water samples in the polluted area can be categorized as having very high salinity (>2.25 dS m^{-1}) and sodium hazard (SAR > 9) and about 71% of the samples have potential for severe Cl^{-1} hazard (>10 meq Cl^-) permitting their use as irrigation only in tolerant crops. Use of such bad quality irrigation water has caused the disappearance of vegetable cultivation from the polluted groundwater area. Groundwater samples of the polluted area contained, on an average, 9.1 g l^{-1} Pb, 4.1 g l^{-1} Cd and 18.5 g l^{-1} Cu, which were more by about 162, 26 and 83% respectively over those in groundwater samples of unpolluted area. Considering WHO limits for groundwater, samples from Bhajankheda, Jadwasa khurd and Dosigaon villages of polluted area contained unsafe levels of Pb and Cd (Saha and Sharma 2006).

In Nagda, water of Chambal river has become severely polluted with effluents from textile industry and is being used for irrigation to winter crops in nearby areas of several villages (Saha 2005). Irrigation water near affected villages had EC ranging from 2.38 to 4.11 and contained Na, K, Ca, Mg, SO_4^{-2} and Cl^-, on an average, 4.7, 9.9, 7.7, 5.8, 1.8, 9.0, and 6.9 times more than the corresponding mean values obtained in irrigation water (ground water) in unaffected villages. Long-term application of these polluted water to soil resulted significant accumulation of salts in the root zone layer of both these areas. There were significant increases in salinity as well as ESP levels in soils due to irrigation with polluted water in both the area, magnitude being much more in the soils irrigated with polluted river water at Nagda. Significant increases in concentrations of Na+, Cl-, SO_4^{-2} and HCO_3^- and decreases in the concentrations of K+ and NO_3^- in the soil solution were observed in the polluted soils of Ratlam. Similarly, polluted soils of Nagda recorded much higher concentration of major cations and anions (except NO_3^-) in the soil solution. Available Cu contents in soils of polluted area were higher as compared to the soils of unpolluted area. Concentrations of Zn and Cu were also considerably more in the in the wheat plant tissue of the polluted area as compared to those of unpolluted area. This indicates possible contaminations of Zn and Cu in the food chain through the soil-plant-animal in the villages using polluted Chambal river water for irrigation in growing crops.

Pithampur (Dhar) Industrial Area, Madhya Pradesh

Pithampur is the second largest industrial area in Asia has both large and small scale industries. The majority of the vehicle-producing companies of India have their factories in Pithampur. Also, this area is housing, food processing, chemical processing, distilleries, manufacturing, and textile industries. Water of wells and tube wells in Cheerkhani and Silotia villages near to the industrial area is having high salinity EC (1.91 - 4.07 mS cm^{-1}) and sodium hazard (SAR > 10) and about 82% of the samples have potential for severe C l- (>10 me l^{-1}) hazard permitting their use as irrigation only in tolerant crops (Panwar et al. 2006). The EC of some of the tube well water of polluted villages has gone up more than 2.5 dSm^{-1} cm^{-1} indicating that effluents of industrial area have contaminated the ground water. The ground water samples of polluted area contained, on an average, 84.2 µg l^{-1} Cr, 3.7 µg l^{-1} Pb and 1.2 µg l^{-1} Cd. Several ground water samples of polluted area had Cr concentrations more than the WHO permitted level for drinking water. Surface soil samples of ground water polluted area of Cheerkhani and Silotia villages had, on an average, higher EC (3.4 times), SAR (3.1 times) due to considerable accumulation of salt ions. The soils receiving polluted ground water were higher in Co (7.5 times) and Cr (1.5 times) as compared to soils of unpolluted area (Panwar et al. 2006).

Patancheru Industrial area, Medak District, Andhra Pradesh

It has about 300 pharmaceutical, heavy engineering, paints, chemical and paper factories established over the last two decades. They generate more than 10 million liters of effluent water per day, most of which directly discharges to the natural hydrological system. Arsenic levels were high in effluent water from industrial areas with concentrations ranging from 1.8 to 97.3 µg l^{-1} with an average of 26.3 µg l^{-1} (Panwar et al. 2006). The high As values up to 15,000 - 30,000 µg l^{-1} were also reported near the exit of central effluent treatment plant (CETP). Nickel concentration varies from 4.7 to 57.4 (average of 23.4 µg l^{-1}), Pb varies from 0.3 to 14.2 µg l^{-1} (average of 2.0 µg l^{-1}) and Zn varies from 32.9 to 293.9 mg kg^{-1} (average of 81 µg l^{-1}). Some sample shows high values of Fe, Ni, Pb and Zn, which are near the vicinity of industrial areas (Panwar et al. 2006). The ground water in some places near the study area is also contaminated with salts (high pH and EC) and some metals like As, Ni, Cr and Zn.

Zinc smelting area in Udaipur, Rajasthan

The zinc smelter plants near Udaipur have smelting capacity of about 49,000 TPA. With the expansion of smelter plant a number of other production units have been commissioned, including sulfuric acid (87,000 TPA), cadmium metal (190 TPA), phosphoric acid (26,000 TPA), single superphosphate (72,000 TPA) and zinc dust (36,000 TPA). Since its inception the effluent from the plant has been discharged into a stream which flows about 3 kms to the east and merges into Berach river. The effluent of zinc smelter is being discharged into a stream, employed for irrigating the crops in the vicinity of the smelter plant. Concentrations of zinc and fluoride in the river water were higher than the permissible limit of 5 and 2 mg l^{-1}, respectively (Panwar et al. 2006). The concentration of these (Zn and Cd) heavy metals decreased with the distance from the discharge point in effluent irrigated soils nearer to the discharge point (Gorla and Bichhari village).. A large variation in the content of total zinc (65 to 1590 mg kg^{-1}), total cadmium (0.07 to 8.37 mg kg^{-1}) and DTPA extractable zinc (19 to 173 mg kg^{-1}) have been recorded in the soils of the area under study. In comparison to a safe concentration determined for soils (Saha et al. 2013), most of the soil nearby Zn smelting area has accumulated toxic levels of Zn and Cd. With few exceptions, total zinc, cadmium and available zinc content of the soil decreases with an increase in the lateral distance from the stream and river (Panwar et al. 2006).

Soil and water pollution by textile industries in Pali, Rajasthan

The textile printing and dyeing industries (more than 800 textile units) located in the Pali town (one of the critically polluted areas identified by CPCB) are discharging industrial effluents into the river Bandi, a non-perennial river with no flow in the lean season, thus severely contaminating both the river as well as the groundwater. The industries here discharge a variety of chemicals, dyes, acids and alkalis besides heavy metals and other toxic compounds. The effluents are multicoloured and highly acidic and/or alkaline. Ground water from downstream villages was highly saline as compared to upstream villages. These well waters were high in soluble Na. Copper concentration in well water samples were above the drinking water standards in all the wells in downstream villages; while Pb is high in Kerla, Sukarlai and Nehada; Cr level is high in Kerla, Sukarlai, Gadhwara and Phikaria; As is high in Jewadiya, Kerla and Phikaria (Panwar et al. 2006). The above well water was not suitable for irrigation due to high salinity (>4 dS m^{-1}). The Nahada dam built for storing water, become an industrial storage tank and thus leads to groundwater contamination. The soils cultivated using contaminated well waters have also developed high salinity (irrigation with high saline water) (Panwar et al. 2006).

Korba (Chhattisgarh) industrial area

Korba city is the Power Capital of Central India with the NTPC's Super Thermal Power Plant working at 90% Plant Load Factor. Korba is also having aluminium industry (BALCO), textiles, engineering workshops, hardware (Al & Fe), detergents, plastic toys, PVC cable pipes, cement products, electricity transformer, bakelite, distemper, clay insulator manufacturing units and other small industries, generating large quantity of acidic effluent, which directly drained in agricultural fields and contaminate the soil. Groundwater samples collected from villages nearby industrial area contained higher levels of heavy metals Cd, Co, Cr, Ni, and Zn as compared to those collected from far away villages (Panwar et al. 2006). The majority of the groundwater samples from the polluted area had heavy metals more than the levels permitted for drinking purpose. Soil irrigated with effluent turned highly acidic. Other soil properties viz. EC, soil organic carbon, DTPA extractable heavy metals and total heavy metals were increased with the application of industrial waste/effluent or contaminated water as compared to the non-polluted soils. The total as well as DTPA extractable heavy metals particularly, Cr and Cu were high in most of the polluted soil (Panwar et al. 2006).

Tiruppur Industrial Area

Tiruppur has been identified as one of the critically polluted area by CPCB. Industrial area discharges more than 90 MLD into Noyyal river (tributary of Cauvery river). It passes through Tiruppur and stored up in the Orathapalayam Dam to be used in agriculture and drinking purposes for the downstream villages in the Tiruppur and Erode District. The Industrial area is having 729 bleaching and dyeing units Due to pollution, drinking water quality, fisheries and the agriculture in Tiruppur area and downstream villages of Noyyal river has been affected. The river water is quite harmful (EC >3 dS m^{-1}) to agriculture in an area of 146 km^2 and critical (EC 1.1 to 3 dS m^{-1}) in 218 km^2 (Panwar et al. 2006). The groundwater in some villages is having high values of Pb and Cr which may be attributed to the industrial activities. The majority of the samples are not suitable for domestic purposes and far from drinking water standards. Irrigation of cropping land with polluted water transformed the productive soils into saline soil (> 4 dS m^{-1}); the dominant cations and anions being Na+ and Cl- and SO_4^{-2}. Irrigation with polluted Noyyal river water resulted buildup of salinity (EC > 4 dS m^{-1}) in soils of agricultural land (Panwar et al. 2006).

Coimbatore Industrial Area, Coimbatore

Coimbatore industrial area is the 2nd largest industrial area in Tamil Nadu. The industrial area is having about 500 textile industry, 200 electroplating industry, 100 foundries and 300 dyeing industries. All the industrial effluent/sewage is going to Ukkadam river, which is the source of irrigation in the nearby area (16000 acre). Heavy metal contents in the city sewage water were quite high and varied widely with the season. IISS investigated changes in soil properties in agricultural land nearby different industrial clusters; namely electroplating industry, textile industry, dye industry and city sewage irrigated areas (Panwar et al. 2006). Groundwater near industrial area has developed salinity due to contamination, mainly with salts of Na+ and Cl-; the magnitude of contamination was more near Textile and dye industries. Sulphate contamination was maximum in the groundwater near electroplating industries. Soils of agricultural land near textile and dye industries have developed severe salinity (EC > 6 dS m^{-1}) and slight alkalinity (pH >8.0). Soils of agricultural land near industrial areas contained 47 to 178 mg kg^{-1} Ni, 47 to 214 mg kg^{-1} Pb, 0.5 to 4.2 mg kg^{-1} Cd and 43 to 241 mg kg^{-1} Cr. Most of the soil had all the heavy metals more than the safe concentration limits determined by Saha et al. (2013), which indicate that these soils may pose threat to the environment. Nickel and Pb concentrations were higher in soils near the electroplating and sewage industrial area; Cd concentration was higher in soils irrigated with mixed effluents, and sewage; Cr concentration was higher in soils irrigated with textile, dye and sewage effluent (Panwar et al. 2006). DTPA extractable heavy metal contents have been also very high as compared to those normally observed in unpolluted soils, which indicates soils of agricultural land near the industrial area of Coimbatore are likely to impart considerable threat to living organisms.

Katedan Industrial Development Area in South of Hyderabad, Andhra Pradesh

Very high concentrations of lead, chromium, nickel, zinc, arsenic and cadmium throughout the industrial area, housing 300 industries dealing with dyeing, edible oil production, battery manufacturing, metal plating, chemicals, etc. (Govil et al. 2008). The random dumping of hazardous waste in the industrial area could be the main cause of the soil contamination spreading by rainwater and wind. The residential area is also contaminated by As and some small areas by Cr, Cu, Pb and Zn. Effluent generated from different industries in and around Katedan area were let into the ponds without proper treatment. As a result, groundwater nearby areas were contaminated with salts and several heavy metals (Cd, Cr, Ni and Cu). All the heavy metals (except Pb) in the groundwater were more than the permissible limits. Due to use of such contaminated groundwater for irrigation, contents of Pb, Ni and Cr in the soil increased.

Thane region of Maharashtra

The random dumping of hazardous waste in the industrial area caused groundwater and soil contamination (Bhagure and Mirgane 2011). Very high concentration of total dissolved solids, total hardness, total alkalinity, chemical oxygen demand, chloride etc. Groundwater samples are heavily contaminated by arsenic, cadmium, mercury, and nickel. Soil samples collected from residential, commercial and industrial areas are heavily contaminated by arsenic, cadmium, mercury, and nickel. In the residential areas the local dumping is expected to be the main source of heavy metals.

Baula-Nuasahi (Chromite) mining belts of Keonjhar District, Orissa

The overburden soils have low nutrient (N, P, and K) content and the microbial population was low. The metal ions were found to have leached to nearby agriculture lands, making them less fertile for crop production. Overburden dumps and seepage water were found to be the main sources of chromium pollution (Dhal and Pinaki 2014).

Manali industrial area in Chennai

In a study, considerable accumulation of Cu, Cr, Co, Ni, and Zn has been observed in soils of the Manali industrial area in Chennai, which is saturated by industries like petrochemicals, refineries, and fertilizers generating hazardous wastes (Krishna and Govil 2008). Soil samples were collected from the industrial area of Manali had elevated concentrations of Cr (149.8-418.0 mg kg^{-1}), Cu (22.4-372.0 mg kg^{-1}), Ni (11.8-78.8 mg kg^{-1}), Zn (63.5-213.6 mg kg^{-1}) and Mo (2.3-15.3 mg kg^{-1}).

Lead pollution in Coimbatore-Pollachi highway of Tamil Nadu

Lead contamination arises mainly from the combustion of petrol transmitted a particulate of lead halide and also as Pb from the evaporation losses of petrol to the atmosphere. An investigation was undertaken to know whether there is a problem of Pb pollution along the road side of Coimbatore-Pollachi highway of Tamil Nadu. Forty soil and plant samples were collected from a soil depth of 0-15 cm at a distance of 3 and 6 m from the road (Stalin et al. 2010). Lead enrichment factor was worked out considering the 10µg g-1 as the average Pb content from non contaminated soils and the results showed that the sample nearer to the road (3m) contains more Pb than at 6 m distance. There is an average enrichment factor of 6.60 for the soil samples with the maximum of 54.9 mg kg^{-1}. Among the plant samples soybean contains a higher concentration of Pb and the enrichment factor was high at 3 m distance (1966 mg kg^{-1}) than other plants.

Management of heavy metal polluted soil

Remediation measures for heavy metal contaminated soil

Soils have varying capacity to immobilize metals (through sorption, complexation, precipitation etc.) due to variable contents of clay types, organic matter, oxides, carbonates, phosphates, sulphides etc. as well as due to prevailing chemical conditions (pH and Eh) and therefore, tolerable level for metals depends considerably on soil properties. Expression of toxicity to organisms, therefore, depends on the degree of contamination and properties of soil. Remediation technologies to counter the toxicity can be grouped into engineering, chemical, and biological approaches.

Engineering approaches

Such technologies can be excavation and landfilling, in-situ vitrification, ex-situ solidification/ stabilization, ex-situ soil washing & soil flushing, creating a subsurface barrier to protect groundwater from contamination, thermal treatment, electrokinetic method etc. (Vangronsveld and Cunningham 1998). All these technologies, though quicker and provide a relatively long-term solution, are cost and energy intensive and applicable to a limited volume and area of soil body.

Chemical approaches

Most of the chemical approaches aim at reducing both total and free ion activity of the metals in soil solution so that their uptake by plant and toxicity to organisms are reduced. Among the chemical methods, application of amendments like phosphates, liming material, Fe/Mn oxyhydroxides, organic materials, zeolites, modified aluminosilicates (beringite) etc. has been advocated (Vangronsveld and Cunningham 1998).

Biological approaches

Certain hyperaccumulator plants like *Thlaspi caerulenscens, Haumaniastrum robertii, Ipomoea alpina, Macadamia neurophylla, Psychotria douarret, Thlaspi rotundifolium, Cystus ladanifer, Salix* sp. etc. are employed to remove heavy metals from soils. Such plants can tolerate high metal levels in soil and accumulate 10~500 times higher levels than other plants & crops. Application of chelates like EDTA has been found to enhance metal extraction by the hyperaccumulators (Huang et al. 1997, Nowack et al. 2006). Rock phosphate has been found to accelerate arsenic removal by hyperaccumulator *Pteris vittata* (Fayiga and Ma 2006). Most of the phytoremediating plants capable of accumulating high concentration metals, also produce less biomass, which limits their overall phytoextraction efficiency. Using modern techniques of biotechnology, several high biomass producing phytoaccumulators have been developed by introducing relevant genes (from hyperaccumulator, bacteria, animals) into non-accumulator plants (Singh et al. 2003). Some of high biomass hyperaccumulators for which regeneration protocols are developed include Indian mustard (*Brassica juncea*), sunflower (*Helianthus annuus*), tomato (*Lycopersicon esculentum*) and yellow poplar (*Liriodendron tulipifera*) (Mello-Farias et al. 2011). Plants have also been used to remove certain metals from soil by converting them to volatile forms (termed as phytovolatilization) (Zayed and Terry 1994). Several plants have also been used for the phytostabilization purpose (inactivation of soluble forms of metals in the rhizosphere) in order to prevent metal contamination of deeper soil layers and groundwater (Cunningham et al. 1995). Some researchers have demonstrated the potential of microbes for removal of metals from soil using 'Bio metal slurry reactor' technique (Vangronsveld and Cunningham 1998) and indirectly by microbially generated biosurfactant (Wang and Mulligan 2004). However, the feasibility of such technologies is yet to be proved at field level.

Integrated management of polluted soil

Generally, engineering methods of decontamination and immobilization are adopted for soils having very high levels of toxic metals so as to prevent their spread in unpolluted area and in living organisms, and the threat is required to be brought down to an acceptable level within a short span of time. Also, successful execution of these technologies requires intervention by the State due to involvement of high cost which may not be bearable by farmers. On the other hand, agricultural land affected with low to moderate level of pollutants may require modifications/interventions in the existing soil, crop and input managements in order improve and sustain soil quality, crop productivity and produce quality. For sustainable agriculture on unpolluted land, integrated soil management involves a combined strategy of effective nutrient, crop, water, soil and land management, fulfilling the objectives of improving soil fertility, water use efficiency, conservation of soil and water and increasing cropping intensity. In the context of polluted agricultural land, however, soil management should additionally address the issues like protection from pollutant build-up and its remediation and improving soil biological environment (Saha et al. 2014). Most often, such management strategies are dependent on:

- Type of pollutants and their mode of toxicity expression
- Contamination level
- Purpose of land use during and after remediation process
- Soil type (that determine their interactions with pollutants), depth of profile and topography
- Climate of the area
- Cropping pattern
- Availability of resources
- Economics

There exist complex inter-relationships among the above determining factors as well as agricultural management technologies (Fig 1). As a result, arriving at an appropriate strategy for combating threats in polluted soil is often not so simple. The task becomes more complex because of two reasons: firstly, ownership of land (and consequently the decision making process) lies with farmers' and secondly, threat from pollutants is occasionally more to consumers rather than to the growers of food due to contamination.

Soils vary widely in respect of physical (depth, texture, structure, compactness etc.), chemical (mineralogical composition, clay type, oxides, organic matter, base-saturation, CEC, soil solution composition, nutrient availability etc.) and biological properties (microbial population, diversity and activity). These soil properties determine effectiveness and adaptability of some of the management options over others. While in situ soil washing and removal of metal ions may be convenient in light textured soils, these may not be easily achieved in Vertisols due to high clay content. On the contrary, manipulation of redox potential for reducing metal toxicity may be easier in latter soil type due to its slower infiltration capacity. Climatic factors, particularly the magnitude and distribution pattern of rainfall and temperature also influence mobility, transformation, transfer and degradation of pollutants in the rhizosphere.

Roles of some of predominant soil and climatic factors on the processes and management for remediation of polluted soils are summarized (Table 6).

Agricultural operations influencing remediation of polluted land

Fertilization

Fertilizers are considered essential in both types of usage of polluted agricultural land: (1) for higher production of food and other economic crops, and (2) for higher removal of metals by phytoremediating crops through higher biomass production. While fertilizer management should enhance mobilization of metals in case of phytoremediation, the reverse is desired during growing of food and fodder crops. Application of chloride containing

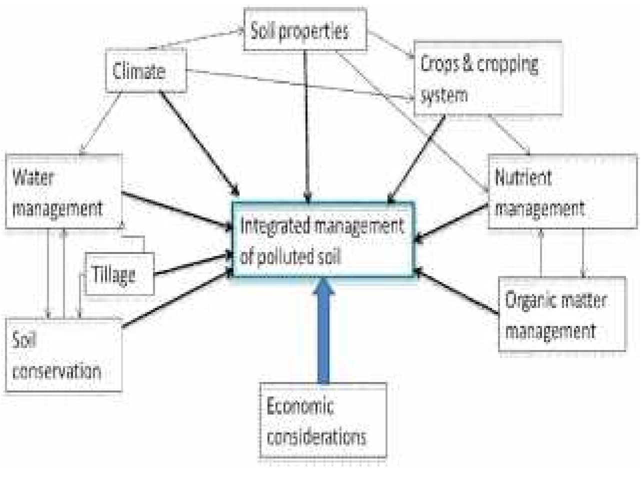

Fig 1. Different controllable and uncontrollable factors affecting management of polluted soils and their interrelationships (Saha et al. 2014)

Table 6. Effect of soil and climatic factors on remediation of polluted soils (Saha et al. 2014)

Properties	Process influenced	Effect on pollution process and soil management
Climate	Infiltration and evapotranspiration	Accumulation of Na, Cl and other mobile pollutants on the surface. Leaching of salts and metals down the profile during rainy season.
	Available soil moisture	Solubility and bioavailability of pollutants and their uptake by plants
	Soil temperature	Activity of soil microorganisms, degradation of organic pollutants, inactivation of inorganic pollutants (e.g. Cr^{6+} to Cr^{3+})
	Length of growing period of crops	Phytoremediation potential under rainfed situations
Geology of underground rocks	Groundwater recharge	Fractured underground rock formation enhances rate and magnitude of groundwater contamination
Land topography	Runoff, soil erosion	Spread of hazards to nearby land and water bodies
Texture and structure of soil	Infiltration	Contamination of groundwater, removal of salts from rhizosphere through subsurface drainage
	Aeration	Biodegradation of organic pollutants
	Compactness	Soil pulverization and photochemical degradation of organic pollutants during land farming.
Depth of soil profile	Vertical & horizontal mobility of water	Spread of polluted area due to industrial effluents
Clay types and contents	Cation exchange capacity (CEC)	Sink capacity of soils for cationic pollutants, removal efficiency during decontamination
Organic matter content	CEC, coordinate complex formation	Sorption and chelation of heavy metals and sorption of organic pollutants influencing their bioavailability
	Microbe population & diversity	Degradation of organic pollutants
Soil reaction	Solubility of minerals and humus, strength of sorption	Expression of heavy metal toxicity, selection of amendment materials for immobilization and phytoextraction
Exchangeable Na	Dispersion of clay, solubilization of humus	Suspended particles carrying contaminated soil particles during runoff and contaminate water bodies
Oxides of Fe, Al	Sorption of anions, soluble Fe and Al ions	Sorption & solubility of anionic pollutants like As, Se, Cr, organic pollutants etc.
	Hardness of soil upon drying (lateritic)	Ease of land farming to degrade organic pollutants

fertilizers like NH4Cl and muriate of potash (KCl) should preferably be avoided in Cd contaminated soil for growing food & fodder crops as this enhances mobility of the metal through the formation of soluble CdCln2-n complex and promote crop contamination (Sparrow et al. 1994 and Lopez-Chuken et al. 2012). Fertilizers like ammonium sulphate and monoammonium phosphate lowers the soil pH during their continuous application and consequently, may increase the availability of metal pollutants (Levi-Minzi and Petruzzelli 1984, Willaert and Verloo 1992); and hence, may be avoided in metal polluted neutral & calcareous soils. In a laboratory experiment, monoammonium phosphate decreased soil pH and the amount of Cd adsorbed by two soils (thereby increasing the availability), while diammonium phosphate precipitated Cd particularly in low organic matter containing soil (Levi-Minzi and Petruzzelli 1984). Contamination of several food crops with As is widely observed in lower Gangetic plains of India and Bangladesh due to irrigation with contaminated groundwater (Meharg and Rahman 2003, Huq et al. 2006). Phosphorus application has been found to reduce its contamination of wheat grain (Pigna et al. 2010). In rice plants (grown on flooded soil), however, added P suppressed uptake of arsenate, not arsenite indicates a different uptake mechanism for different forms of as species (Abedin et al. 2002). High available calcium in soils inhibits accumulation of several heavy metals by crop (Kurtyka et al. 2008 and Suzuki 2005) and hence, frequent application of Ca containing fertilizers (like SSP, CAN, gypsum) and lime may be advisable in non-calcareous soils in high rainfall areas.

Soil organic matter management

Due to its role in maintaining soil fertility and crop productivity, improvement and maintenance of organic matter status in agricultural soil are essentially advocating, particularly in tropical regions where rate of C mineralization is quite high. Application of organic matter has been found to reduce the availability of heavy metals in contaminated soil (Walker et al. 2004, Sklodowski et al. 2006). However, strength of metal complexes with humic acid increases with increasing pH and decreasing ionic strength (McBride 1994) and therefore, combined application of lime and organic matter may be most effective strategy in reducing/eliminating the adverse impacts (i.e. phytotoxicity and food contamination) in heavy metal polluted acidic soils.

Tillage operations

Tillage methods influence root proliferation (hence rhizosphere depth and volume), aeration, partitioning of rainwater and soil erosion and therefore, can be important for the management of polluted soils. Limited studies have indicated a role of tillage for amelioration and management of polluted soil. Conservation tillage has been recommended in case of polluted land as it reduces runoff & soil erosion during high intensity rainfall and, thereby, protects the nearby unpolluted area and aquatic life from toxicants (Holland 2004). Reduced tillage or no-tillage promotes higher metal uptake from surface horizon due to restricted root proliferation in the deeper layer (Oliver et al. 1993) and therefore may be advisable during phytoextraction of surface contaminated land. On the contrary, enhanced aeration and exposure of below-surface soils to sunlight due to repeated tillage operations can accelerate biodegradation of organic pollutants (Rhykerd et al. 1999).

Soil and water conservation and management

Highly polluted agricultural land is also a source of contamination for nearby land and surface water bodies and therefore, management strategies warrants appropriate measures to check soil erosion. In high rainfall area, soil tillage across the slope, contour farming, cover cropping, mulching, etc. may be adopted to reduce impact of raindrops and soil loss through runoff water. Growing grasses and cover crops having high phytoremediation potential can be a good alternative in such situation as these can reduce runoff soil loss as well (Cook et al. 2009). However, trees (like Populus spp. and Salix spp.) may be grown along with grasses so as to phytostabilize metals in deeper soil layer and prevent downward metal flux (Quinn et al. 2001). In arid regions, contaminated soil particles carried away by wind may have severe health implications on human and animal populations when enters the body through the respiratory route. Capping of polluted land with fertile soils and growing grasses can prevent air pollution with contaminated dust. Often groundwater of the area surrounding industrial cluster records elevated salinity and use of such water for irrigation is likely to increase the osmotic potential in the rhizosphere causing physiological water stress to the crop. Moreover, elevated Cl- (normally associated with salinity of the groundwater) in soil solution may enhance the mobility and uptake of heavy metals (particularly Cd) in contaminated land (Lopez-Chuken et al. 2012). Therefore, water management strategy for cultivated land around the industrial area should focus on increasing water use efficiency through efficient irrigation methods and also on reducing dependency on groundwater through conservation of rainwater and soil moisture.

Selection of crops and cropping systems

Crops differ widely in respect of their ability in uptake of metals and in combating heavy metal stress by adopting various mechanisms like exclusion, sequestration, metal homeostasis (Manara 2012). Selection of crops for the polluted land can be decided based on the perceived threat(s) to the farming. A comparatively lower level of pollution poses threat only to the quality of food and fodder due to contamination with toxic metals (Saha et al. 2013) and therefore, appropriate strategy in such situation would be to minimize their transfer to aboveground biomass. Results indicate that bioconcentration is generally the highest in leafy vegetables followed by root vegetables and minimum in grain crops (Page et al. 1987). Therefore, the cultivation of leafy and root vegetables (like spinach, lettuce, cabbage, potato, radish, beet, coriander etc.) in soils having elevated levels of metals should be avoided and growing of other crops can only be taken up after ensuring that national requirements for food & fodder quality in respect of heavy metal contents is met. In an experiment under controlled condition, different cereals, oilseeds, sugarcane, and fiber crop exhibited tolerance to high soil Cd levels (Wang 2002). Though grain of cereal crops got contaminated, edible parts of other crops remained free from contamination. Even varieties differ in the metal contamination in grain due to difference in uptake pattern, upward and basipetal translocation in plant parts (Chan and Hale 2004) indicating the importance of genotype selection in the contaminated soil. Crop rotation can also influence heavy metal mobilization and uptake by plants due to residual effects of several organic acids in the root exudates from previous crops (Nigam et al. 2001). Concentration Cd in grain was more in wheat grown after lupins and lowest in wheat grown after cereal, particularly under zero-tillage (Oliver et al. 1993).

A higher level of heavy metal pollution may affect productivity of common food crops as well as severely contaminate the food-chain and therefore, the situation warrants decontamination of crop land. Most appropriate strategy in such situation can be avoidance of non-food & non-fodder crops and selection of appropriate phytoremediating plants. Several oilseed crops (particularly Brassica sp.), flowering plants, fibre crops, short duration trees (like eucalyptus, poplar, willow etc.) have exhibited their phytoremediation potential while generating economic produce during the process (Broadley et al. 1999, Angelova et al. 2004, Su and Wong 2004, Indoria and Poonia 2006, Ruttens et al. 2011). Use of metal contaminated lands for production of bio-fuel crops like sugar (sugarcane, sugar beet), starch (maize, wheat, rice), oilseeds (rapeseed, sunflower, jatropha) can be a viable option. Incineration of contaminated biomass can generate energy as well as reduce the volume for appropriate disposal or for metal-recovery. Meers et al. (2010) estimated that cultivation of maize in a moderately contaminated soil could produce 33,000-46,000 kW h of renewable energy (electrical and thermal) per hectare per year; though its phytoremediation potential is very low. Hemp (Cannabis sativa), flax (Linum usitatissimum) and peanut (Arachis hypogaea) were also found suitable for both biodiesel production and phytoextraction of Cd from contaminated soil (Shi and Cai 2009). Biomass residues after biodiesel/bioethanol production can further be incinerated for energy production with consequent reduction in volume for disposal of hazardous waste.

Conclusions

Heavy metal pollution is emerging with speedy rate, due to industrialization and modern lifestyle. It is moving through the soil - plant continuum to human or animal, and interfere with the biological process in the human body. Most of the remediation techniques, converting the toxic form of heavy metal to non toxic form; or available form to unavailable form in soil and reduced the crop uptake. The primary strategy should be segregation of heavy metal containing waste, and its safe disposal. Use of heavy metal contaminated for the non edible food crops like flowers, caster & jatropha etc. The regular monitoring of effluent, soil, crop produce, where the contaminated water is used for crop production activities. A strong policy should be initiated to the contaminated water discharging units as well as its consumers. A wide awareness campaign with the help of the government agencies or non government organizations (NGOs) regarding heavy metal toxicity and its consequences.

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Targeted yield approach of fertiliser recommendation for sustaining crop yield and maintaining soil health

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Abstract

The major challenges in 21st century are food security, environmental quality and soil health. Besides, shrinking land holdings and increasing cost of inputs in India merit adoption of scientific use of plant nutrient for higher crop productivity. The soil testing programme was started in India during the year 1955-56 with the setting up of 16 soil testing laboratories under the Indo-US Operational Agreement for "Determination of Soil Fertility and Fertilizer Use". In 1965, five of the existing laboratories were strengthened and nine new laboratories were established to serve the Intensive Agricultural District Programme (IADP) in selected districts. Chemical indices of nutrient availability chosen for use in the soil testing laboratories consisted of organic carbon or alkaline permanganate oxidizable nitrogen, as a measure of available nitrogen, sodium bicarbonate (Olsen's extractant) extractable phosphorus, as a measure of available phosphorus and neutral normal ammonium acetate extractable potassium, as a measure of available potassium. Background research for the choice of critical values consisted of a few pot culture and field experiments with paddy and wheat, carried out in the Division of Soil Science & Agricultural Chemistry at Indian Agricultural Research Institute, New Delhi. Taking a simplistic view of the situation, the differences among soil groups in the range of properties, which influence the susceptibility to absorption by plants of native and applied nutrients, were ignored. The generalized recommendations of fertilizer use developed for the soil testing laboratory area were thought applicable to the medium category of soil testing estimates with an arbitrary adjustment (decrease or increase by 25-50 per cent) for high and low categories of soil test estimates. The ICAR project on soil test crop response AICRP (STCR) has used the multiple regression approach to develop relationship between crop yield on the one hand, and soil test estimates and fertilizer inputs, on the other.

Keywords: Targeted yield approach for fertilizer recommendation

Nutrient supplying power of soils, crop responses to added nutrients and amendment needs can safely be assessed through sound soil testing programme. Soil test calibration that is intended to establish a relationship between the levels of soil nutrients determined in the laboratory and crop response to fertilizers in the field permits balanced fertilization through right kind and amount of fertilizers. Liebig's law of minimum states that the growth of plants is limited by the plant nutrient element present in the smallest amount, all others being in adequate quantities. From this, it follows that a given amount of a soil nutrient is sufficient for any one yield of a given percentage nutrient composition. Ramamoorthy and his co-workers in the year 1967 established the theoretical basis and experimental proof for the fact that Liebig's law of the minimum operates equally well for N, P and K. This forms the basis for fertiliser application for targeted yields, first advocated by Truog in the year 1960. Among the various methods of fertiliser recommendation, the one based on yield targeting is unique in the sense that this method not only indicates soil test based fertiliser dose but also the level of yield the farmer can hope to achieve if good agronomic practices are followed in raising the crop.

Basic data requirement

The essential basic data required for formulating fertiliser recommendation for targeted yield are

- Nutrient requirement in kg q^{-1} of produce, grain or other economic produce
- The per cent contribution from the soil available nutrients
- The per cent contribution from the applied fertilizer nutrients

The above mentioned three parameters are calculated as follows.

Nutrient requirement of N, P and K for grain production

$$\text{kg of nutrient } q^{-1} \text{ of grain} = \frac{\text{Total uptake of nutrient (kg)}}{\text{Grain yield (q)}}$$

Contribution of nutrient from soil

$$\text{\%Contribution from soil (CS)} = \frac{\text{Total uptake in control plots (kg ha}^{-1}\text{)}}{\text{Soil test values of nutrient in control plots (kg ha}^{-1}\text{)}} \times 100$$

% Contribution of nutrient from fertilizer

Contribution from (CF) = (Total uptake of nutrients) - (Soil test values of nutrients in fertilizer treated plots x CS)

$$\text{\%Contribution from fertiliser} = \frac{\text{CF} \times 100}{\text{Fertilizer dose (kg ha}^{-1}\text{)}}$$

Calculation of fertilizer dose

The above basic data are transformed into workable adjustment equation as follows :

$$\text{Fertilizer dose} = \frac{\text{Nutrient requirement in kg q}^{-1}}{\text{\%CF}} \times 100\ \text{T} \times \frac{\text{\%CS}}{\text{\%CF}}$$

$$= \text{a constant} \times \underset{(\text{q ha}^{-1})}{\text{yield target}} - \text{b constant} \times \underset{(\text{kg ha}^{-1})}{\text{soil test value}}$$

Similarly the contribution of nutrients from organic manure can also be determined

The differentiation of significant multiple regression equations provides a basis for soil test-fertilizer requirement calibration for maximum yield per hectare, maximum profit per hectare and maximum profit per rupee investment on fertilizer. The resultant fertilizer adjustment equations have been tested in follow up and frontline demonstrations conducted in different parts of the country. In these trials soil test based rates of fertilizer application helped to obtain higher response ratios and benefit: cost ratios over a wide range of agro-ecological regions (Dey and Srivastava 2013).

Use of Targeted Yield Equation and Development of Prediction Equation for Cropping Sequence

Nutrient availability in the soil after the harvest of a crop is much influenced by the initial soil nutrient status, the amount of fertilizer nutrients added and the nature of the crop raised. But recently, the monoculture is replaced by cropping sequence approach. To apply soil test based fertilizer recommendations, the soils are to be tested after each crop, which is not practicable. Hence it has become necessary to predict the soil test values after the harvest of the crop. It is done by developing post-harvest soil test value prediction equations making use of the initial soil test values, applied fertilizer doses and the yields obtained or uptake of nutrients. The post-harvest soil test values were taken as dependent variable and a function of the pre-sowing soil test values and the related parameters as yield/uptake and fertilizer nutrient doses. The functional relationship is as follows:

Prediction Equation for Cropping Sequence

The method of calculation for prediction of post harvest soil test values for cropping sequences is given below:

$$YP/H = f\ (F,\ IS,\ \text{yield/nutrient uptake})$$

where, YP/H is the post harvest soil test value, F is the applied fertilizer nutrient and IS is the initial soil test value. The mathematical form is

$$YP/H = a + b1F + b2\ IS + b3\ \text{yield/uptake}$$

where, a is the absolute constant and b1, b2 and b3 are the respective regression coefficients. Prediction equations for post-harvest soil test values were developed from initial soil test values, fertilizer doses applied and yield of crops/uptake of nutrients to obtain a basis for prescribing the fertilizer amounts for the crops succeeding the first crop in the cropping sequence.

During last fifteen years, the different centres of AICRP on STCR developed prediction equation by using

Table 1. Soil Test based balanced fertilization and response Ratios (RR) in existing and improved practice for different crops in Madhya Pradesh and Chhattisgarh

Crop	Location/ AER	Soil type	Fertilizer Response Ratio (kg grain/kg nutrient)				
			Present practice		Improved practice		
			Fertilizer dose	RR	Fertilizer dose	RR	Type of intervention
Rice	Jabalpur/ 10 hot sub-humid	Medium black	GRD: 80-70-40	8.47	STCR: 3.5 t ha^{-1} 76-66-0	11.13	Soil test based balanced fertilization
Linseed	Jabalpur, MP/10 hot sub-humid	Medium black	GRD: 60-40-20	5.21	STCR: 2.0 t ha^{-1} 89-51-19	8.29	- do -
Chickpea	Jabalpur/ 10 hot sub-humid	Medium black	GRD: 20-60-20	9.00	STCR: 1.5 t/ha 22-36-0	12.76	- do -
Urid	Jabalpur/ 10 hot sub-humid	Medium black	GRD: 20-50-20	0.361** (Mean of three trials)	STCR: 1.2 t ha^{-1} 25-35-0	0.464**	- do -
Mustard	Jabalpur, MP/10 hot sub-humid	Medium black	GRD50-30-20	4.38	STCR: 1.6 t ha^{-1} 68-42-16	5.44	- do -
Mustard	Jabalpur/ 10 hot sub-humid	Medium black	GRD: 50-30-20	2.29	STCR: 2 t ha^{-1} 88-46-35	2.34	- do -
Soybean	Jabalpur, MP/10 hot sub-humid	Medium black	GRD: 20-80-20	8.28	STCR: 2.5 t ha^{-1} 15-52-0	13.77	- do -
Sunflower	Jabalpur/ 10 hot sub-humid	Medium black	GRD: 80-40-25	4.31	STCR: 2 t ha^{-1} 197-27.4-0	5.10	- do -
Rice	Narsinghpur, MP		GRD: 80-70-40	11.45**	STCR: 4 t ha^{-1} 91-74-0	19.07**	- do -
Wheat	Jabalpur, MP/10 hot sub-humid	Medium black	GRD: 100-60-30	14.77**	STCR: 4 t ha^{-1} 59-57-28	41.01**	- do -
Chickpea	Durg, Chattisgarh/11 Hot/moist/dry sub humid transitional	Vertisol	Farmers' Practice 10-30-0 GRD: 20-50-20	2.78 2.76	STCR: 1.2 t ha^{-1} 20-0-0	7.90	- do -
Mustard	Durg, Chhattisgarh	Vertisol	Farmers' Practice 60-40-0 GRD: 120-80-40	2.71 6.53	STCR: 1.3 t ha^{-1} 103-83-0	6	- do -
Soybean	Durg, Chhattisgarh/11 hot/moist/dry sub humid transitional	Vertisol	Farmers' Practice 12-30-0 GRD: 20-50-20	20.2 15.0	STCR: 2.0 t ha^{-1} 20-35-0	20.1	- do -

(Source: AICRP on STCR)

IPNS = Integrated Plant Nutrient Supply; STCR = Soil Test Crop Response; * Higher yield obtained with lesser fertilizer dose than farmers' practice; ** Response ratio calculated over farmers' practice; 1 Average of two demonstrations; 2 Average of four demonstrations; *** In case of wheat and maize at Palampur the high response ratio in farmers' practice is due to very low rates of fertilizer application. Even though the response ratio is high the level of yields the farmers are getting is very poor. In STCR technology the response ratio is not as high as in farmers' practice but the yields are very good.

the targeted yield equation for different cropping sequences like rice-rice, rice-maize, rice-wheat, maize-tomato, maize-wheat, potato-yellow sarson, paddy-ragi, maize-Bt. Cotton, wheat-groundnut, okra-wheat, paddy-chick pea, soybean-wheat, rice-pumpkin, bajra-wheat, cotton-maize and soybean-onion. The predicted values can be utilized for recommending the fertilizer doses for succeeding crop thus eliminating the need of soil test after each crop. This provides the way for giving the fertilizer recommendations for whole cropping sequence based on initial soil test values. For example, in Potato- Yellow Sarson cropping sequence:

Potato (Kufri Jyoti)

PHN = 104.94 + 0.28 FN - 0.041 SN - 0.11 Y ($R^2 = 0.35^{**}$)

PHP = -2.74 + 0.091 FP + 0.84 SP + 0.013 Y ($R^2 = 0.78^{**}$)

PHK = 31.28 + 0.71 FK + 0.45 SK - 0.17 Y ($R^2 = 0.70^{**}$)

Yellow Sarson (PYS-I)

PHN = 107.91 + 0.36 FN - 0.08 SN - 0.79 Y ($R^2 = 0.72^{**}$)

PHP = 23.19 + 0.26 FP + 0.011 SP + 0.24 Y ($R^2 = 0.70^{**}$)

PHK = 153.25 + 0.42 FK + 0.02 SK - 0.54 Y ($R^2 = 0.56^{**}$)

Benefits of soil test based targeted yield approach

During the last more than four decades the STCR project has generated numerous fertilizer adjustment equations for achieving targeted yields of important crops on different soils in different agro ecological regions of the country. These fertilizer adjustment equations have been tested in follow up and frontline demonstrations conducted in different parts of the country. In these trials soil test based rates of fertilizer application helped to obtain higher response ratios and benefit: cost ratios over a wide range of agro-ecological regions (Dey 2012). It is evident from above tables that STCR based approach of nutrient application has definite advantage in terms of increasing nutrient response ratio over general recommended dose of nutrient application. Yields and response ratios can be increased if the fertilizer prescriptions are made as per the table 1 for specified crops and locations.

Economic analysis of fertilizer doses associated with different yield targets

An appraisal of the effect of nutrients (NPK) applied on crop yield and benefit: cost ratios (BCR), both under (NPK) alone and under IPNS for 15 agricultural and horticultural crops (Dey and Santhi 2014) are furnished in Table 3. The input output prices used in these analyses were: Produce prices:-- Paddy (rough rice) and wheat grain Rs 12,000 t^{-1}, rice straw Rs. 1,200 t^{-1} wheat straw Rs.500 t^{-1}, maize grain Rs. 8,000 t^{-1} maize straw Rs. 500 t^{-1}, cotton Rs. 25,000 t^{-1} onion Rs. 9,000 t^{-1}, okra (Bhendi) Rs. 10.000 t^{-1} cabbage Rs. 3500 t^{-1}, potato Rs. 7000 t^{-1} carrot Rs. 5,000 t^{-1}, beetroot Rs. 3300 t^{-1}. radish Rs. 3,000 t^{-1}, tomato Rs. 3,300 t^{-1} and Ashwagandha Rs. 82,000 t^{-1} Input prices -Rs. 11.76/kg N through urea, Rs 47.63/kg P_2O_5 through SSP and Rs. 28.00/kg K_2O through MOP, 250/t for FYM and Rs 750/t for vermicompost. Economic analysis of the data showed that out of 66 crop x target combinations, the BCR was between 1and 2 in 35 % cases and between 2.1 and 3.0 in 62% cases. In 3% cases BCR was above 3.Irrespective of the crops, higher yield has been recorded at higher yield targets over lower target coupled with higher net return and BCR. As in the case of yield, wherever three targets (low, medium and high) were tried, the BCR was relatively higher between low and medium target levels then between medium and high target levels both under NPK alone and IPNS. Again, irrespective of the crops and yield targets, yield increase was higher with IPNS

Table 2. Average Response Ratios (kg grain/kg nutrients)

Crop	No. of trials	Farmer's practice	STCR- IPNS recommended practice
Rice	120	11.4	16.8
Wheat	150	10.3	14.2
Maize	35	12.7	17.7
Mustard	45	8.0	8.2
Raya	25	4.8	7.6
Groundnut	50	5.1	6.8
Soybean	17	9.6	12.2
Chickpea	35	6.1	9.4

then under NPK applied through fertilizers alone. In the regard, farmers can choose the desired yield targets according to their investment capabilities and availability of organic manures but would generally benefit form adopting an appropriate IPNS package as apart form contributing nutrients, organic manures also improve soil physical conditions. At present, the soil test based recommendations are relatively on a stronger footing when these involve only fertilizers as compared to IPNS. This is because there are several issues concerning the nutrient which need to be sorted out as illustrated using STCR information form Andhra Pradesh. One of the outstanding problems is that while the composition of fertilizers is fairly standard, that of organic manures can vary several fold even within the same location or form lot to lot.

Fertilizer recommendations for fixed cost of investment and allocation under resource constraints

The soil test-fertilizer requirement calibration for targeted yield also provide the means for calculating soil critical levels above which there is no fertilizer requirement indicated levels of expected crop production.

A new dimension to the value of the utility of soil testing has been added by the concept of fertilizer application for targetted yield demonstration laid by IARI in farmers' fields by choosing the yield target at such a level so that the cost of fertilizer requirement becomes more or less same as what was being practiced by farmers already.

When fertilizer availability is limited or the resources of the farmers are also' limited, planning far moderate yield targets which are, at the same time, higher than the yield levels normally obtained by the farmer provides means, far saturating mare areas with the available fertilizers and ensuring increased total production also.

Fertilizer recommendation through targeted yield approach for maintenance of soil health

Fertilizer recommendation for realizing in the short term greater fertilizer use efficiency on the one hand and far maintenance of sail fertility in the long term an the other seem to have two opposing dimensions. If soil fertility is to be maintained or even increased, heavier doses of fertilizers have to be used to take into account the inevitable lasses in the availability due to leaching and fixation. Therefore, to get the best out of fertilizer investment, the turnover from it must be very quick. This is ensured when fertilizers are applied far law yield targets. Under such situations, the excess native soil nutrient (S) will make a great contribution to increase the yield. This would mean low doses of application of fertilizer and exhausting of the unutilized excess nutrients from the soil. The soil fertility would, therefore, deplete at a faster rate as a result of this exhaustion. Thus, these two approaches seem to be pulling in different directions and it will be necessary to adjust the fertilizer practices over seasons in such a way so as to strike a balance between the two.

The generation of basic data for targeted yield of crops in a rotation would enable application of fertilizer far appropriate yield targets so that over seasons, the twin objectives of high yields and maintenance of soil fertility (Table 2 and 3) could be achieved (Dey and Gulati 2013).

Linking soil fertility maps with STCR parameters for spatial fertilizer recommendation

An attempt was made with joint venture of IISS, Bhopal and NBSSLUP, Nagpur to create spatial fertilizer recommendation maps using available validated fertilizer adjustment equations (STCR's generated) and Geographic Information System (GIS). The district level soil fertility index of 10 districts of India were prepared, which can be used to generate balanced fertilizer recommendation for specified crops for entire district based on the average soil fertility status of that district. District wise soil fertility georeferenced maps were prepared using index values for nitrogen (N), phosphorus (P) and potassium (K) for ten states. Corresponding equivalent soil nutrient values in respect of N, P & K were calculated from the index values. Reasonable limits for targeted yields were defined. The recommendations in the form equations for targeted yields developed by Subba Rao and Srivastava (2001) have been interlinked with the fertility maps. The use of this recommendation system suggested for varied applications for targeted yields in different districts of states. This can be used up to field level also, if the farmer has the knowledge of his fertility status and the yield target. The maps can also be updated from time to time based on the soil test result data base. It can be further narrowed down to block/village level depending the availability of information. As an example N soil fertility map in the year 2001 is depicted below. These fertility maps can also be used to study the changing trends in the fertility of nutrients and can be correlated with fertilization practices of farmers of a particular region (Table 4). These maps, however, only indicate the general fertility level in a district since the data collected and used was not georeferenced.

Table 3. Economic analysis and benefit: cost ratios of fertilizer doses for different yield targets

Crop	Yield target and treatments	Fertilizer doses (kg ha^{-1}) N	P_2O_5	K_2O	Yield (t ha^{-1})	Fertilizer cost (Rs ha^{-1})	BCR
Rice - Flooded (TNAU Farm, Coimbatore)	6 t ha^{-1}NPK fertilizer	137	56	23	6.01	4922	1.52
	7 t ha^{-1}NPK fertilizer	172	56	23	6.94	5286	1.74
	7 t ha^{-1}IPNS package*	118	36	23	7.11	3746	1.75
Rice - SRI (TNAU Farm, Coimbatore & Farmer's fields, Coimbatore Dt.)	7 t ha^{-1}NPK from fertilizer	173	62	74	6.68	7059	1.92
	8 t ha^{-1}NPK from fertilizer	222	83	99	7.65	9336	2.10
	9 t ha^{-1}NPK from fertilizer	271	100	100	8.18	10775	2.18
	7 t ha^{-1}IPNS package*	133	39	39	6.94	4514	1.97
	8 t ha^{-1}IPNS package*	182	60	67	7.94	6874	2.15
	9 t ha^{-1}IPNS package*	232	80	95	8.34	9199	2.16
Wheat - Hill Farmer's fields, Kalrayan foothills, Salem Dt. & Kolli foothills, Namakal Dt.)	3.5 t ha^{-1}NPK from fertilizer	156	111	41	3.55	8269	1.54
	4.0 t ha^{-1}NPK from fertilizer	194	129	59	4.07	10077	1.66
	3.5 t ha^{-1}IPNS package*	109	100	28	3.63	6828	1.49
	4.0 t ha^{-1}IPNS package*	147	117	37	4.16	8337	1.62
Wheat - Plains (Farmer's fields, Coimbatore Dt.)	3 t ha^{-1}NPK from fertilizer	119	91	51	2.90	7161	1.33
	4 t ha^{-1}NPK from fertilizer	196	110	72	3.93	9560	1.66
	3 t ha^{-1}IPNS package*	65	74	37	2.98	5325	1.31
	4 t ha^{-1}IPNS package*	152	105	55	4.05	8328	1.61
Maize - Hybrid (Farmer's fields, Coimbatore and Dindigul Dts.)	9 t ha^{-1}NPK from fertilizer	244	98	82	8.97	9833	2.04
	10 t ha^{-1}NPK from fertilizer	290	124	97	10.09	12032	2.17
	11 t ha^{-1}NPK from fertilizer	329	139	113	10.33	13653	2.13
	9 t ha^{-1}IPNS package*	202	78	52	9.23	7546	2.05
	10 t ha^{-1}IPNS package*	249	104	69	10.5	9813	2.21
	11 t ha^{-1}IPNS package*	289	119	86	10.59	11474	2.14
Rain fed Bt Cotton (Farmer's fields, Perambalur Dt.)	2.8 t ha^{-1}NPK from fertilizer	103	71	74	2.67	6665	1.46
	3.2 t ha^{-1}NPK from fertilizer	123	81	89	3.07	7796	1.64
	2.8 t ha^{-1}IPNS package*	78	51	48	2.84	4690	1.51
	3.2 t ha^{-1}IPNS package*	99	67	64	3.24	6147	1.68
Onion (Farmer's fields, Coimbatore Dt.)	17 t ha^{-1}NPK from fertilizer	89	18	26	17.24	2632	2.34
	20 t ha^{-1}NPK from fertilizer	117	33	31	18.75	3816	2.50
	17 t ha^{-1}IPNS package*	37	14	14	17.72	1494	2.33
	20 t ha^{-1}IPNS package*	71	34	32	19.48	3350	2.50
Okra (Bhendi) (Farmer's fields, Coimbatore Dt.)	15 t ha^{-1}NPK from fertilizer	78	45	15	15.5	3480	2.01
	17 t ha^{-1}NPK from fertilizer	97	54	15	16.59	4133	2.14
	15 t ha^{-1}IPNS package*	51	30	8	15.95	2253	2.10
	17 t ha^{-1}IPNS package*	70	39	8	17.36	2905	2.18
Cabbage (Farmer's fields, Coimbatore Dt.)	60 t ha^{-1}NPK from fertilizer	139	64	23	59.90	5327	2.43
	70 t ha^{-1}NPK from fertilizer	194	93	41	70.50	7859	2.78
	60 t ha^{-1}IPNS package*	109	49	15	61.00	4036	2.44
	70 t ha^{-1}IPNS package*	164	78	29	71.80	6456	2.79

Potato (Farmer's fields,	30 t ha^{-1}NPK from fertilizer	105	306	59	27.60	17460	1.85
Nilgiris Dt.)	40 t ha^{-1}NPK from fertilizer	175	446	131	38.80	26967	2.38
	30 t ha^{-1}IPNS package*	98	297	55	29.20	16837	1.94
	40 t ha^{-1}IPNS package*	168	437	127	40.40	26344	2.46
Carrot (Farmer's fields,	40 t ha^{-1}NPK from fertilizer	125	145	39	40.90	9468	2.45
Nilgiris Dt.)	50 t ha^{-1}NPK from fertilizer	173	256	66	52.50	16075	2.92
	60 t ha^{-1}NPK from fertilizer	221	367	127	59.90	23634	3.07
	40 t ha^{-1}IPNS package*	117	139	36	43.30	9004	2.54
	50 t ha^{-1}IPNS package*	165	250	64	53.70	15639	2.92
	60 t ha^{-1}IPNS package*	213	361	120	62.60	23058	3.15
Beetroot (Farmer's fields,	40 t ha^{-1}NPK from fertilizer	99	134	80	39.50	9786	2.37
Coimbatore and Dindigul Dts.)	50 t ha^{-1}NPK from fertilizer	163	186	131	49.98	14443	2.77
	40 t ha^{-1}IPNS package*	59	113	54	40.48	7588	2.37
	50 t ha^{-1}IPNS package*	123	165	99	51.37	12077	2.78
Radish (Farmer's fields,	40 t ha^{-1}NPK from fertilizer	112	50	71	37.20	5686	2.23
Coimbatore and Dindigul Dts.)	50 t ha^{-1}NPK from fertilizer	181	78	114	48.80	9035	2.74
	40 t ha^{-1}IPNS package*	67	24	52	38.40	3387	2.24
	50 t ha^{-1}IPNS package*	136	52	87	50.60	6512	2.78
Tomato (Farmer's fields,	70 t ha^{-1}NPK from fertilizer	164	135	148	70.90	12502	2.47
Coimbatore and Dindigul Dts.)	80 t ha^{-1}NPK from fertilizer	209	177	188	80.80	16152	2.71
	90 t ha^{-1}NPK from fertilizer	254	219	228	88.30	19801	2.86
	70 t ha^{-1}IPNS package*	120	113	113	72.20	9957	2.50
	80 t ha^{-1}IPNS package*	165	155	153	81.30	13606	2.71
	90 t ha^{-1}IPNS package*	210	197	193	89.50	17256	2.88
Ashwagandha (Farmer's fields,	0.7 t ha^{-1}NPK from fertilizer	49	74	66	0.671	5949	1.31
Salem Dt.)	0.9 t ha^{-1}NPK from fertilizer	79	109	77	0.871	8276	1.24
	0.7 t ha^{-1}IPNS package*	20	51	40	0.696	3784	1.28
	0.9 t ha^{-1}IPNS package*	59	87	68	0.905	6741	1.19

IPNS package*: For SI. Nos 1-9 and 14 - 15, FYM was applied @12.5 t ha^{-1} For SI. Nos. 10-13, Vermicompost was applied @ 5 t ha^{-1}.

Table 4. Benefits of STCR recommendations as reflected by front line demonstrations on gram under arid condition

Particulars	Farmers' practice (FP)	General dose recommendation (GRD)	STCR	STCR-IPNS*
Average Yield (q/ha)	9.33	13.03	16.51	19.28
Average fertilizer used ($N+P_2O_5+K_2O+S$)	10.8+27.6+0+0	20+40+0+0	20+29+20+36.8	20+16.2+15+26.5
% Change over FP		+39.7	+76.96	+106.65
Yield response (kg/kg of nutrient)	24.30	21.72	15.60	24.81
B:C Ratio	1.47	2.32	3.16	3.34

*5 t FYM/ha

Subsequently, the scientist at IISS took up a research project to prepare web based soil fertility map for two districts i.e., Hoshangabad and Guna of Madhya Pradesh by following multistage random sampling for collection of soil samples where tehsils were considered as strata in each district. The GIS based soil fertility map for N, P, K was prepared for Hoshangabad district and the soil test values were revalidated. The method has been found to be better and soil fertility can be monitored over a period of time.

On similar lines, another research project has been completed to map the soil fertility of some districts in India. Soil fertility maps of a total of 175 districts have been completed under that project. Fertiliser recommendation equations derived from STCR studies i.e. soil nutrient efficiency (Es), fertilizer nutrient efficiency (Ef) and nutrient requirement (NR) of a particular crop are now being linked with the soil fertility values on the map which makes possible to provide spatial fertilizer recommendation in the form of maps. The recommendations can be obtained by an extension agent/ farmer simply by locating his area on the map.

Application of Information and Communication Technologies (ICT)

Agricultural development and sustainability crucially depend upon relevant information access at opportune time. There is a vast scope of extending ICTs through public, private and non governmental organizations with respect to extension, marketing and community services. The ideal delivery model for these ICTs is envisioned to be a multi-pronged strategy involving institutions under National Agricultural Research System (NARS) to go online, share their contents, and rural information kiosks providing information access to the farmers. India has 37% of world ICT enabled projects in rural areas. Agricultural resource information using GIS models, expert systems, databases on successful technologies have critical role in governance and decision making by farmers.

On-line fertilizer recommendation systems developed by AICRP (STCR) http://www.stcr.gov.in

All India Coordinated Research Project on Soil Test Crop Response (AICRP-STCR) based at Indian Institute of Soil Science has developed a computer aided model that calculates the amount of nutrients required for specific yield targets of crops based on farmers' soil fertility (Majumdar et al. 2014). It is accessible on Internet (http://www.stcr.gov.in). This software program reads data, performs calculations and generates graphical and tabular outputs as well as test reports. This system has the ability to input actual soil test values of the farmers' fields to obtain optimum dose of nutrients. The application is a user friendly tool. It will aid the farmer in arriving at an appropriate dose of fertilizer nutrient for specific crop yield for given soil test values. Efforts are on way in developing bioinformatics, E-choupals, digital libraries and e Governance that can benefit agriculture immensely by way of providing information and assisting the users in adopting the newer technologies.

Computer software, including spreadsheets, databases, geographic information systems (GIS), and other types of application software are readily available. The global positioning system (GPS) has given the farmer the means to locate position in the field to within a few feet. By tying position data in with the other field data mentioned earlier, the farmer can use the GIS capability to create maps of fields or farms. Sensors are under development that can monitor soil properties, crop condition, harvesting, or post harvest processing and give instant results or feedback which can be used to adjust or control the operation.

DSSIFER

Decision Support System for Integrated Fertiliser Recommendation (DSSIFER) is a user friendly software and the updated version (DSSIFER 2010) encompasses soil test and target based fertiliser recommendations through Integrated Plant Nutrition System developed by the AICRP-STCR, Department of Soil Science and Agricultural Chemistry, TNAU, and the recommendations developed by the State Department of Agriculture, Tamil Nadu. If both recommendations are not available for a particular soil - crop situation, the software can generate prescriptions using blanket recommendations but based on soil test values. Using this software, fertilizers doses can be prescribed for about 1645 situations and for 190 agricultural and horticultural crops along with fertilisation schedule. If site specific soil test values are not available, data base included in the software on village fertility indices of all the districts of Tamil Nadu will generate soil test based fertiliser recommendation. Besides, farmers' resource based fertilizer prescriptions can also be computed. Therefore, adoption of this technology will not only ensure site specific balanced fertilization to achieve targeted yield of crops but also result in higher response ratio besides sustaining soil fertility. In addition, the software also provides technology for problem soil management and irrigation water quality appraisal. Moreover, STLs of all the organisations can generate and issue the analytical report and recommendations in the form of Soil Health Card (both in English &Tamil) which can be maintained by the farmers over long run.

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Epilogue

Among the various methods of formulating fertilizer recommendation, the one based on yield targeting has found popularity. This method not only indicates soil test based fertilizer dose but also the level of yield the farmer can hope to achieve if good agronomy is followed in raising the crop. It provides the scientific basis for balanced fertilization not only between the fertilizer nutrients themselves but also that with the soil available nutrients.

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Strategies for promoting water and nutrients use efficiencies

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Abstract

Nutrient and water are the most crucial inputs for agricultural production. Rainfed area occupying about 65% (89 M ha) of the cultivated land in India accounts for only 40% of total food production, whereas irrigated area covering 35% (53 M ha) of the cultivated land contributes 60% to the national food basket. Low water use efficiency (WUE) however, has been the concern along with the decreasing availability of water for agriculture. For efficient conservation and utilization of these vital resources, suitable state of the art agro-techniques need to be promoted. As a universal phenomenon, water losses start from the moment rain drops fall on the ground. In an irrigation system, water is lost during conveyance by evaporation, transpiration by weeds and seepage, while lost in the field by deep percolation beyond root zone and by runoff at end of border and furrows. The magnitudes of these losses vary widely on account of the different physiographic features, water control and conveyance structures and management practices. Vagaries of monsoon and declining water table due to over exploitation have resulted in shortage of fresh water supplies for agricultural use, which too calls for an efficient use of this resource.

Low efficiency of inputs/fertilizer use is another key factor pushing the cost of cultivation and pulling down the profitability in farming. Total factor productivity (TFP), an important measure to evaluate the performance of a production system, is showing declining trend which is a serious issue. A fatigue in the ratio between the inputs and output is indicative of TFP deceleration with concomitant un-sustainability of crop productivity. The challenge is how to increase food production in the country by around 60 per cent over next two decades without jeopardizing the soil and water resources which are already under great stress. One of the critical constraints to higher crop productivity is the low efficiency of applied nutrients especially N and P. Use efficiency of applied N is only about 30-40 per cent. The P use efficiency ranges from 20-40 per cent only. Hence, there is urgent need to increase nutrient use efficiency from the view point of costs and water quality concerns.

Keywords: Water and nutrient efficiency

Water resources of India are limited in relation to the needs and hence available water has to be used in the most efficient manner possible. Improving WUE in agriculture will require an increase in crop water productivity (an increase in marketable crop yield per unit of water removed by plant) and a reduction in water losses from the crop root zone. The amount of water required for food production depends on the quantity of agricultural commodities produced. For example, the production of 1 kg beef would require 14 times more water than for 1 kg of wheat grain. Hence, enhancing WUE in agriculture may also require some socio-economic adjustment to encourage and develop more water efficient enterprises. For comprehensive improvement of WUE in agriculture, it is necessary to raise the following ratios to their maximum: soil-stored water content/ water received through rainfall and irrigation, water consumption/ soil storage of water, transpiration/ water consumption, biomass yield/ transpiration, and economic benefit/ biomass yield. Upgradation of all these component parameters is the key issue for enhancing WUE.

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). However, experimental plots do not accurately reflect the efficiencies obtainable on-farm. Differences in the scale of farming operations and management practices i.e. tillage, seeding, weed and pest control, irrigation, harvesting usually result in lower nutrient use efficiency. Nitrogen recovery in crops grown by farmers rarely exceeds 50% and is often much lower. A review of best available information suggests average N recovery efficiency for fields managed by farmer's ranges from about 20% to 30% under rainfed conditions and 30% to 40% under irrigated conditions.

Scope for improving water and nutrient use efficiencies in agriculture

In modern agriculture judicious use of water and essential plant nutrients in crop production is very important to increase productivity and sustainability of cropping system. Under rainfed conditions, soil water may be lost from the soil surface through evaporation or through plant uptake and subsequently lost via stomata on plant leaves (transpiration). It can also be lost through runoff and deep percolation through soil. Improving water use efficiency in arid and semi-arid areas depends on effective conservation of moisture and efficient use of limited water. When irrigation is considered, water losses also include the mismanagement of irrigation water from its source to the crop roots. These losses not only cause wastage but also a potential hazard of soil salinity and water pollution resulting from the transport of nitrate, phosphate, sediments and agro-chemicals to the adjacent water bodies.

Use of N and P nutrients in crop production is influenced by climatic, soil, plant, and social economic condition of the farmers. Overall, the nutrient use efficiency by crop plants is lower than 50% under all agro ecological conditions. The low nutrient use efficiency is related to the loss and unavailability due to many environmental factors. The low nutrient use efficiency not only increase cost of crop production but also responsible for environmental pollution. Improving nutrient use efficiency is essential from economic and environmental point of view. The most important strategies to improve nutrient use efficiency are the use of adequate rate, effective source, timing and methods of application, timely supply of adequate water and control diseases insects and weeds. In addition to it decreasing abiotic and biotic stresses, using nutrient efficient crop species and genotypes are also important in increasing nutrient use efficiency.

The Strategy for promoting the use efficiency of these two viral resources should aim at integrating these techniques with simple agricultural practices so that it looks as a routine to the farmer rather than an additional activity. It should not make his engagement more complex in terms of time, money or space.

Status of water use efficiency in different crops in India

Water use efficiencies are different in different crops in India. Singh et al. (2010) reported range and average values of water-use efficiency of selected crops (Table 1). Among the food grain crops, WUE of wheat, maize, sorghum are much higher (1.24, 0.91 and 0.88, kg m^{-3},resp.) than that of rice (0.45kg m^{-3}). Among the legume crops, chickpea, lentil and kidney bean are more efficient user of water (having WUE of 1.60, 1.05 and 0.67kg m^{-3}, resp.) than pigeon pea, green gram and black gram which is in the range of 0.28-0.46 kg m^{-3}. Among the oilseed crops, WUE of sesame is much lower than that of soybean, mustard, groundnut, sunflower and linseed. Of the two important cash crops, WUE of sugarcane is much higher (4.68 kg m^{-3}) than that of cotton (0.26 kg m^{-3}). Among three important vegetable crops, cauliflower is more efficient user than tomato. The WUE of tomato is higher than that of brinjal.

Strategies for efficient water management and enhancing its use efficiency

Strategies for efficient management of water for agricultural use involves conservation of water, integrated water use, optimal allocation of water and enhancing water use efficiency by crops. Water use efficiency by crops can also be improved by selection of crops and cropping systems based on available water supplies and seasonal evapo-transpiration (Prihar et al. 2000). Other several

Table 1. Water use efficiency of some food grain crops grown in India

Crops	WUE range (kg m^{-3})
Food grain crops:	
Rice, wheat, maize, sorghum and pearl millet.	0.45-1.24
Pulse crops:	
Gram, lentil, moong, arhar, urad and lobia.	0.25-1.60
Oilseed crops:	
Groundnut, mustard, sunflower, sesame, linseed and soybean	0.36-0.67

Source: Singh et al. (2010)

factors like crop, variety, agronomic practices, climate, evapo-transpiration, irrigation, fertilization, plant population and interaction of productive factors influences water use efficiency.

On the broader perspective, the strategies for increasing water use efficiency include appropriate integrated land and water management practices like - soil-water conservation measures through adequate land preparation for crop establishment, rainwater harvesting, crop residue incorporation, efficient recycling of agricultural waste water, conservation tillage to increase water infiltration, reduce runoff and improve soil moisture storage, and adequate soil fertility to remove nutrient constraints for maximizing crop production for every drop of water available through either rainfall or irrigation. In addition, novel irrigation technologies such as deficit irrigation (omitting irrigation at times that have little impact on crop yield), drip irrigation and sprinkler irrigation can improve the water use efficiency of crops. In sandy soils of low fertility, nutrient deficiencies often override water shortage as the main factor limiting crop productivity. Crop growth may be so poor that it can utilize only 10 to 15% of total rainfall, the remaining being lost through evaporation, deep percolation and runoff. The resulting WUE may be very low as the actual amount of water required for food production would be higher than the average value of 2000-5000 kg water kg^{-1} food. Under such situations, increasing nutrient supply often leads to an increase in both crop production and WUE. Fertigation, which combines irrigation and fertilization, maximizes the synergy between these two farm inputs in increasing their efficiencies.

Selection of crops and cropping systems based on available water supplies

Selection of crops and cropping systems for high water use efficiency should be done on the basis of availability of water under the following three categories viz., rainfed crops, limited irrigated crops, fully irrigated crops and mixed cropping system.

Rainfed crops

The amount of rainfall converted into plant-available soil water is determined by the amount and intensity of rainfall, topography, infiltrability and water retentivity of soil, depth of root zone and soil depth. Depth of soil due to its effect on the available water storage capacity decides the type of cropping system that can be followed in a locality. In the shallow Vertisols of Indore region with 100 mm of available water, only mono-cropping of sorghum or corn can be practiced.

Limited irrigated crops

Selection of crops and cropping sequences under limited irrigation situation should be done in such a manner that there should be minimum water stress during the growing season although some water stress to the crops and associated yield reduction is inevitable. Therefore, along with selection of crops, special care should be taken for irrigation scheduling of these crops.

Fully irrigated crops

Under this condition, selection of crops is not constrained by water availability but by adaptability of the crops to prevailing climatic and soil condition. In general, C4 plants have potential for greater water use efficiency than C3 plants, particularly under semi-arid environment.

Regulating seasonal evapo-transpiration

Seasonal evapo-transpiration can be regulated by choosing better irrigation method, irrigation scheduling, tillage, mulching and drip irrigation under different crops.

Selection of Irrigation methods

Different methods are used to apply irrigation to the crop depending on the land slope, amount of water and equipment available, the crop and method of cultivation crops. These methods are classified as surface, subsurface, over head or sprinkler and drip irrigation methods. Among them, surface irrigation methods are most common but normally more wasteful. Sprinkler irrigation is adopted where land leveling is uneconomical and drip irrigation is used where water is scarce. Efficient micro irrigation methods and technologies i.e. sprinkler and drip irrigation, micro sprinklers, cablegation, surge irrigation, LEWA (low energy water application) and LEPA (low energy precision application) for utilization of available water in scarce areas have been reported to result in 30-50% saving of water and 20-40% increase in crop yields.

Bandyopadhyay et al. (2010) reported that when 20 cm irrigation to wheat was supplied up to flowering stage or 14 cm irrigation was supplied up to tillering stage, through sprinkler method in 4 and 3 splits, respectively at critical growth stages, it resulted in higher grain yield and WUE of wheat than that in flood irrigation method in a Vertisol of Madhya Pradesh. Yadav et al. (2000) conducted the experiment on water management studies in sugarcane at Rahuri (Vertisols) and showed that the drip method saved more than 60% water compared to furrow method and produced 12-15% more cane yield. In an effort to lower operational cost of drip system, planting pattern has been changed to cut down initial investment on laterals and drippers. Three distinct patterns of planting, viz. normal, paired row and pit method were evaluated. The yield in paired row planting in drip irrigation method was better than all surface irrigation treatments, indicating that the cost of drip system could be reduced by adopting paired row planting (Table 2). Similarly, the study was conducted on performance of drip and conventional surface (check basin) irrigation methods in clay soil at Rahuri in banana crop and found that the normal planting pattern had an edge over paired planting pattern. Nevertheless, fruit yield and WUE of banana were higher under drip than that obtained under check basin method of irrigation.

Prabhakar and Srinivas (1992) revealed that irrigation equal to replenishing 100% of pan evaporation (Epan) showed the maximum vegetative growth and yield of okra at Hessaraghatta, Bangalore. However, the water use efficiency was the highest with irrigation given to replenish 25% of pan evaporation. Alternative furrow irrigation saved up to 30% water without any adverse effect on productivity compared with irrigation of every furrow (Table 3). Prasad et al. (1999) showed that the seed yield of sunflower increased significantly at IW: CPE ratio of 0.8 (1.49 t ha^{-1}) with 39 cm depth in 6 irrigations. But water use efficiency was higher at 0.6 ratio in sandy soil of Pusa, Bihar (Table 4).

High frequency water management by drip irrigation minimizes soil as a storage reservoir for water, provides at least daily requirement of water to a portion of the root zone of each plant and maintains a high soil matric

Table 2. Effect of drip and furrow irrigation methods on water-use efficiency in sugarcane crop at Rahuri, Maharashtra

Irrigation method	Cane yield (t ha^{-1})	Water applied (cm)	WUE (kg m^{-3})
Drip, paired row	130.7	91	14.3
Drip, pit method	138.6	68	20.3
Irrigation in each furrow	114.7	216	5.31
Irrigation in paired furrow	111.4	160	6.96
Irrigation in alternate furrow	92.1	143	6.44

Source: Yadav et al. (2000)

Table 3. Yield, consumptive use and water use efficiency of Okra in relation to irrigation regimes and method of irrigation

Treatment	Fruit yield (t ha^{-1})	Consumptive use (mm)	Water Use efficiency (kg ha^{-1} mm^{-1})
Epan replenishment (%)			
100	16.06	302.5	53.1
75	13.53	269.0	50.7
50	11.20	206.5	54.7
25	9.96	158.5	63.9
CD (P=0.05)	2.48	--	--
Irrigation method			
Every furrow	13.43	275.5	48.6
Alternative furrow	12.02	193.0	63.2
CD (P=0.05)	NS	--	--

Source: Prabhakar and Srinivas (1992)

potential in the rhizosphere to reduce plant water stress. Application of 80% of recommended dose of N and K_2O through drip fertigation sandy soil at Gujarat was found to be the most efficient in obtaining significantly higher total potato tuber yield (420 q ha^{-1}) as compared to application of recommended dose of N and K_2O through furrow irrigation (Sasani et al. (2006). Fertigation also resulted in better fertilizer use efficiency by saving 40% water and labour.

Irrigation Scheduling

An ideal irrigation schedule must indicate as to when irrigation water is to be applied and the how much quantity of water to be applied. Several approaches for scheduling irrigation have been used by scientists and farmers throughout the world. The available soil moisture in the root zone is a good criteria for scheduling irrigation. When the soil moisture in a specified root zone depth is depleted to a particular level (which is different for different crops), it is to be replenished by irrigation. This can be discussed under following two conditions namely adequate irrigation and limited irrigation. Under adequate water supply condition, the objective of irrigation is to secure potential yield of crops without wasting water. Under limited irrigation, water should be supplied at critical crop growth

Table 4. Effect of irrigation levels on growth, yield and water use efficiency in summer sunflower (average of 3 yrs)

Irrigation (IW:CPE)	Water applied inclusive of rainfall (cm)	Plant height (cm)	Yield (t ha^{-1})	WUE based on ET (kg ha^{-1}cm^{-1})
0.8	39.06	188	1.46	47.4
0.6	29.06	172	1.33	50.4
0.4	21.06	167	1.14	49.8
Rainfed	5.06	160	0.73	61.7
CD (P=0.05)	--	9.5	0.13	4.8

Source: Prasad et al (1999)

Table 5. Critical growth stages of selected crops in respect of water demand

Crop	Critical growth stage(s)
Rice	Transplanting to tiller initiation, panicle initiation to flowering
Wheat	Crown root initiation, booting, milking, grain formation
Maize (kharif)	Silking
Maize (rabi)	4-5 leaves, knee-high, taselling, silking, grain formation
Sorghum (kharif)	Booting
Sorghum (rabi)	Vegetative, booting
Pearlmillet	Flowering
Pigeonpea	Flower initiation, pod development
Chickpea	Branching, pod development
Kidney bean	Vegetative, flowering, pod development
Greengram (summer)	Vegetative, flowering, pod development
Soybean	Flowering
Sesame	Flowering
Mustard	Branching, siliqua development
Groundnut (kharif)	Pegging, pod development
Groundnut (rabi)	Vegetative, branching, flowering, pegging, pod development
Sunflower	Vegetative, disc formation, flowering

Source: Yadav et al. (2000)

stages to achieve maximum water use efficiency. The first step in this effect is to generate quantitative information relating to yield reductions with water deficit during various periods of growth that can be used to optimize the dated inputs of limited water for maximum water use efficiency. There are different methods of irrigation scheduling viz., critical crop growth stage approach, soil moisture depletion approach, irrigation water at different cumulative pan evaporation (IW/CPE) approach etc.

Yadav et al. (2000), after extensive experimentation conducted over years, has identified critical growth stages of various crops in respect of their water demand (Table 5). Kaushik and Chaubey (1999) reported that application of one irrigation at branching (45 days after sowing, DAS) produced significantly higher chick pea grain yield as compared with no irrigation and one at flowering (75 DAS) or at pod filling stage (105 DAS) in sandy soil at Ujhani, Badaun in Uttar Pradesh. The maximum water use efficiency was recorded in one irrigation at branching.

Kar et al. (2004) recorded that with two supplemental irrigations, WUE of maize, groundnut, sunflower, wheat and potato was 0.55, 0.22, 0.23, 0.41 and 2.27 kg m^{-3}, respectively. It increased by 40, 14, 22, 38 and 7% when three irrigations were applied. With four supplemental irrigations, WUE of 1.32, 0.36, 0.36, 0.63 and 2.87 kg m^{-3} was obtained in the respective crops. Among all the five crops, the highest water use was observed in sunflower crop, probably due to its deeper root system.

Masanta and Mallik (2009) revealed that the four irrigations each at crown root initiation, maximum tillering, flowering and milking stage enhanced the wheat productivity, which was 498% higher than one irrigation given at crown root initiation stage. Water expense efficiency was highest under four irrigation treatments at Purulia district of West Bengal under red and laterite agro-climatic zone (Table 6).

Tillage

Tillage practices mainly influence the physical properties of soil viz., soil moisture content, soil aeration, soil temperature, mechanical impedance, porosity and bulk density of soil and also the biological and chemical properties of soil which in turn influence the edaphic needs of plants viz., seedling emergence and establishment, root development and weed control. Tillage also influences the movement of water and nutrients in soil and hence their uptake by crop plants and their losses from soil-plant system. Tillage affects water use efficiency by modifying the hydrological properties of soil and influencing root growth and canopy development of crops. Tillage methods influence wettability, water extraction pattern and transport of water and solutes through the soil profile through its effect on soil structure, aggregation, total porosity and pore size distribution. Tillage system suitable for a soil depends upon soil type, climate and cropping system practiced. Shallow inter-row tillage into growing crops has been reported to reduce short term direct evaporation loss from soil even under weed-free condition by breaking the continuity of capillary pores and closing the cracks.

Deep tillage to a depth of 30-45 cm at 60-120 cm space intervals helps in breaking subsoil hard pans in alfisols facilitating growth and extension of roots and improving grain yield of crops as well as increasing residual soil moisture. However, the benefit is absent in suboptimal rainfall years and restricted to only deep-rooted crops in high rainfall years. Conservation tillage practice normally

Table 6. Effect of irrigation scheduling on grain yield of wheat and water use efficiency

Treatments	Grain yield (kg ha^{-1})				Water use efficiency (kg $ha^{-1}cm^{-1}$)	
	I^{st} year	II^{nd} year	Pooled	%Increase over control	I^{st} year	II^{nd} year
T_1- One irrigation at (CRI)	398	452	425	--	37.2	39.7
T_2.- Two irrigation (CRI, PI)	746	880	813	91.29	47.8	52.5
T_3- Two irrigation (CRI, FS)	1010	1180	1095	157.64	60.9	68.8
T_4 -Three irrigation (CRI,MT, GSF)	1500	1686	1593	274.82	76.1	79.1
T_5- Four irrigation (CRI,MT,FS, GFS)	2466	2620	2543	498.35	107.5	100.1
LSD(0.05)	7.23	4.02	--	--	--	--

Source: Masanta and Mallik (2009)

stores more plant available moisture than the conventional inversion tillage practices when other factors remain same. The high soil moisture content under conservation tillage is due to both improved soil structure and decrease in the evaporation loss under continuous crop residue mulch cover. Increase in the available water content under conservation tillage, particularly in the surface horizon, increases the consumptive use of water by crops and hence improves the water use efficiency.

In Vertisols at Bijapur of Karnataka state (Patil and Sheelavanter 2006) tillage depth influenced the sorghum yield and water use efficiency. Higher grain and straw yield observed in deep tillage as compared to medium and shallow tillage due to higher water content in the top 0.60 meter soil profile. Water use efficiency increased significantly from shallow to medium and medium to deep tillage. The magnitude of increase in WUE was 29 and 72% more in medium and deep tillage over shallow tillage.

Effect of different tillage treatments and moisture regimes on water use efficiency of sunflower grown after puddled rice in loamy soil at Hyderabad (Gurumurthy 2000) showed that deep tillage and fine seed bed prepared by using disc plough once and rotavator twice (both tractor drawn) resulted in highest water use efficiency by sunflower. However, there was not much variation in water use efficiency due to moisture regimes (Table 7). Sarkar and Rana (1999) reported that ploughing of soil to a depth of 15 cm before puddling of rice super imposed by same depth of tillage for land preparation operation for wheat crop proved to be best for productivity and water use efficiency in loamy soil under rice-wheat crop rotation.

Mulching

Mulching increases the infiltration of water into the soil by reducing the runoff, increasing opportunity time to infiltration, reducing the evaporation losses and controlling weed infestation. Mulching is known to influence water use efficiency of crops by affecting the hydrothermal regime of soil, which may enhance root and shoot growth, besides helping in reducing the evaporation (E) component of the ET. Under moisture stress conditions, when moisture can be carried over for a short time or can be conserved for a subsequent crop, mulching can be beneficial in realizing better crop yields.

Singh et al. (2008) compared the effects of using single 30 mm irrigation and paddy-straw mulch @ 5 t ha^{-1} on field surface on WUE of sweet potato during rabi season. Water use efficiency as well as productivity of the crop was highest under straw-mulch treatment. While early application of the irrigation water produced moderate benefits, late application of irrigation had no significant effect on tuber yield and WUE of the crop. Use of mulch thus can enhance water productivity several folds during dry season when no irrigation water is available.

Reduction in water use and increase in water use efficiency due to ;(i) placement of polythene sheet at 30 cm depth; (ii) compaction to increase the bulk density of soil to 1.75 g cm^{-3} ; (iii) and clay mixing without reduction in yield of rice in loamy sand soil (Table 8) was reported by Gupta et al. (1984). Das et al (1995) revealed that water use decreased up to 24.2, 42.2 and 40.0 per cent in gram, moong and soybean, respectively and water use efficiency increased up to 83.8, 85.8 and 74.9 per cent in the respective crops due to inter row mulch treatments over control. The effect of mulch on water use efficiency was in the order white polythene> black polythene>straw mulch > control.

Application of surface mulch enhances the productivity significantly by improving soil moisture status over no mulch treatment and use of white polythene mulch found to be better compare to black polythene as well as

Table 7. Effect of tillage treatments and soil moisture regime on water use efficiency of sunflower in rice based cropping system in loamy soil at Hyderabad

Tillage	Soil moisture regime (IW/CPE ratio)				Mean
	0.6	0.8	1.0	1.2	
Zero tillage	2.30	2.44	2.30	2.16	2.30
Country plough twice + bullock drawn cultivator twice	2.78	2.88	2.80	2.69	2.79
Country plough twice + power tiller rotavator twice	2.99	3.11	2.94	2.90	2.98
MB plough once + cultivator twice, both tractor drawn	3.25	3.36	3.08	3.01	3.17
Country plough once + rotavator twice, both tractor drawn	3.57	3.64	3.47	3.44	3.53
CD (P=0.05)	Tillage : 0.19		Moisture : 0.09		

Source: Gurumurthy (2000)

straw and leaf mulch (Masanta and Mallik 2009). Water expense efficiency was also maximum under white polythene mulch (Table 9). Application of mulch not only improves the productivity but also reduce the number of irrigations. However, due to the high price of synthetic mulch the economic gain is maximum under locally available mulch material i.e. straw and leaf mulch.

Improved planting geometry

Modifying plant density, spacing, and geometry are important agronomic practices that influence utilization of soil water and rainfall, and the overall control of soil evaporation under dry land conditions. To obtain maximum possible yield, it is essential for the crop to utilize as efficiently as possible all the available production factors like water, nutrient, light and CO_2. Effect of planting geometry on yield and WUE of sugarcane at Rahuri, Maharashtra (Table 10) revealed that paired row or four row planting were superior to normal planting in drip irrigated crop (Yadav et al. 2000).

Zhang et al. (2007) reported that the FIRB (Furrow irrigated raised bed planting) and MRFP (mulched ridge and furrow planting) pattern had lower water consumption than the FP (flat planting) pattern due to decreased evaporation from top soil. Water use efficiency for FIRB and MRFP was 2.26 and 2.16 kg m^{-3}, which was 20.2 and 14.9 higher over FP.

Fertilization

Irrigation imposes greater demand for fertilizer nutrients. Higher yield means greater nutrient uptake by crops .Nutrient availability is highest for most crops when water tension is low. When soil moisture tension is low, the abilities of plants to absorb nutrients and the soil to supply them are optimal and therefore, nutrient availability is at its highest level. When the water supply is deficient, the stomata close, intake of CO_2 is reduced and photosynthesis decreases. There is strong interaction between fertilizer rates and irrigation levels for crop yield and water use efficiency. Application of nutrients facilitates

Table 8. Effect of compaction and clay mixing on yield and WUE of rice on loamy sand soil

Treatment	Grain yield (q ha^{-1})	Water (cm)	WUE (kg ha^{-1} cm^{-1})
Puddling	79.7	25.2	31.8
Polythene at 30cm	85.4	147	58.1
compaction to get 1.75 BD 1.75 g cm^{-3}	84.4	215	39.2
2% clay	81.8	240	34.1
4% clay	83.1	240	34.6
2% Na-clay	84.6	221	38.3
CD (P=0.05)	4.18	7.0	2.31

Source: Gupta et al. (1984)

Table 9. Effect of mulch on grain yield of wheat and water use efficiency

Treatments	Grain yield (kg ha^{-1})				Water use efficiency (kg $ha^{-1}cm^{-1}$)	
	Ist year	IInd year	Pooled	%Increase over control	Ist year	IInd year
T_1-Black Polythene	3625	3785	3705	105.83	211.49	165.86
T_2.-White Polythene	3987	4048	4017	123.16	240.32	186.62
T_3-Paddystraw	2915	3020	2967	64.83	154.97	130.28
T_4-Forest leaf	2628	2709	2668	48.22	133.67	108.97
T_5- Control (no mulch)	1725	1875	1800	--	75.16	71.51
LSD(0.05)	10.53	7.32	--	--	--	--

Source: Masanta and Mallik (2009)

root growth, which can extract soil moisture from deeper layers. Further, application of fertilizers facilitates early development of canopy that covers the soil and intercepts more solar radiation and thereby reduces the evaporation component of the evapo-transpiration. Reddy and Reddy (2006) reported that under adequate irrigation, suitable fertilization generally increases yield considerably, with a relatively small increase in ET and therefore, markedly improves water use efficiency.

Strategies for efficient nutrient management and enhancing nutrient use efficiency

Nutrients play a key role in increasing agricultural production through intensive cropping. Sustainable agriculture can be achieved by efficient utilization of this costly input. Nutrient use efficiency can be improved by checking the path ways of nutrient losses from soil-plant system, making integrated use of nutrients from all possible sources, optimal allocation of nutrients to crops and maximizing the utilization of applied and native nutrients by the crops. Use of fertilizers has contributed much to the remarkable increase in production of rice and wheat in India that has occurred during the past three decades. During the last half-decade or so while fertilizer consumption is touching new heights, the production of both rice and wheat is showing a trend of plateauing. In fact, fertilizer efficiency in food grain production expressed as partial factor productivity (PFP) has been decreasing exponentially since 1965.

Efficiencies are calculated as ratios of inputs to outputs in a system. A recent scientific review identified 18 different forms of nutrient use efficiency. Four of them that are very commonly used i.e.; Partial factor productivity (PFP); Agronomic efficiency (AE); Physiological efficiency (PE); and Recovery efficiency (RE). These ratios increase as rates of fertilizer application are decreased, even to levels well below the economic optimum. This is because, the crop response to applied nutrients typically follows a diminishing return function as yields approach the potential limit. This might cause one to falsely conclude that the lowest fertilizer rate results in the most efficient cropping system. This is untrue. Cropping systems depend on multiple inputs, including land, labour, seed, plant protection, capital, and more. At the rate, where the net return to the use of a plant nutrient peaks, it is making its best contribution in increasing the efficiency of all other inputs involved. This most economic rate is also often associated with minimal nutrient loss.

Best management practices ensure effective use of fertilizers in improving the efficiency of all inputs used in cropping systems. The goal of their use is to apply the most appropriate sources at the right rate, time, and place. Apparent nutrient efficiency of applied fertilizer is commonly calculated by the difference method, but tracer techniques allow us to determine recovery efficiency directly. For both techniques, NUE measurements can be based on total nutrients in the grain or on total nutrients in grain plus straw. The apparent efficiency data have been assumed to become nearer to direct measurements once the system is near steady-state with respect to its nutrient content and input via external addition, wet and dry deposition, biological fixation, etc. Reported estimates of fertilizer use efficiency vary widely, as do reporting methods itself. Hence, when fertilizer NUE data are reported, it is extremely important that the methods used to calculate NUE are not misunderstood. Statistics of different nitrogen use efficiency terms for different cereal crops is given in Table 11.

Current Status of Nutrient Use Efficiency

A recent review of worldwide data on nitrogen (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. However, experimental plots do not accurately reflect the efficiencies obtainable on-farm.

Differences in the scale of farming operations and management practices (i.e. tillage, seeding, weed and pest control, irrigation, harvesting) usually result in lower nutrient use efficiency. Nitrogen recovery in crops grown rarely exceeds 50% and is often much lower. A review of

Table 10. Effect of planting pattern on yield and water use efficiency of sugarcane at Rahuri, Maharashtra

Planting pattern	Cane yield (t ha^{-1})	Water applied (cm)	WUE (kg m^{-3})
Paired row planting (0.75 m)	158.8	91.4	17.37
Four row planting (0.90 m)	161.4	106.4	15.16
Normal planting (1.00 m)	136.8	193.0	7.08

Source: Yadav et al. (2000)

best available information suggests 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% when grown under good weather conditions (Table 12). Fertilizer recovery is impacted by management, which can be controlled, but also by weather, which cannot be controlled.

While most of the focus on nutrient efficiency is on N, phosphorus (P) efficiency is also of interest because it is one of the least available and least mobile mineral nutrients. First year recovery of applied fertilizer P ranges from less than 10% to as high as 30%. However, because fertilizer P is considered immobile in the soil and reaction (fixation and/or precipitation) with other soil minerals is relatively slow, long-term recovery of P by subsequent crops can be much higher. There is little information is available about potassium (K) use efficiency. However, it is generally considered to have a higher use efficiency than N and P because it is immobile in most soils and is not subject to the gaseous losses that N is or the fixation reactions that affect P. First year recovery of applied K can range from 20% to 60%.

Factors

Fertilizer N use efficiency is controlled by crop demand of N, supply of N from the soil and fertilizers and N losses from soil-plant system. Nitrogen needs of crop plants are met by applying fertilizer N and net N mineralization from soil organic matter. Fertilizer N is applied in forms readily available to plants but mineralization of N is controlled by water, temperature and aeration. Once these factors become optimum, amount of N that is mineralized depends upon the quality and quantity of organic matter in the soil. Also a strong interaction between C and N dynamics is obvious because N transformations are driven largely by biological activity. High rates of net N mineralization can result in dilution of fertilizer N. But if crop demand for N and the amount of fertilizer N remain constant, an increase in net N mineralization will lead to a decrease in observed REN. Relative magnitude of different N loss mechanisms will depend upon soil, weather, fertilizer and crop management. On broader perspective, climate exerts the strongest effect on the amount and pathways of N losses.

Challenges

Decisions regarding improvements in fertilizer N use efficiency will begin at the field scale where farmers need to deal with the variability in soils, climates, and cropping patterns As there exists a large fertilizer-N substitution value of soil N, it is important to know the amount and temporal variations of the indigenous N supply during crop growth for determining the optimal timing and amount of fertilizer N applications. Strategies based on applying N at the right rate, right time, and in the right place have already been developed and are in use. Recent literature on improving REN has emphasized on achieving greater synchrony between crop N demand and the N supply from all sources throughout the growing season. This

Table 13. Various N-use efficiency terms for major cereals across the regions

Crop	Fertilizer rate	AEN	PFPN	REN	RENI5	PEN
Maize	123±5.8	24.2±1.6	72.0±4.4	0.650±.03	0.40±0.02	36.7+1.8
Rice	115±3.7	22.0±0.6	62.4±1.8	0.460±0.01	0.44±0.02	52.8±1.6
Wheat	112±3.6	18.1±0.7	44.5±1.2	0.57±0.02	0.45±0.01	28.9±1.3

Table 14. Nitrogen fertilizer recovery efficiency by maize, rice and wheat

Crop	Region	No. of farms	Avg.N rate, kg ha^{-1}	N recovery, %
Maize	North Central U.S.	56	103	37
Rice	Asia-farmer practice	179	117	31
	Asia-field specific management	179	112	40
Wheat	India-unfavorable weather	23	145	18
	India-favorable weather	21	123	49

approach explicitly recognizes the need to efficiently utilize both indigenous and applied N, because losses of N via different mechanisms increase in proportion to the amount of available N present in the soil at any given time.

Options

Most of the fertilizer-N is lost during the year of application. Consequently, N and crop management must be fine-tuned in the cropping season in which N is applied. Two broad categories of concepts and tools have been developed to increase nitrogen use efficiency. Those in the first category include genetic improvements and management factors that remove restrictions on crop growth and enhance crop N demand and uptake. Management options that influence the availability of soil and fertilizer-N for plant uptake come in the second category. These include site-specific N application rates to account for differences in within-field variation in soil N supply capacity (in large fields), field specific N application rates in small scale production fields, remote sensing or canopy N status sensors to quantify real-time crop N status, better capabilities to predict soil N supply capacity, controlled release fertilizers and fertigation.

Optimizing Nitrogen Use Efficiency

Strategies to improve nitrogen use efficiency can be grouped into two namely Product Strategy: Coated fertilizers, slow-release fertilizers, urease and nitrification inhibitors and Fertilizer Management Strategy: Split application, N rate based on plant analysis, variable rate (time and space, precision farming), etc.

Product strategy

Numerous products supplying plant nutrients have emerged, offering a variety of nutrient contents, physical forms, and other properties to meet individual needs. Finding new sources of fertilizers and modifiers to minimize losses, thereby achieve higher use efficiency is a challenging task. Much of the work has been done on N with major source as urea containing high N (46%) and its proneness to losses. The complexities of N management occur due to its solubility, mobility and vulnerability to denitrification. The approaches have been to manipulate the granule size variations, coatings with neem or coal tar modifiers or additives to control the nutrient release rate. Table 13 provides the details on slow-

Table 13. Consumption ('000 tonnes) of slow release fertilizers in 1995-96

Slow-release Fertilizers	USA	Western Europe	Japan	Total	% Total SRNF
Urea-form(UF)	190	. 30	5	225	40
Sulphur coated urea (SCU) /SCU+P	100	2	6	108	19
Polymer coated urea (PCU) /PCU NPK'S	45	20	72	137	24
Isobutylidene-diurea (IBDU)/Crotylidene-diurea (CDU)	14	35	33	82	15
Others	7	-	3	10	2
Total	356	87	119	562	100

Table 14. Slow release forms of urea to improve N use efficiency

Fertilizer forms	Example
Coated with inert material	Urea coated with polymer, lac, gypsum, neem cake, sulphur, and rock phosphate
Enlargement of the granule	Urea supergranule, granular urea
Limited solubility forms of urea	Urea form, Oxmide, Urea-Z
Coated with urease inhibitors	Hydroquinone, phenyl phosphorodiamidate (PPD)
Coated with nitrification inhibitors	Nitrapyrin. AM (acetylene. 2-amino-4-chloro-6-methyl-peyrimidine), DCD (dicyandiamide), ATC (4-amino 1,2,4-triazole).encapsulated Ca-carbide, neem cake, karanj cake, DMPP (3-4-dimethylpyrazole phosphate)

release nitrogenous fertilizers (SRNFs) being manufactured, marketed and used in USA, Western Europe and Japan. Farmers' use of SRNFs has almost doubled over the past ten years across the globe, but it still accounts for only 0.15% of the total fertilizer N used. The main reason for its limited use is its high cost, which could be almost 3 to 10 times the cost of conventional fertilizers.

Application of controlled release fertilizers (CRFs) is an approach for minimizing non-point contamination in agriculture (Table 14). The CRFs have higher N-use efficiency, thus reducing N loss through leaching and volatilization while keeping higher yields. New gel-based CRFs were developed by mixing and processing N, P and K fertilizers with natural and semi natural organic materials and inorganic materials. These gel-based fertilizers were earlier produced, had lower price than coated CRFs, and pressed better physical and chemical properties. The gel-based CRFs showed significant positive influence on agronomical, physiological and biochemical characteristics of maize plants. These increased dry biological yield of maize by 26.8-42.3%, and improved N-use efficiency by 17.0-31.7%, P-use efficiency by 8.0-16.0% and K-use efficiency by 4.6-18.3%. Besides, the nutrients (N, P and K) in gel-based fertilizers were leached more slowly into the soil than common fertilizers.

IARI'S urea coating technology employing neem oil emulsion needing 0.5-1.0 kg neem oil per tonne of urea was found superior to prilled urea. The use of nitrification inhibitors might contribute to increased NUE or apparent N recovery efficiency. Maintenance of more NH4+available in the soil might also increase P absorption, and therefore increase P-use efficiency (PUE). The use of ammonium N source with the nitrification inhibitor 3, 4-dimetyipyrazole phosphate (DMPP) shows promise to increase NUE and PUE. Large granular forms of N and P fertilizer proved better than powdered and prilled forms for increasing nutrient uptake and grain yield of rice in irrigated lowland. Compacting phospho-gypsum (PG), diammonium phosphate (DAP), $ZnSO_4$ and KCl separately with urea slowed down urea hydrolysis and reduced NH3 volatilization loss. The new product increased the rice yield and NUE as compared to that obtained with prilled urea. Coating P fertilizer could limit the contact of applied P with soil resulting in early season deficiencies for crops like wheat. The development of thin polymer coating has improved the opportunity to coat fertilizer granules and increased the predictability of time of availability of nutrients from the controlled release product. At IISS, the study showed that urease inhibitor (UI) or urease inhibitor-nitrification inhibitor (NI) coated urea applied at 100% rate and nitrification coated urea applied at 80% rate improved apparent N recovery in maize (Table 15).

Scope of Nanotechnology in Slow-release Fertilizers

Nanotech materials (scale below 100 microns) are in development for the slow release and efficient dosage of water and plant nutrients for increasing the efficiency of nutrients and water. These inexpensive nanotech applications to increase soil fertility and crop production would be a major growth in agriculture in developing countries in near future. The nanoporous zeolites are being utilized for slow release and efficient dosage of water and fertilizer for plants. In China, different nanoparticle (clay-polyester, humas-polyster and plastic-starch) have been tried for slow release of N to wheat. The increase in yield due to clay and plastic (nanomaterial coating) was around 4.5% over chemical fertilizer application apart from saving through leaching losses of N fertilizer. There is great scope in Indian agriculture for improving fertilizer-use efficiency of major crops through nanotechnology. A series of laboratory experiments is being carried out at IISS to know the effect of rock phosphate nano-sized particles on germination and growth of seeds of soybean and mustard. In both the crops, germination was not affected up to 200

Table 15. Effect of UI and NI coated urea and plain urea on nutrient uptake by maize

Treatments		Nutrient uptake (Grain + Stover) ($kg\ ha^{-1}$) N	P	K	Apparent N Recovery (%)
T_1	Control (no urea)	70.1	13.6	82.0	-
T_2	Urea at 100% rate	117.1	19.3	117.3	47
T_3	UI coated urea at 100% rate	131.7	21.0	132.1	62
T_4	UI and NI coated urea at 100% rate	136.8	21.5	138.2	67
T_5	NI coated urea at 80% rate	105.6	17.6	106.9	36
T_6	UI and NI coated urea at 80% rate	113.5	19.2	113.5	44

ppm P (applied through TCP -nanoparticles and RP nanoparticles), and an increasing trend was observed in root growth of the crops. Results so far indicated that plant root might have got the unique mechanism of assimilating nano-sized rock phosphate particle for its growth and development.

Fertilizer Management Strategy

Applying nutrients at the right rate, right time, and in the right place as a best management practice (BMP) is the best bait for achieving optimum nutrient efficiency.

Right rate

Most crops are location and season specific depending on cultivar, management practices, climate, etc., and so it is critical that realistic yield goals are established and that nutrients are applied to meet the target yield. Over- or under-application will result in reduced nutrient use efficiency or losses in yield and crop quality. Soil testing remains one of the most powerful tools available for determining the nutrient supplying capacity of the soil, but to be useful for making appropriate fertilizer recommendations good calibration data is also necessary.

Other techniques, such as omission plots, are proving useful in determining the amount of fertilizer required for attaining a yield target. In this method, N, P, and K are applied at sufficiently high rates to ensure that yield is not limited by an insufficient supply of the added nutrients. Target yield can be determined from plots with unlimited NPK. One nutrient is omitted from the plots to determine a nutrient-limited yield. For example, an N omission plot receives no N, but sufficient P and K fertilizer to ensure that those nutrients are not limiting yield. The difference in grain yield between a fully fertilized plot and an N omission plot is the deficit between the crop demand for N and indigenous supply of N, which must be met by fertilizers. Nutrients removed in crops are also an important consideration. Unless nutrients removed in harvested grain and crop residues are replaced, soil fertility will be depleted. In a just concluded experiment at IISS, Bhopal nutrient omission trials conducted on farmers' fields deficient in N, P, S and Zn revealed that the balanced application of all these deficient nutrients at recommended rates helped in higher apparent recovery of applied P. K and S by soybean as compared to nutrient missing plots (Table 16).

Right time

Greater synchrony between crop demand and nutrient supply is necessary to improve nutrient use efficiency, especially for N. Split applications of N during the growing season, rather than a single, large application prior to planting, are known to be effective in increasing N use efficiency. Tissue testing is a well known method used to assess N status of growing crops, but other diagnostic tools are also available. Chlorophyll meters have proven useful in fine-tuning in-season N management and leaf color charts have been highly successful in guiding split N applications in rice (Table 17) and now maize production in Asia. Precision farming technologies have introduced, and now commercialized, on-the-go N sensors that can be coupled with variable rate fertilizer applicators to automatically correct crop N deficiencies on a site-specific basis.

Right place

Application method has always been critical in ensuring fertilizer nutrients are used efficiently. Determining the right placement is as important as determining the right application rate. Numerous placements are available, but most generally involve surface or sub-surface applications before or after planting. Prior to planting, nutrients can be broadcast (i.e. applied uniformly on the soil surface and may or may not be incorporated), applied as a band on the surface, or applied as a subsurface band, usually 5 to 20 cm deep. Applied at planting, nutrients can be banded with the seed, below the seed, or below and to the side of the seed. After planting, application is usually restricted to N and can be as a top-dressing. In general, nutrient recovery efficiency tends to be higher with banded applications because less contact with the soil lessens the opportunity for nutrient loss due to leaching or fixation reactions. Placement decisions depend on the crop and soil conditions, which interact to influence nutrient uptake and availability.

Table 16. Apparent recovery (AR) of nutrients under balanced fertilization by soybean

Nutrient	Apparent Recovery (%)
P	22
K	68
S	31

Organic materials have a major role to play in maintaining buffering capacity of soil and are important for maintaining soil physical conditions and biological properties. A range of factors such as soil temperature, moisture and chemical composition of the organic material influences N release from organic sources in soil. Nitrogen losses also occur from their use. Controlling N release from organic sources depends on their nutrient content and quality, soil properties, and the environmental and management factors. The build-up of soil organic matter is required to increase the potential for N mineralization. The challenge in optimizing crop N uptake in organic and cover crop-based systems does not entirely rely on developing organic matter pools but is more important to influence the rate and timing of N mineralization. It was found that interactions among inputs (manure, cover crops and fertilizer) and soil organic matter influence the rate of soil N mineralization. It is also well known that N from many organic fertilizers often shows little effect on crop growth in the year of application because of the slow release characteristics of organically bound N. Nitrogen immobilization after application can occur, leading to enrichment of the soil N pool. This process increases the long-term efficiency of organic fertilizers.

It was commonly held that P was irreversibly fixed in soils because of precipitation reactions and as a consequence the efficiency of P fertilizer was low. The recent and ongoing analysis of experimental data from long-term experiments, which permit an adequate evaluation of the efficiency of soil and fertilizer P, support the thinking that the recovery of added P over time can be high, thus supporting the concept of reversibility, given adequate time. This new paradigm has major implications for fertilizer use in the context of both agronomy and the environment. The best strategies for sustainable crop production and environmental safety with respect to P are to produce optimum crop yields by: (a) alternative P application only to winter crops, (b) periodic reduction in P rates according to accumulated P. and (c) occasionally without fertilizer P to enable the utilization of residual fertilizer P that had accumulated in the soil over the years. Application of rock-phosphate along with green leaf manure and P solubilizing bacteria and fungi gave significantly higher grain yield compared to application of rock-phosphate alone. The total dry matter, P and Ca uptake in soybean was significantly improved with the use of low-grade rock-phosphate in conjunction with phosphate solubilizers and FYM. Aspergillus awamorii was found to be efficient P-solubilizer, followed by Bacillus striata in solubilizing North Carolina and Mussoorie rock-phosphates. About 64-71% equivalent of water-soluble P requirement of crops could be met through rock-phosphates, seed inoculation of P solubilizing microbes and FYM.

Potassium, an essential nutrient required by plants in large quantities is present in soils in four pools, of varying availability to plants, in dynamic equilibrium. Potassium deficiencies have been observed in crops, such as cotton. maize and sorghum in Vertisols. Application of K fertilizers in many of the soils exhibits

Table 17. Comparison of chlorophyll-meter-based N management with fixed schedule applications of urea tablets in transplanted rice

Treatment	Rate (kg N ha^{-1})	Yield (t ha^{-1})	AEN (kg^{-1})
1995-96 wet seasons			
Control	0	5.27 ba	-
Prilled urea	55	6.23 a	17b
Prilled urea	110	6.61 a	12b
Urea tablet	55	6.51a	22 ab
Urea tablet	110	6.44 a	11 b
SPADh	30	6.19 a	30 a
1996 dry season; rice cv. IR64			
Control	0	4.40 d	-
Prilled urea	90	6.31b	21 be
Urea tablet	55	6.29 b	34 a
Urea tablet	110	6.99 a	24 b
SPAD	60	5.28 c	15c

no yield response to applied K despite an increase in K uptake. The high K uptake or tissue concentration might improve the quality of produce but not the yield. Though most Indian soils are testing medium to high in K status, variable response to applied K is reported in many crops. This is due to the K dynamics interplay between pools in different soil types modified by moisture and luxury consumption from plants.

Increased use of S-free fertilizers, intensive cropping, and use of high-yielding varieties have led to S deficiency in many soils. Sulphur deficiency is increasingly becoming one of the limiting factors to further sustainable increases in agricultural production. Sulphur fertilizer, besides enhancing yield and quality of crops, enhances nutrient uptake and fertilizer-use efficiency through interaction of S with other fertilizer nutrients. Application of S along with N, P and K to pulses and oilseeds showed greater response than to cereals. Sulphur not only improved grain yield but also improved the quality of crops. Interactions of S with N and P are positive, while its application decreases the contents of Zn, B and Mo in plant system. The combined use of leaf colour chart (LCC) for N management and recommended P. K, S and Zn fertilizers increased the yield of rice and wheat in rice - wheat cropping system. Improved N-use efficiency or full benefit of applied N was noticed due to overcoming deficiency of K, S and Zn through fertilizer application. Inclusion of limiting nutrients in fertilization programme has shown excellent results. Balanced and adequacy of all limiting nutrients for different cropping systems in alluvial and lateritic soils of West Bengal ensured high relative agronomic efficiency (RAE). For rice and jute, the RAE for the soil test and yield target-based recommendation exhibited the highest value, much in excess of 100%.

Plant nutrients rarely work in isolation. Interactions among nutrients are important because a deficiency of one restricts the uptake and use of another. Numerous studies have demonstrated that interaction between N and other nutrients, primarily P and K, impact crop yields

Table 18. Effect of balanced fertilization on agronomic efficiency of N (AEN)

Crop	Control yield (t ha^{-1})	N applied (kg ha^{-1})	AEN (kg grain kg^{-1}N) N alone	AEN (kg grain kg^{-1}N) +PK	Increase in AEN (%)
Rice (wet season)	2.7	40	14	27	100
Rice (summer)	3.0	40	11	81	671
Wheat	1.5	40	11	20	85
Pearl millet	1.1	40	5	15	219
Maize	1.7	40	20	39	100
Sorghum	1.3	40	5	12	126
Sugarcane	47	150	79	228	189

Source: Prasad (1996)

Table 19. Nitrogen use efficiency in rice through integrated nutrient management

Treatment	Apparent Nitrogen Recovery (ANR, %) 1st rice	Apparent Nitrogen Recovery (ANR, %) 2nd rice	Agronomic efficiency (AE, %) 1st rice	Physiological efficiency (PE, %) 1st rice
GM-N40 + N0	24.8	28.0	18.0	72.7
N40	43.3	44.9	23.5	54.5
GM-N40 + N40	35.6	35.7	15.5	43.5
N80	46.3	43.9	17.1	37.0
GM-N40 + N80	44.3	45.6	14.4	32.5
N120	31.8	30.8	10.3	31.4
GM-N40 + N120	34.4	38.7	9.7	28.2

Source: Mohanty et al. (1998)

and N efficiency (Prasad 1996). For example, data from a large number of multi-location on-farm field experiments conducted in India show the importance of balanced fertilization in increasing crop yield and improving N efficiency (Table 18).

Adequate and balanced application of fertilizer nutrients is one of the most common practices for improving the efficiency of N fertilizer and is equally effective in both developing and developed countries. In a recent review based on 241 site-years of experiments in China, India, and North America, balanced fertilization with N, P, and K increased first-year recoveries an average of 54% compared to recoveries of only 21% where N was applied alone. The greatest NER, PEIN, and NHI were attributed to the better physical, chemical, and biological properties of soil that would have caused greater nutrient uptake and yield, leading to better fertilizer use efficiencies. Mohanty et al. (1998) observed relatively higher NUE of rice with urea as compared with combined use of GM and urea up to 80 kg N ha^{-1} (Table 19). However, the trend was reverse at 120 kg N ha^{-1}.

Precision Agriculture

With the introduction of geographical information systems (GIS) and global positioning systems (GPS), farmers can now refine nutrient recommendation domain to the site-specific conditions of each field. Managing a field for inherent soil variability can be done with GIS and GPS technologies without expensive and time-consuming grid-based techniques. Global positioning systems linked to yield monitors also provide field maps that are used to control variable-rate seeders and variable-rate chemical applicators. By managing a field using productivity zones and N treatments that account for spatial soil variability, N-use efficiency has been shown to increase when compared with conventional N application treatments. Although all farmers' fields can be considered to be heterogeneous for available N and yield, the degree of heterogeneity has to be large enough to recover the cost associated with site-specific application of N fertilizer. Precision farming technologies have now been developed to spatially vary N prescriptions within a field, based on various information sources (maps of soil properties, terrain attributes, remote sensing, and yield maps). These practices include the timely and precise application of N fertilizer to meet plant needs varying across the landscape. Significant increases in N-use efficiency have taken place over the past 10 years using precision agriculture management practices. Achieving synchrony between N supply and crop demand without excess deficiency is the key to optimizing trade-offs among yield, profit, and environmental protection in both large scale systems in developing countries. The determination of rates and dates for N application must be more precise in this context. Models and diagnosis indicators have been developed to meet these requirements. A much better understanding of crop-soil-microclimate interactions on crop growth and nutrient demand, combined with better weather prediction, will be needed before site-specific farming management practices will be used widely.

Table 20. Comparative evaluation of tools and strategies for enhancing N use efficiency

Tools/Strategies	Benefit-Cost	Limitations
Site-specific N management	High	Has to be developed for every site infrastructure required
Chlorophyll metre	High	Initial high cost
Leaf colour chart	Very high	None
Plant analysis	High	Facilities need to be developed
Controlled release fertilizers	Low	Lack of interest by industry
Nitrification inhibitors	Low	Lack of interest by industry
Fertilizer placement	High	Lack of equipment
Foliar N application	High	Lack of equipment, risk
Models and decision support systems	Medium	Tools are yet to be perfected
Remote sensing tools	Low	Needs fine tuning
Precision farming technology	High	Needs fine tuning
Breeding strategies	Medium	Limited research effort

(Source: Ladha et al. 2005)

Comparative Evaluation

Ladha et al. (2005) compared different strategies to improve N use efficiency on the basis of benefit cost ratio and limitations (Table 20). If a new technology leads to at least a small and consistent increase in crop yield with the same amount or less N applied, the resulting increase in profit is usually attractive enough for a farmer. With very high benefit -cost ratio and with no limitation, use of simple and inexpensive leaf colour chart assists farmers in applying N when the plant needs it. As use of leaf colour chart can adequately take care of N supply from all indigenous sources, it ensures significant increase in REN and reduced fertilizer N use. This tool is particularly useful for small to medium size farms in developing countries. Similarly, precision farming technologies based on gadgets like optical sensors have demonstrated that variable rate N-fertilizer application has the potential to significantly enhance N use efficiency by crops like rice and wheat.

Modern N management concepts usually involve a combination of anticipatory (before planting) and responsive (during the growing season) decisions. Improved synchrony can be achieved by more accurate N prescriptions based on the projected crop N demand and the levels of mineral and organic soil N, but also through improved rules for splitting of N applications according to phenological stages, by using decision aids to diagnose soil and plant N status during the growing season (models, sensors), or by using controlled-release fertilizers or inhibitors. Important prerequisites for the adoption of advanced N management technologies are that they must be simple, provide consistent and large enough gains in fertilizer N use efficiency, involve little extra time and be cost-effective.

Interaction effect of water and nutrient on water and nutrient use efficiency

Nutrient, water and tillage are the key inputs interact among themselves synergistically to improve the crop yield and hence the input use efficiency. Tillage practices favorably modify the soil physical and biological environmental facilitating root proliferation. These actively growing roots can uptake nutrient and water from a greater soil volume and thus improve the water and nutrient use efficiency. So optimum synergistic combination of water, nutrient and tillage found for different cropping system, soil types and agro climatic regions to improve the overall input use efficiency.

Bhale and Wanjari (2009) reported that the significant and positive interaction between applied nitrogen and water supply was observed on wheat yield and water and nutrient use efficiency by wheat (Table 21) with 80 kg N ha^{-1}, N use efficiency increased up to 300 mm water supply in sandy loam soil.

Interestingly, with 120 Kg N ha^{-1}, it did not increase when water supply was increased from 50 mm to 125 mm, but increased markedly when water supply was further increased to 300 mm. This implies that the balance between these two inputs influenced input use efficiency. Similarly, it was also reported that the application of pine needle mulch (PNM) @ 10 t ha^{-1} with 60 kg N ha^{-1} registered significantly higher tuber yield and water use efficiency over 120 kg N ha^{-1} without mulching, indicating saving of 60 kg N ha^{-1} through the former treatment. Thus application of pine needle mulch proved effective in potato through favourably modifying the soil hydro thermal regime and saved water and nitrogen consumption without scarifying crop yield and thereby enhanced water and nitrogen use efficiency.

Table 21. Nitrogen and irrigation effects on water use efficiency (kg grain/mm) and nitrogen use efficiency (kg grain/ kg fertilizer N) in sandy loam soil

Irrigation (mm)	WUE N rate (kg ha^{-1})				NUE N rate (kg ha^{-1})		
	0	40	80	120	40	80	120
0	5.3	7.6	8.1	6.0	8.5	5.5	1.5
50	6.3	9.5	11.3	13.3	20.2	18.4	17.8
125	5.7	10.3	11.9	11.8	33.2	25.5	17.0
300	4.6	7.4	9.5	10.2	30.2	30.3	23.7

Source: Bhale and Wanjari (2009)

Conclusion

To meet the food needs of the burgeoning population, India will need to produce 300 million tonnes of food grains by 2020. Rainfed area occupying about 65% (89 M ha) of the cultivated land in India accounts for only 40% of total food production, whereas irrigated area covering 35% (53 M ha) of the cultivated land contributes 60% to the national food basket. Nutrient and water are the most crucial input for agricultural production. Low water use efficiency (WUE) however, has been the concern along with the decreasing availability of water for agriculture. For efficient conservation and utilization of these vital resources, suitable state of the art agro-techniques needs to be promoted. In modern agriculture judicious use of water and essential plant nutrients in crop production is very important to increase productivity and sustainability of cropping system. Improving water use efficiency in arid and semi-arid areas depends on effective conservation of moisture and efficient use of limited water. Water use efficiency by crops can also be improved by selection of crops and cropping systems based on available water supplies, seasonal evapo-transpiration (ET) and other several factors like crop, variety, agronomic practices, climate, evapo-transpiration, irrigation, fertilization, plant population and interaction of productive factors influences water use efficiency. Enhancement of NUE can be achieved by following the best crop management practices to achieve good yields, adopting right method and timing of fertilizer application, and practicing balanced NPK application, site specific integrated nutrient management, etc. From the nutrient management point of view, the means and ways to enhanced NUE by using recycling of the plant nutrients by using more and more organic manures and crop residues, putting more reliance on biological nitrogen fixation and use of phosphate solubilising organisms, reducing the rate of fertilizer application, using the right source of nutrients, applying the nutrients at right time, placing the nutrients at right place and balanced site-specific nutrient management (SSNM).

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Land degradation in India : Strategies to manage Chambal ravines in Madhya Pradesh

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Abstract

Ravines described as 'Cancer of Land' are the most physically degraded form of once cultivated fertile land. On both banks of Chambal river, ravines have resulted into not only a loss of non-renewable land-resource but also destruction of rural economy and creation of socio-economic problems through dacoit-infestation. Out of 4.386 M ha area under ravines, MP has 0.68 M ha. The World in famous Chambal ravines covered an area of 515 thousand ha in M.P., Gujarat and U.P. states and are up to 70 m deep where Chambal flew through alluvial tract. The seriousness of the problem of ravine formation altercated the attention of not only the State Government and the National Government but also of the International Agencies such as World Bank, European Economic Communities now European Union (EU) and so on. Numerous ravines reclamation schemes were launched from time to time by Central and State Governments, but failed. The main reason of failure of ravine reclamation projects was that watershed approach for simultaneous treatment of table land, peripheral land and the ravine land after identifying the main stream and stabilising it was not adopted. Also the formation of ravines in Chambal area is different than other ravines was not kept in mind.

Very deep Chambal ravines in MP pose a serious and peculiar problems as these are not in sequence with shallow, medium and deep ravines, e.g. those formed on banks of some other rivers. Here, based on available information, strategy is suggested that should include integrated development addressing ecological, economical and social imbalances, resource base use of ravines for sustainable production, arresting further advancement into cultivated table lands and a multi-tier plantation model including economical viable fruit, timber and fuel wood tree, grasses, flower, vegetables and suitable crops on watershed/micro-watershed system.

Keywords: Ravine land, ravine formation, management, watershed, sustainable use of ravines.

Ravines represent the most degraded form of once cultivated fertile land. Ravine land has been so severely eroded by run-off water that it is almost completely unsuitable for agricultural production. Consequently, it is classed as wasteland. Gullies and ravines form an extensive net work along the Yamuna, Chambal, Sone, Damodar and Mahi rivers and their tributaries in Uttar Pradesh, Madhya Pradesh, Rajasthan, Bihar and Gujarat states of India. At least two thirds of arable land in our country suffers from degradation of one kind or another and one third parts is almost unsuitable for cultivation.

A peculiar characteristic of the Chambal ravines in MP is that these are very deep all along their length which may be 3 km or more, i.e. when the gully advances during rainy season it is not by erosion of surface soil to form shallow or medium gully at first and its conversion into deep gully later on. On the other hand the lowest sandy layer of the soil gets washed away at first creating a big cavity underneath and then the whole chunk of upper layers of soil falls off to form deep gully. At some spots the cavity stays below the upper layer till the end of rainy season and the soil above falls off in the next rainy season leading to advancement of the deep gully. The cavity is formed at a depth of 6 to 10 m and appears to be formed by under currents of rain water absorbed by highly permeable surface soil.

The Chambal region of Madhya Pradesh has provided huge number of warriors to the nation and is a major producer of oilseeds, pulses and the milk. Even maximum productivity of wheat is achieved under limited irrigations. Soil and water quality is very good. But the precious land has been converted into ravines. Here, therefore, an effort has been made to assess the situation of ravines of Chambal in Madhya Pradesh, review the efforts made to control, reclaim and eliminate the rainves and to utilize them properly for improving the ecology, social and economic conditions of the people.

Ravines in India

Out of 328.0 M ha area of the country nearly 100 M ha is severely eroded (Dhruvnarayana and Rambabu 1983). No recent and accurate data on the extent of ravines in India are available. However, the severity of the problem of formation of ravines and their spread can be judged from the fact that more than 40 lakh ha of land is already covered by these presently and 0.5 per cent of the net cultivated land gets converted into ravines every year. The state-wise data on area under ravines show that the largest area under ravines land is in UP (11.23 M ha), followed by MP (0.683 M ha), Bihar (0.60 M ha), Rajasthan (0.452 M ha), and Gujarat (0.40 M ha) (Planning Commission 1972). In spite of unproductive nature of ravines, a large population particularly in the state of UP, MP, Rajasthan, Gujarat and Bihar continue to reside and depend upon the land under ravines for their livelihood. Accordingly, this area is not included under ravines and thus various data on extent of ravines in India, are an under-estimate.

Area under ravines in Madhya Pradesh

As per Chambal CADA (1997) district-wise data on area under ravines and under different rivers in MP are presented in Table 1. As shown in this table, in MP, Chambal division alone has an area of 0.31 M ha under ravines, of which 0.192 M ha area lies in Morena district and 0.119 M ha in Bhind district. After Chambal division, Gwalior division has the highest hectarage under ravines of which again Gwalior district has the highest area under ravines followed by Guna district. Datia district though very small in size has as much area under ravines as Shivpuri district. The Chambal and Gwalior divisions of the state suffer most severely from land-degradation by ravine-formation, as 0.568 M ha (about 90% of the total ravinous area in MP) lies in these two divisions.

According to report of the Chambal Command Area Development Authority (CADA), out of a total 2375 villages of Chambal Division, 498 villages in district Morena and 449 villages in district Bhind are affected by the problem of severe soil-erosion and ravine-formation, covering nearly 40 percent of the total villages. On an average, about 210 ha of each affected village are under ravines. In three districts viz. Morena, Sheoper and Bhind out of a geographical area of 16.13 lakh ha, ravines occupy nearly 3.10 lakh ha which is about 20% of their total geographical area. The proportion of ravine land is more pronounced in district Bhind (26.75%) as compared to district Morena including Sheopur (16.35%).

Ravine land of different river basins

Out of estimated 4.386 M ha area under ravines in the country about 0.683 M ha is in MP. These ravines are formed mostly along the river Chambal, Sindh, Betava, Kunwari and other tributaries of main river Yamuna. All these rivers are mainly north flowing peninsular rivers in the State which join major river Yamuna in UP under ravines. The river basin wise area of ravines in the State is given in Table 2 for major river basins so affected.

As evident from Table 2, other important rivers and tributaries forming ravines in MP are Betawa, Kunwari, Pahuj, Sindh and Vaisali. The bed level of Yamuna controls the maximum depth and extent of ravines of these rivers.

Chambal ravines

Chambal is an inter-state river flowing through MP, Rajasthan and U. P. It emerges from the northern slopes of Vindhyan range about 14.4 km south west of Mhow town of Indore district at an elevation of 854 m above mean sea level (MSL). Chambal with its tributaries forms the infamous Chambal ravines, not only degrading completely the once fertile land but also providing a shelter to dacoits. The total area under ravines formed by Chambal and its tributaries is 0.515 M ha of which 0.226 M ha is in MP.

Chambal valley is covered by two prominent soil types viz. black soils (Vertisol and associated soils) and alluvial soils (Entisols). The Vertisols are not so erodible and only V- shaped gullies are formed by run-off water. But alluvial soils of the Chambal valley are highly fragile and have very high rate of soil-erosion due to their high dispersion coefficient. The soil particles are highly scattered by splash erosion caused by rain-drop and start running with run-off water as if ahead of it. Also, the vertical fall between the river bank and the river-bed is much higher after the river enters the alluvial soils zone i.e. beyond 600 km of its initial run. This high fall associated with fragile nature of alluvial soil results in severe ravines formation as deep as 70 m and degrading the land completely into sharp triangular vertices. The landscape of Chambal ravines includes scenarios of different types of ravines formed in watersheds of its various tributaries in Bhind and Etawa district where Chambal has largely dissected the land into irregular shapes made of steep ridges, deep trenches and low sloping hills and thus divided itself into many streams. During rainy season, these streams become flooded and are difficult to cross over. The areas neighboring the junction of these streams

Table 1. Area under ravines in different districts of Madhya Pradesh

District	Ravine land (M ha)
Morena*	0.192
Bhind	0.119
Gwalior	0.108
Guna	0.097
Chhattarpur	0.040
Datia	0.026
Shivpuri	0.026
Sagar	0.025
Damoh	0.025
Panna	0.020
Tikamgarh	0.005
Total	0.683

*Includes Sheopur district

Table 2. Ravine area of different river basins in Madhya Pradesh

River basin	Ravine area (M ha)
Sindh	0.182
Chambal	0.095
Kunwari	0.084
Paravati	0.057
Pahuj	0.047
Vaisali	0.033
Betwa	0.031
Kev Dhasa	0.021
Asan	0.031
Seep	0.013
Kuno	0.007
Sank	0.002
Other	0.093
Total	0.683

joining it on either side, as well as the ravines (deep) formed along the Chambal river itself. On the right bank the river Chambal is joined by its tributaries viz. Kalisdindh, Parvati, and Kuno rivers which along with main river form lot of gullies (medium in depth) as their basin is covered by black soil and elevation of Chambal river-bed is also not too much below the general level of the adjoining catchments of the tributaries. Consequently, the ravines of this triangular area are characteristically narrow, V-shaped, parallel to each other and 3 to 4 m deep and have stabilized with time, though these appear to be at comparatively younger stage of development. Further down, with increasing depth of alluvium, the depth of the ravines increases considerably, the shape of ravines change from V-shape to U- shape, with vertical walls and flat bottoms. The depth varies from 30 to 60 m. This dissected tract consists of long strips between the Chambal and Kunwari and tributaries like Asan. They seem to erode each others banks cutting into the adjacent areas. This erosion has resulted in the formation of numerous platforms, knolls and plain bluffs. After Kuno river basin a belt of ravines nearly 3-4 km wide exists up to Morena. Further east wards, these ravines almost merge with the ravines of Yamuna and Kunwari and make a bewildering net-work of ravines.The entire countryside with Yamuna and Kunwari, are wild and untamed yet picturesque and present a unique view. As far as the eye can see, there are labyrinths of dissected ravines and some valleys green with Acacia trees.

Recurring spread of ravines

A study by Chambal CADA (1997), Gwalior, revealed that in Chambal division, revines covered 0.228 M ha in 1943-44 and 3.107 lakh ha in 1975-76-an increase of 36% in 32 years. They farther brought out that during the earlier period of 1943 to 1950, the growth of ravines was 1380 ha/year, whereas in the later period of 1950-51 to 1975-76, it increased to 2130 ha/year. Singh and Rao (1996) used remote sensing techniques and reported that the area under gullies and ravines in 66 villages of Morena district increased to 218.695 km^2 in 1994 from 130.15 km^2 in 1969, i.e. an increase of 88.545 km^2 in 25 years. This amounts to an increase of 3.5418 km^2/year or 2.72 percent of the fertile land lost per annum from 1969 to 1994.

The ravines are still being formed along the main river Yamuna and its tributaries, viz. Chambal, Kunwari, Asan, Seep, Vaishali, Kuno, Parvati, Sank and Sindh. The worst ravines are in the vicinity of Chambal river and are expanding faster than ever before. These are still gobbling up many villages and communities in Bhind and Morena districts. It is estimated that ravines have affected 948 villages in Bhind and Morena districts. Mrigpura village in Morena district is being gobbled up by the ravines so rapidly that all the land around it has turned into deep pits. The village is now divided into several parts. In Porsa block, Ratanbasai village has split into 8 segments. The streets and roads have been destroyed and it takes a tough walk cross three kilometers to cover all segments of the old village. The ravines are eating into the social life of the village. Nayakpura, Rubara, Ajitpura, Khandoli, Jaghona, Rithona, Mahuwa, Sessani and Gaushpur are among the innumerable ravines-affected villages in this region. About 20 percent of Chambal Division (total area 1.164 M ha) i.e. around 0.311 M ha has been covered by ravines (Anonymous 2009). What could be the life of people whose houses are divided into so many parts, who have no land left to till, who have lost all the pastures and grazing land for their livestock, and finally have no work to do and no means to bring up their families.

Regardless of the reliability of the data on extent and spread of ravines, it is apparent that both the area under ravines already formed as well as the present rate of formation of ravines is so great that M.P. is fast running out of good arable land. The population with ravine land survives on rainfed cultivation on flat bottoms of U-shaped ravines and by rearing livestock. This is not adequate for sustainable livelihood. Poverty, social injustice and menace of dacoits have tended to exacerbate the problem at the grass-root level. The problem of tackling the growth and spread of ravines, therefore needs to be addressed by integrating it with socio cultural transformation of the region.

Efforts made in the past

Earlier efforts on ravine reclamation As early as 1919, the ruler of the erstwhile Gwalior State appointed a commission with following terms of reference: 1. To suggest ways and means to arrest further extension of ravines. 2. To suggest means for making available fodder, fuel and timber for agricultural purposes to such villagers who had no access to forest nearby.

Later on, the government of India invited Dr. Schuhart, an American Expert on soil conversation, to suggest solution of the problem. He visited ravines affected areas in 1945 and had suggested contour bunding starting from the ridge, control on grazing and afforestation for soil conservation in the area. Based on these recommendations, numerous attempts were made to develop Chambal Valley by reclaiming the ravines during last few decades. Rightly the objective was to stop the large scale land-degradation and to restore the degraded land to some vitality and use for biomass production.

The government of Madhya Pradesh executed several ravine reclamation projects for Chambal ravines viz. Chhonda project (1955-56), Bagchini project (1955-56), Nayakpura Project (1956-57), Deori Hingona (1959-65), Jawasa Project (1962-70) and Dimini- Chandpur Project (1967-68). Under these programmes, an area of 9080 ha was treated from first five year plan to 1970-71, comprising 3100 ha of ravine reclamation and 5980 ha of ravine afforestation at a cost of Rs. 44.23 lakhs.

Later on, Chambal Multipurpose Hydel Project for Chambal Valley was started as a joint venture of the Govt. of the then Madhya Bharat (now part of MP) and Rajasthan to exploit the irrigation potential of the river Chambal. Accordingly, besides construction of dams and network of canals to irrigate 2.83 lakh ha in Chambal Division, rectangular fields were created by large scale land-leveling using bull-dozers on the part of command area under ravines. But soon there were problems particularly with rectangular fields and a World Bank supported Command Area Development Project was taken up in 1975 with a financial credit of Rs 24 million. But the results were again not worth the investment (Chambal CADA 1997).

The Government of India has invested heavily on measures to control soil erosion. Vast sums of money have been allocated to soil conservation in various five year plans during 1969-1990. The budget for soil conservation for this period was Rs. 16 billion (Kern and Sanghi 1993). In 1971, ravine control scheme started under Central sector protecting 13500 ha table land and leveling 3000 ha ravine land, at a cost of Rs. 201.20 lakhs upto 1981. In 1980, a World Bank Project was launched in Chambal Command Area, covering 82000 ha land under aerial seeding. Unfortunately, the seed did not stay on slope and gathered on the bed of deep ravines. The result was that not a single plant grew on slopes but a thick forest of Prosopis (*Prosopis juliflora*) developed on the bed of ravines. Being thorny plants, the thick vegetation pushed the wild neel gais (blue bulls) to farmers' fields ruining their crops.

During 1988-92, ravine reclamation was undertaken in MP and UP as per Govt. of India instructions under Dacoity Prone Area Development Programme. Construction of 476km of peripheral bund along with table land treatment on 5229 ha and shallow ravine treatment of 2776ha was done at a cost of Rs 362.44 lakhs, in Madhya Pradesh (Table 3).

The results of evaluation of ravine reclamation work executed under various state and central government schemes have been quite disheartening. Sebastian (2001) reported that there have been programmes galore in the past for reclamation of ravines in the troubled intersections of MP, Rajasthan and UP. However, nothing has worked successfully. Jha (2004) reported that numerous ravines reclamation and soil erosion control schemes launched from time to time by the Central and State governments, such as Ravine Erosion Control scheme, various afforestation programmes, and the Dacoit Prone Area Development Programme, have not helped at all. Thus, it can be concluded that in spite of expenditure of carores and carores of rupees on reclamation of Chambal ravines, the problem remains unsolved and not only any ravenous land has not been really reclaimed but ravines have been spreading fast year after year.

Strategies to manage ravines

Watershed based management of rain-water

Since formation of ravines is a function of uncontrolled run-off, the management of rain-water on watershed basis is the only appropriate approach for the control and reclamation of ravines (Verma 1983). Watershed based development of land and water resources for gully control and consequent enhanced and stable agricultural production has already been demonstrated on farmer's fields at Indore, MP (Verma 1982). This experience of black soils can not be transferred to alluvial soils for ravine control and reclamation as such because alluvial soils particularly in Chambal Valley have much higher dispersion coefficient and pitching of earthen bunds/banks is not successful unlike black soils. Also, the problem of caving under the structures due to underground water-flow is serious. Obviously, what is needed is fool-proof technology based on local experience, transferred to farmers' fields with their cooperation and active involvement (Verma 1987).

Land and Water Management Works

Land and water management works have to be planned for the entire watershed starting from the ridge and including the table land which usually exists just below the ridge and above the ravine land. Again the ravine land maybe classified into 3 categories depending upon the depth of ravines viz. (i) shallow ravines (less than 1m deep), (ii) medium ravines (1 to less than 3 m deep), (iii) deep ravines (3 to 10 m deep) and very deep ravines (>10 m deep). Appropriate works and planting programmes have to be planned for different depths of the ravines.

Table land

Usually it is flat or gradually sloping and thus run-off water may not cause serious erosion. However to increase the productivity of such land through conserved water, field bunding (in alluvial soils) is necessary. If the average rainfall of the area is less and infiltration rate of the soil high, field outlets may not be necessary as most of the rain-water will seep into ground water quickly. In case of high intensity rain, the run off may flow over these stable (grassed) bunds (15-20 cms high). If bunds are constructed afresh, compaction of bunds and planting of grass may be done or natural grass maybe allowed take over to create a vegetative cover on the bunds. Bunding will prevent the sheet and rill erosion by interfering with free flow of run-off over large areas, as the whole area is divided into many bunded fields. On black soil, graded bunds should replace the field-bunds contour bunds. As soil under ravines is very susceptible to water-erosion, emphasis must be laid on raising kharif crop on sloppy land at least, as a good crop-cover (like that of soybean) is the cheapest soil conservation measure. On sandy loam soil dominant ravinous land, groundnut and pigeonpea are much more remunerative than pearlmillet,

Table 3. Earlier Ravine Reclamation work

Scheme	Sector	Period	Area covered (ha)	Expenditure (lakh Rs)
Ravine reclamation	State	1955-73	1240	30.19
	Central	1970-84	1748	102.15
Ravine erosion control (CADA)	State & World Bank	1976-87	13500	201.20
Dacoity Prone Area Development Prog. (UP & MP)	Central	1988-92	8005	362.44

Source: Action Aid, India (1996)

blackgram, greengram and sorghum. There is an immense potential to increase their yields by choice of proper varieties, timely sowing and adopting other improved practices of crop production.

Peripheral bund

Between the table-land and the ravinous land a peripheral or water diversion bund must be constructed to lead the run off from table land to a safe place (water reservoir, farm pond or a stable grassed water way depending upon the location), without causing any soil erosion. Peripheral bund is essentially a graded bund the cross-section of which will depend upon the run off to be tackled and the type of soil. The bund should be covered with vegetation like grasses, agave (*Agave sisalana*), munj (*Saccharum munja*), kans (*Saccharum spontaneum*), etc. on the upper side (the side along which water will flow) and the utility trees on the outer side (side facing ravine land). Suitable deep rooted tree species like babul (*Acacia* species), shisham (*Dalbergia sissoo*) or fodder-cum-fuel species like subabool (*Luchaena leucocephala*) or fruits tree like ber (*Zizyphus mauritiana*), guava (*Psidium guajava*), aonla (*Emblica officinalis*), jamun (*Zyzygium cumini*), etc. can be planted.

If the peripheral bund meets a deep pit, a suitable drop-structure on the bund must be constructed and the ravine starting from the pit should be developed as a grassed waterway.

Shallow and medium gullies/ravines

If shallow and medium gullies/ravines are still active i. e. they are increasing in depth and width with time and their head is still falling apart, following steps must be taken for their control and reclamation:

- Identification of main gully
- Its stabilization by a bund (earthen gully-plug) across the general slope and with a drop-structure (gabion or masonry structure) of appropriate size. Such bunds will be repeated at different points on the main gully (Anonymous 1979). The drop-structure (gabion) with reverse filter will retain the silt up-stream and allow only run-off water to pass through. The level of gully-bed will rise as a result of silt-deposition and banks will be stabilized.
- By continuous deposition of silt against the bund, the area between two successive bunds will take the form of a bench-terrace in due course of time.
- Smoothening of land on both sides of the gully (between two bunds) to reduce the slope of land below 3 percent (on which erosion can be checked by good crop cover in rainy season with crop-rows sown across the slope). Leveling of hummocks and isolated steep banks of secondary/tertiary ravines is to be done with minimum disturbance to the top-soil.
- Planting of munj (*Saccharum munja*) on the bunds to stabilise these.
- Construction of run-off collection ponds/tanks at suitable sites.

Land use plan

If the peripheral bund between the table-land and shallow ravines land has been constructed well with gabion drop-structures wherever necessary, it will divert the surplus run-off water from table-land safely and control further deepening and widening of shallow ravines. Under such circumstances, shallow ravines can be reclaimed just by establishing proper vegetative cover. The vegetation should be selected such that it provides not only a good soil-cover but is more remunerative also and makes the best use of land and water resources. Some appropriate systems are suggested below.

Agri-horticulture system is most suitable for management of ravinous land with shallow ravines. Fruit plants such as guava (*Psidium guajava*), grafted plum (*Prunus armeniaca*), aonla (*Emblica officinalis*) and karonda (*Carissa carandas*) can be planted intercropped by kharif crops such as blackgram, greengram, pigeonpea (short duration variety) depending upon topography of the land. Mohpatra and Jha (2009) found that aloevera (*Aloe barbadensis*) planting in the inter-tree spaces of plum (*Prunus armeniaca*) trees gave a net return of Rs. 75000/ ha.

When land-slope is more, a better vegetative cover has to be provided and for this either a Horti-silvi-pastoral system or a Silvi-pastoral system will be more suitable than Agri-horti system. Vrious horti-silvi-pastoral systems have been suggested (Anonymous 2009):

Deep ravines

Lower part of the watershed has deep and broad (U-shaped) main ravine/gully. Its banks are too vertical to be stable and thus plant any crop/tree on them. Also, the bed may not be utilized because it may be submerged under water not only during the rains but also later on because of 'back water flow' of rivulet/river into the gully/ ravine.

Works

For reclamation of deep gullies/ravines, it is necessary to construct a series of earthen bunds of appropriate cross-section and with a composite gabion or masonary drop structure, across the slope on the bed of gully/ravine. To protect his bund from water-erosion, planting of munj (*Saccharum munja*), agave (*Agave sislana*), aloevera (*Aloe barbadensis*) etc. should be done. The composite gabion drop-structure is most suitable as surplussing arrangement on these bunds as huge amount of run-off running at a fast speed during high intensity rains can easily wash away the earthen bund (serving as a gully-plug) if surplussing arrangement is not satisfactory and adequate. The silt-deposit against the composite gabion will raise the level of ravine bed and thus reverse the process of bed-corrosion. With the rise of bed-level, the banks will also become more stable and come to a natural angle of repose and thus will be able to support any kind of plantation on these. Later on when the bed-level of the ravine has risen sufficiently, the banks of ravine and the adjoining land can be graded (with a land-grader) so as to reduce the slope to less than 3 per cent. While reclaiming a deep gully, care has to be taken not to keep the height of crest-wall of the gabion above gully/ravine-bed more than 60cms to start with. The crest-wall can be raised every year suitably if necessary to tackle too much low depth of the ravine. That is, no attempt should be made to raise the bed-level of the ravine to a desirable height just in one shot, because the calculated height of the crest-wall if maintained just in the first year, may impound too much water against the gabion which will not only be inconvenient to farmers' movement but may be too hard on the crest-wall of the gabion and it may bend or deform the gabion.

Land-use Plan

After initial stabilization and reclamation work (a series of water diversion/contour bunds with suitable surplus-run off disposal systems), agri-horticulture and silvi-pastoral systems as above can be tried. Alternatively, afforestation with fuel and fodder trees can be undertaken. Even bamboo plantation can be tried. Besides these, many sustainable livelihood systems can be suggested to make the best use of so called 'waste land'. These are:

Mixed farming system

This can be easily adopted by farmers, and fortunately most of the marginal and small farmers have already adopted long back one such system i.e. keeping milch animals with cropping. The system can be more profitable if deep ravines on farmer's holding are put under 'Horti-silvi-pastoral' system. Grasses such as *Cenchrus ciliaris, Stylosanthes scabra, Penisetum pedicillatum, Panicum turgidum* and *Chrysopogon fulvus* should be planted on the bottom of the ravine and trees for fuel and fruits can be planted on the top of banks of the ravine. In rabi, wheat, gram or mustard can be grown on the bottom of the ravine, particularly if during monsoon season, the ravine-bed was submerged under back-flow water of the river, while trees can continue to grow on sides and top of the ravine.

Goatary based livelihood system

It is easier to feed and maintain a herd of goats on poor ravine land, although many farmers object to their introduction on such land. Goats feed on grasses and shrubs which grow well even under arid conditions. Grasses already suggested can be grown on the bottom of ravine for controlled grazing while *Hardvickkia binata, Parkinsonia aculeata, Prosopis cineraria, Sesbania sesban, Cassia auriculata, Ziziphus rummularia* and *Ziziphus jujuba* can be planted all over the ravinous land, particularly where moisture regime is not favorable for fruit trees.

Run-off collection and Recycling

Run-off collection and its recycling and its use for recharge of underground-water is a very important component of ravine reclamation and control technology. Run off collection can be done in several ways depending upon the site in watershed. Runoff will get stored temporarily even against peripheral bund, contour/graded bunds and submersible check dams, the construction of which will be necessary for the control of the ravine formation. Also, at suitable sites farm ponds or tanks can be constructed to store runoff. If at any site, construction of a peripheral bund is not feasible, construction of a bund along the boundary of two farmers both having ravinous land along the boundary, will be very appropriate to hold silt and water upstream the bund. The bund has to be of an appropriate cross-section according to the catchment above bund. Also, it should be compacted and protected by planting *Saccharum* species, agave, grass, etc. Further, it must be provided with a waste-weir of appropriate type and size and at an appropriate point on the bund, to dispose off excess of run-off. This bund will serve double purpose of holding water (for recycling/charging) and reclaim and control ravine-formation. Formation of gullies which was taking place earlier will stop because as soon as run-off water from table-land meets the stored-water, it loses its velocity/abrasive power.

At certain sites just below the table land, the rain-water causes small land-slides forming deep-pits. It will be quite appropriate to construct a bund such that a number of pits can be converted into a tank. The tank will not only store run-off but will also stabilize the table-land. On land with deep ravines if it is not possible to afforest, suitable dam can be constructed against a number of deep and U-shaped ravines to create a good water-reservoir fit for fish culture. Needless to say that the dam will have to be ably designed and constructed.

Potentially, the table lands of this area are highly productive under better managed conditoins. The climate, and the quality of soil and water are good. The area is free from major insect pest and diseases ofthe crops (Tomar 2009). Thus if properly managed these ravines can be converted into lush gree areas providing better food, fodder, fuelwood and fibre resulting into better socio-economic enviornment to the people of the ravines. The management should include the following :

An integrated development of the wastelands of ravines must address the ecological, economic and social imbalances of the region.

Focus on developing the resource base of the ravines for sustainable use.

Adoption of effective measures for arresting further advancement of ravines into cultivated table land.

The reclamation and restoration of ravines ecosystem should include in-situ soil and moisture conservation (Watershed based management) following a multi tier plantation model of successful trees, shrubs, grasses adn legume species. This should include fruit trees vegetable, flowers, medicinal plants and other economic plantations.

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Impact of long term fertilizer management for sustainable soil health and crop productivity: Issues and Challenges

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Abstract

Continuous cropping without adequate restorative practices may endanger the sustainability of agriculture. Nutrient depletion is a serious cause of soil degradation. A quantitative knowledge on the depletion pattern of plant nutrients from soil helps to understand the status and state of the soil health degradation and may serve as a tool in devising nutrient management strategies as an instrument to provide indicators for the sustainability of agricultural system. Therefore, this approach has been applied widely which yielded significant improvement of the crop productivity as well as in maintaining the soil fertility. Thereby, maintaining the soil health is only a key prerequisite to sustain crop productivity and consequently soil health of the cultivated soils. Several studies perceive that soil fertility decline is widely spread in Central Indian soils specially covering regions of Madhya Pradesh. This could be a result caused by improper management practices followed such as inadequate nutrient replenishment and simultaneously coupled with high losses as compared to natural ecosystems. In this perception, present study moreover, a sort of compilation of research emphasized the focus on studies pertaining to consequence effects of nutrient management based on inadequate or low-external input agriculture without considering soil test based recommendation on soil chemical, physical and biological parameters that determine its health and fertility status as well as their subsequent effects on productive capacity potentials of the soil. Efforts have also been made to review the pertinent research work related to the adequate nutrient management for sustainable soil fertility and crop productivity under intensified cultivation based on more than three decades findings of long term fertilizer experiment to study changes in soil quality, crop productivity and sustainability. Permanent Mannurial Experiments provide valuable information on the impact of long term adoption of nutrient management system with varying sources, types and combinations of plant nutrient inputs on soil fertility as well as productivity. The knowledge on resource based nutrient management may play a vital role for any decision support system which aims to demonstrate the role of society in sustaining agricultural and conversely, the role of healthy soil in sustaining healthy society.

Keywords: Long term fertilizer management, crop productivity

Recent agricultural trends indicated that productivity of major crops is not rising as quickly as did during the early 1970s. Part of the explanation for such a decline in production growth is the mismanagement of nutrients and soil fertility. According to Tomar and Dwivedi (2007) the basic concept of plant nutrient management is to limit the unfavourable exploitation of soil fertility and plant nutrients (Yadushvanshi and Swarup 2006). The maintenance (Dwivedi et al. 2015 b) and improvement of soil fertility with adequate plant nutrition based on soil test value at an optimum level to sustain the desired crop productivity through optimization of the benefits from all possible sources is the main concern (Tandan1995, Dwivedi et al. 2009 a) seems to be more than the use of fertilizer alone (Dwivedi et al. 2007). Since, agriculture is a soil-based industry 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 (Tandon 1998, Dwivedi et al. 2009 b). Therefore, to produce more and more yield from an unit land area, the conservation and maintenance of soil fertility, should be of the most important tactical targets for sustaining productivity (Dakshinamurthy et al. 2005). It has been recognized that integrated plant nutrient management system pertains to the combined use of organic and inorganic fertilizers in proper proportion accompanied by sound cultural management practices in crop production (Swarup and Rao 1999).

Future strategies would be planed to redress the proper management of soil fertility in order to create synergies with yield increasing technologies developed for a predominant cropping system of a region (Gruhn et al. 2000). To meet the projected demand of food required by coming decades will need substantial increases in the yield potential of crops. The management of nutrients and soil fertility, along with continuous technological change, farmer participation, technology transfer and suitable environment policy are key components for attaining sustainable health of the soil and subsequent productivity of agricultural crops in the long run. In this regard, present attempt discusses review of some current issues in plant nutrient use and the role of nutrients in creating an enabling environment for plants to growth and soil fertility.

Current status of nutrient management

In the recent years, intensive cultivation using high yielding varieties of crop with imbalanced fertilization has led to excessive mining out scarce native soil nutrients to support plant growth and production that severely affected the fertility status (Tandon 1999 and Swarup and Ganeshmurthy 1998). In this regard, Dilshad et al. (2010) suggested that production capacity of the major soils groups has deteriorated over the years. The use of chemical fertilizers has been increasing steadily but not being applied in balanced proportions. These practices in long run may reflect moreover, on emerging deficiency of major, secondary as well as micronutrients. It is now well known that under intensively cultivated soils in many parts of the Madhya Pradesh, nutrient deficiencies have been induced mainly by imbalanced fertilization (Dwivedi et al. 2007). Similarly, low to very low organic matter content in most of the soils (Katyal 2001, Tandon 2004) is another concern Swarup and Rao 1999 stated that the addition of organic manures to soil through various sources like FYM, compost and organic residues etc has been reduced considerably because a major portion of organic residues is used as fuel by the rural people. A lot of research has been compiled on soil fertility (Gruhn et al. 2000), Finck (2006) has concluded that major reasons for the depletion of soil fertility as listed below:

- Decline trends in fertility of the soil especially due to sub optimal, imbalance and inadequate fertilizer application, non adoption of recommended practices in predominated cropping of the state;
- The increased intensity of cropping, especially changes in crop sequence with HYV, makes current management practices of fertilizer recommendation less effective;
- Under low fertility soils imbalance and inadequate application of fertilizer is used by most of the farmers without following proper soil testing recommendations,
- Gradual decrease in the status of soil organic matter and deficiencies of secondary and micronutrients are prevalent under improper supplementation of fertilizer nutrient.

Major issues on nutrient management in present scenario

In recent years, Robert (2011) suggested that gains in technology-driven crop production were challenged and threatened by many factors such as soil fertility as well as crop productivity related problems, extreme climate changing situation from the external environment etc. which may affect the crop yield potentials to a considerable extent.

On the contrary, the last decades were marked by confinding research and development of new super-hybrids, environment-friendly pest and disease management practices, use of fertilizers based on soil test (Swarup et al. 2001, Thakur et al. 2009, Dwivedi et al. 2015 c). Furthermore, Sekhon (1997) covering aspects relating to plant nutrient needs and policy issues described that in recent years and perhaps in unforeseen periods into the future, the unstable global weather conditions shall be the dominant barrier to the sustainability of food and agricultural production, incomes and livelihood of small, vulnerable poor farmers in the MP state. In this connection, Subbarao and Reddy (2005) considering major aspects of nutrient management practices followed under intensive farming identified the following common constraints to the sustainability of soil fertility and subsequent effects on productivity of crop are summarized as under:

Declining trends in soil fertility and over mining of inherent soil nutrients

The adoption of intensive cultivation and short duration high yielding varieties as well as without proper soil testing, the blanket application of plant nutrients are proving to be inadequate to sustain the loss of inherent soil reserves to maintain long-term and cost-effective high crop production.

Inadequate application of mineral fertilizers

Many areas of the Madhya Pradesh witnessed both the conditions of inadequate availability and affordability of key agricultural inputs like fertilizers supplying nutrients. There is a serious concern about the overdose of fertilizers as shown by the general trend for some farmers to apply improper additions of inorganic fertilizers. Inadequate awareness concerning efficient fertilizer use and appropriate practices have resulted in inefficient releases of soil nutrients with respect to the actual needs of the crop plant for optimum growth and production into the already weakened ecosystem, causing soil health problems including water and soil pollution. Hence, there is a common agreement on the need for the efficient and balanced use of nutrients and adoption of scientific measures to ensure that soil health is sustained while engaging farmers to improve crop yields through the use of proper agricultural management.

Decline in level of soil organic matter reserves

Poor on-farm management of soil organic matter along with sub-optimal use of biological and organic nutrient sources, combined with the concurrent soil nutrient mining, poor water management and poor soil cover have collectively caused the rapid degradation/decline of soil organic matter. The general absence of comprehensive nutrient recycling, and composting along with poor land management practices has led to a loss of soil infiltration capacity and soil erosion that eventually resulted in the rapid removal of surface soil organic matter reserves.

Future challenges on nutrient management for sustainable soil health and crop productivity

The major challenge for agriculture over the coming decades will be chiefly confined to meet the world's increasing demand for healthy food in a sustainable way. Declining soil fertility and mismanagement of plant nutrients have made this task more difficult. In this regard, Tomar and Dwivedi 2007 pointed out that as long as agriculture remains a soil-based industry, major increases in productivity are unlikely to be attained without ensuring that plants have an adequate and balanced supply of nutrients. They called for an Integrated Nutrient Management (INM) approach to the management of plant nutrients for maintaining and improving the soil health, where both natural and man-made sources of plant nutrients are used.

The agriculture is under persistent pressure to narrow the gap between food supplies and demand by the ever increasing human population, aggravated by significant loss of arable land from urbanization and pollution. As a consequence of this negative trend in the food supplying capacity of the regions natural resource base, Asian countries have mainstreamed into their national policies the promotion and use of high yield food security programmes. This is further enhanced and fully supported by policy support for fertilizer recommendation with soil test to encourage farmers to use optimum fertilizers to ensure high crop yields. Common barriers and root causes of the decline in agricultural land productivity and the ensuing threat to food security include the following:

- Increasing population and rapid urbanization accompanied with industrialization declining man-arable productive soil;
- Compilation of the previous research studies in the form of research papers and popular articles/books/ bulletins may need to be utilized for the benefit of research scientists and farming community.
- Lack of proper knowledge for balanced fertilizer practices based on a sound soil testing recommendations along with integrated use of fertilizer.
- Development and assessment of management practices for major crops grown in various agro climatic regions for their beneficial role in improving soil fertility for sustainable crop production
- Defining of the role of organic manures and biofertilizers in increasing input use efficiency due to their favourable improving effect on soil physical, chemical and biological environment in maintaining the favourable health of the cultivated soils.
- Establishing the beneficial role of integrated use of chemical fertilizer and biofertilizers along with organic manures for improving nutrient availability under different production systems on various types of soils of Madhya Pradesh;
- Policy support for loss of inherent soil fertility reserves or soil nutrient mining induced by the imbalanced use of fertilizers following proper soil test recommendations.

Research gaps in nutrient management for sustainable soil health and crop productivity

Gaps in nutrient management between scientists and farmers remain a major factor that make the complex dynamics of soil-plant nutrient management to effectively sustain the balance between soil nutrient reserves with actual plant nutrient uptake and nutrient export or removal from the soil. The information generated on the possible research gaps while considering previous research findings may include followings:

- Under intensified cultivation, the appropriate nutrient management approach needs to be followed for sustaining soil fertility and subsequent crop productivity.
- Specific recommendations of fertilizer for various crops generally are not based on soil test and relevant practices for nutrient management to a specific region which may be mismatching the current practices developed and generated at research levels with the actual resources followed by the farmers.
- Organic manure and biofertilizers are not included due to non availability, hence, availability must be ensured as per the requirement.
- Nutrient balance in relation to soil fertility management at individual farm level needs to be worked out for nutrient release characteristics to determine for nutrient requirement of the crops.

Adequate plant nutrient supply holds the key in improving the healthy food production and sustaining livelihood. In this context, while considering fertilizer issues for sustainable agriculture the suitable to the crop based nutrient management practices have been developed and recommended that in most of the cases farmers are not applying fertilizers at recommended rates. Therefore, proper management of nutrients plays an important role which involves integrated use of organic manures, crop residues, green manures, biofertilizers etc. with inorganic fertilizers to supplement part of plant nutrients required by various cropping systems and thereby fulfilling the nutrient gap. Hence, integrated use of organic manures with optimal levels of NPK fertilizer is the need of the hour, (Tomar 2008) as it will not only improve the nutrient status and soil health, but also prove to be a boon in stabilizing the crop yields over a period of time (Tembhare et al. 1998). Therefore, integrated nutrient management system is the only way to maintain and improve the nutrient status of Indian soils. In other words, an adequate and specific nutrient management system is an ecologically, socially and economically viable approach, which on the whole is non-hazardous without causing any danger to normal health of the soil in achieving the sustainable and global security for healthy feed.

Strategies for sustainable soil health and crop Productivity

The basic concept of plant nutrient management system is to maintain the soil fertility (Hopkins et al. 1995) for sustaining crop productivity through optimizing all possible sources (organic, inorganic biological in an integrated manner appropriate to each farming situation (Gruhn et al. 2000, Yadav 2002, Roy et al. 2003, Tomar and Dwivedi 2007 and Tomar 2008). Integrated plant nutrient system management includes the precise use of inorganic, organic and biological resources so as to sustain optimum yields (Brar et al. 1998) improve or maintain the soil properties (Tembhare et al. 1998) and provide crop nutrient packages which are technically sound economically attractive practically feasible and environmentally safe (Subbarao and Reddy 2005). The principal aim of the integrated approach is to utilize all the sources of plant nutrients in a judicious and efficient manner (Tandon 1995).

Compilation of research studies summarized in report of FAO (2005) and Dilshad et al. (2010) on Integrated Plant Nutrient Management and revealed that declining soil fertility and mismanagement of plant nutrients made the task of providing healthy food for the world's population demand in 2020 and beyond more difficult. The negative consequences of environmental damage land constraints, population pressure, and plant nutritional deficiencies have been reinforced by a limited understanding of the processes necessary to optimize nutrient cycling, minimize use of external inputs, and maximize input use efficiency, particularly in tropical agriculture. All these ultimately decreased the potentials of soil resources.

In the time of energy crisis and rapid depletion of non-renewable energy sources, as observed by Finck (2006) the biggest 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 (Subbarao and Reddy 2005).

Significance of nutrient management for sustainable soil health and crop productivity

The challenge for agriculture over the coming decades will be to maintain the health of soil meet the world's increasing demand for healthy food in a sustainable way. Declining soil fertility and mismanagement of plant nutrients have made this task more difficult. In integrated nutrient management, Soil Fertility, and Sustainable Agriculture: Current Issues and Future Challenges. 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 approach recognizes that soils are the storehouse of most of the plant nutrients essential for plant growth and the way in which nutrients are manage will have a major impact on plant growth, soil fertility, and agricultural sustainability for ensuring healthy feed.

Impact of nutrient management on crop productivity

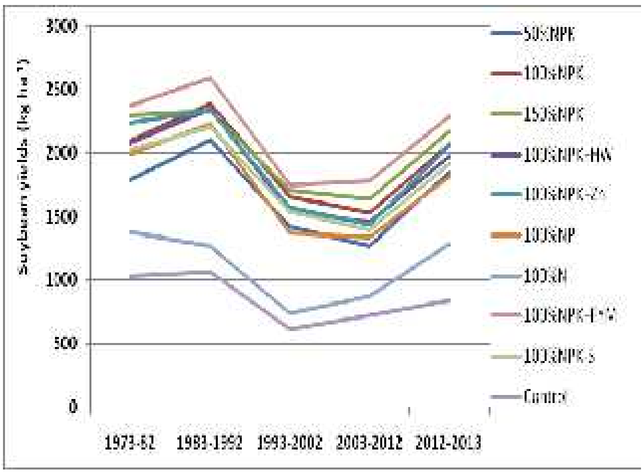
The data on about four decades of Long Term Fertilizer Experimental findings revealed that increasing yield trend was recorded with the successive application of fertilizer over control, On the other hand, continuous cropping without supplementing with inorganic fertilizers invariably reduced the crop yields. Hence, fertilizer responses to the successive levels is obvious (Dwivedi et al. 2007, Yadushvanshi and Swarup 2006).

The data pertaining to the grain yield of soybean and wheat (Fig 1) indicated that the lowest grain yield was recorded in control. While, the yield was increased in treatment receiving sub optimal fertilizer dose (50% NPK), which was significantly higher than that obtained with application of 100% N alone. This indicated that imbalanced nutrient application resulted in lower productivity when the N alone was practiced. Similarly, it was also noted that further inclusion of P fertilizer (100% NP) was increased around 29% higher yields. While, there was a further improvement obtained when K nutrient included (100% NPK) and accounted to around over imbalanced (NP application). These results established the importance of "P" application as a major fertility constraint in controlling productivity of soybean grown especially in black soil (Thakur et al. 2010, Dwivedi and Rawat 2014).

Similarly, addition of S through SSP exhibited in increasing the yield over without S supplementation through DAP fertilizer. Thereby, inclusion of S in fertilizer schedule was found to be essential for crop growth and productivity responses in terms of yield under balanced application of fertilizers. Application of recommended optimal dose (100% NPK) resulted in grain yield, but exclusion of sulphur (i.e. 100% NPK-S) dose had resulted in comparatively lower grain yield which was accounted to about 17% decline in yield of soybean. On the other hand, the grain yield obtained in 100% NPK + FYM treatment was significantly higher than 150% NPK treatment. The data clearly indicated that addition of integrated application of fertilizer with FYM was found to be beneficial for maintaining the fertility and consequently improved the productivity potential of crops of soybean-wheat cropping system (Sawarkar et al. 2010, Dwivedi and Rawat 2014).

These findings indicated that balanced application of recommended NPKS through fertilizer produced the higher yield over imbalanced applications. While, integrated use of optimal fertilizer and organic manure was found to be superior over 100% NPK for sustaining the fertility of soil and subsequent productivity of crops.

The data also revealed that 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



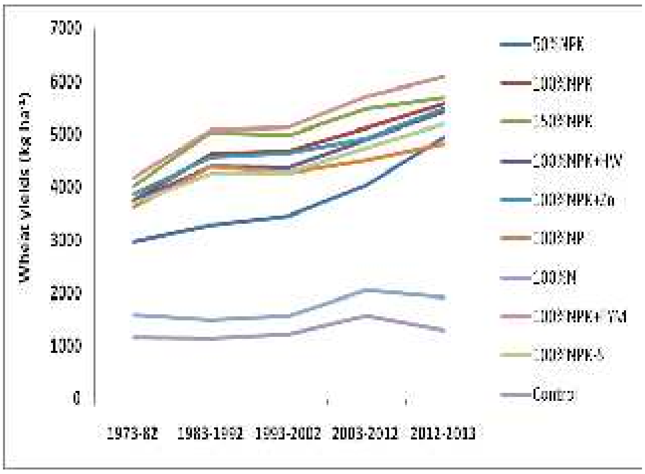


Fig 1. Effect of Long term fertilizer application on productivity of soybean- wheat (kg ha^{-1})

maintained a higher yield level over the years. Absence of S in fertilizer schedule has shown reduction in soybean-wheat yields throughout the period (Tembhare et al. 1998; Dwivedi and Dikshit 2002). Increases in yield on application of 150% NPK over 100% NPK indicate that the doses of NPK used are insufficient to obtain the potential yield of wheat. Sustaining the productivity at higher level on incorporation of FYM compared to 100% NPK or 150% NPK suggests that FYM application not only fulfill nutrient required but also maintain the favorable environment in improving the soil health (Sharma et al. 2000, Tomar and Dwivedi 2007, Tomar 2008 and Dwivedi et al. 2009 a). Thus to sustain the crop productivity on long term basis there is a need for balanced fertilization (Dwivedi and Dikshit 2002, Dwivedi et al. 2009 b, Dwivedi et al. 2012). Similarly, the results clearly demonstrate that P, K and S are essential for sustaining the yield.

Impact of nutrient management on pattern of nutrients removal

The effect of fertilizer and manure addition on nutrient uptake (Fig 2) by crops revealed that the wide variation has been obtained which clearly reflect the influence of varying fertilizer application on crop growth and yield. In this connection, the increasing trend with higher uptake of N, P, K, S and Zn by soybean was obtained with successive application of fertilizer over control and the maximum uptake of nutrients was recorded when 100 % NPK with FYM application. Hence, increasing rates of fertilizer addition resulted in successive increment in the uptake of nutrients.

However, inclusion of K with 100 % NP (100 % NPK) had also resulted in slight increase in the uptake of these nutrients. Further, the maximum uptake of nutrients was found with 100% NPK+FYM, followed by 150% NPK while, minimum content was noted in control.

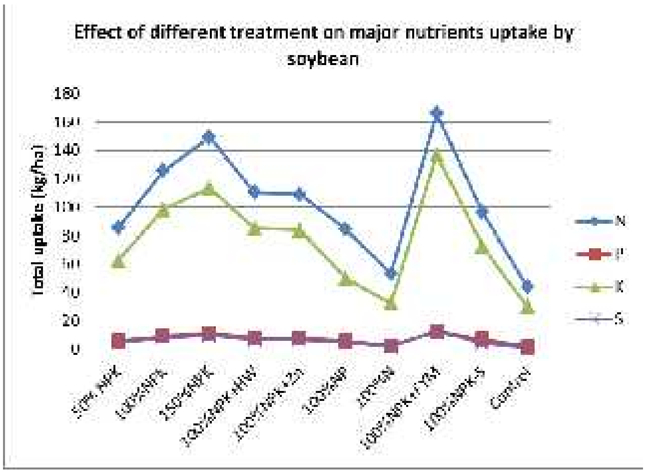
Similar, trend has also been observed with rabi wheat crop and the data indicated that highest uptake of N, P, K and S by wheat (Fig 2) was observed in 100% NPK + FYM treatment followed by 150% NPK while, lowest uptake was associated with control and N alone. An abrupt increment in respect of nutrient uptake was obtained when P fertilizer was added (NP) in the schedule. However, further inclusion of K with 100 % NP i.e. 100 % NPK had also resulted in slightly higher uptake of NPK and S nutrients. This indicated that P is one of the important factors governing the yield in soybean-wheat cropping sequence. In general, higher uptake of nutrient N, P, K and S was recorded in grain rather than the straw at the harvest of the crop. It was also noticed that higher amount of nutrients was harvested by wheat crop in comparison to the nutrient content obtained in soybean (Subbarao and Reddy 2005, Dwivedi et al. 2009 a).

Impact of nutrient management on changes in physical environment of the Soil

Soil physical conditions influence the growth of roots and soil microorganisms. Use of fertilizers and manure may results in changes in soil physical properties that may include the following:

Soil Aggregation

Soil aggregation is one of physical properties of soil, which governs the root growth, and exchange of air into soil and



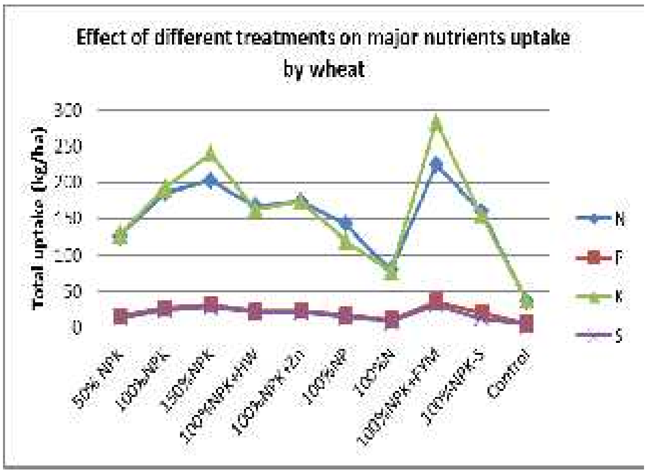


Fig 2. Effect of Long term fertilizer application on major nutrients uptake (kg ha^{-1}) by Soybean and wheat

also acts a storehouse of soil organic carbon. The data presented in Fig 3 revealed that 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 (Singh et al. 2002, Dwivedi et al. 2007). 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.

Bulk Density

Though there is no significant change in bulk density however, a slight decline was recorded in the plots that received balanced nutrition. The maximum decline was noted in NPK + FYM treatment as compared to control probably due to application additional amount of organic manure. Initial (1972) bulk density of surface soil (0-15 cm) - 1.30 (Mg m^{-3}) (Dwivedi et al. 2007).

Infiltration rate

Application of balanced fertilizer and manure improved the initial and cumulative infiltration rates (Table 1) 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. 4).

Impact of nutrient management on changes in chemical environment of the soil

Soil analysis after 43 years revealed (Table 2) that the data on available NPK contents in soil clearly indicate

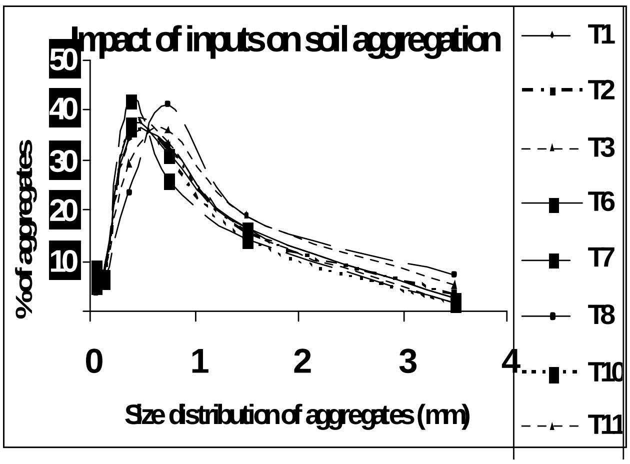


Fig 3. Effect of Long term fertilizer application on soil aggregation (mm)

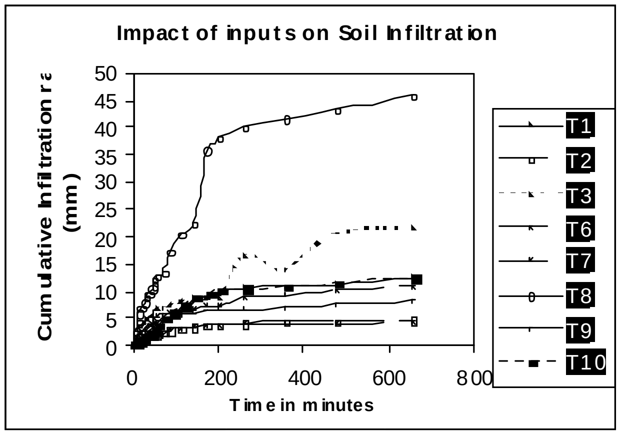


Fig 4. Effect of Long term fertilizer application on cumulative infiltration rate (mm) in soil

Table 1. Effect of Long term fertilizer application on infiltration rate in soil

Treatment		Infiltration rate (mm hr^{-1}) Initial	Constant
T_1	50% NPK	7.20	0.30
T_2	100% NPK	11.66	0.70
T_3	150% NPK	16.92	0.90
T_6	100% NP	10.80	0.60
T_7	100% N	3.96	0.20
T_8	100% NPK+FYM	29.16	1.00
T_{10}	Control	4.44	0.30

that cultivation of crops without addition of fertilizers and manure had caused substantial lowering of available nutrient status, which indicates deterioration in soil health. Similar findings with fertilizer addition on soil health have been reported by Swarup and Srinivasa Rao (1999), Dwivedi and Dikshit (2002), Dwivedi et al. (2009 b). However, balanced use of fertilizers either alone or in combination with manure had helped in strengthening the nutrient status of soil. Since removal of K by crops was higher and resulted in substantial lowering in available status of K. These findings indicate that use of balanced fertilizer either alone or in combination with organic manure is conductive for maintaining soil health as reported by Swarup and Srinivasa Rao (1999). On the other hand lowering in available S status of soil in N P K without S treatment indicates that use of sulphur free fertilizer will have deleterious effect on soil health especially of sulphur fertility (Dwivedi and Dikshit 2002).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 (Table 2) revealed significant increase in soil organic carbon in all the treatment except control and 100% N alone. However, largest increase in soil organic carbon was recorded in 100% NPK + FYM followed by 100 % NPK.

The increase in soil organic carbon 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, Singh et al. 2012, Dwivedi et al. 2015 a). The larger increase in soil organic carbon in NPK + FYM was due to 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. The largest increase in organic carbon content i.e. 0.94 % in optimal NPK+ FYM treatment could be assigned to addition of more amount of carbon through leaf fall compared to other treatments

Table 2. Effect of Long term fertilizer application on Soil test values after harvest of wheat (1972-2014)

Treatment	pH	EC (dSm^{-1})	OC ($g\ kg^{-1}$)	Available Nutrients ($kg\ ha^{-1}$)			
				N	P	K	S
50% NPK	7.51	0.15	5.62	223	24.8	252	23.4
100% NPK	7.56	0.17	7.65	293	38.1	280	37.1
150% NPK	7.59	0.19	8.80	332	46.6	309	44.8
100% NPK + HW	7.56	0.16	7.59	285	35.1	263	34.6
100% NPK + Zn	7.60	0.17	7.62	287	35.7	264	35.9
100% NP	7.57	0.19	6.67	264	31.4	231	32.9
100% N	7.44	0.14	5.23	208	10.7	193	11.1
100% NPK + FYM	7.53	0.20	9.96	359	48.1	357	48.6
100% NPK - S	7.57	0.17	7.25	264	33.4	257	11.6
Control	7.50	0.14	4.18	179	9.7	181	11.3
CD (P=0.05)	NS	NS	6.17	6.8	5.6	7.1	7.7
Initial (1972)	7.6	0.18	5.7	193	7.6	370	15.6

Treatment	Available Micronutrients ($mg\ kg^{-1}$)			
	Zn	Fe	Mn	Cu
50% NPK	0.50	18.04	12.89	1.34
100% NPK	0.58	22.06	15.35	1.66
150% NPK	0.62	25.54	16.06	1.76
100% NPK + HW	0.55	20.40	14.08	1.60
100% NPK + Zn	1.26	21.56	14.70	1.60
100% NP	0.53	18.74	13.65	1.45
100% N	0.40	17.79	11.60	1.23
100% NPK + FYM	0.95	32.34	17.22	1.93
100% NPK - S	0.47	18.78	12.54	1.40
Control	0.26	13.44	11.03	1.20
CD (P=0.05)	6.84	7.96	6.61	6.32
Initial (1972)	0.33	2.47	16.10	0.11

Source Annual Report AICRP LTFE 2014

in addition to continuous use of FYM during the period of experimentation.

Impact of nutrient management on pattern of nutrient buildup and depletion in soil

Available nutrient status over the initial values after harvest of wheat was illustrated in Fig 5, Fig 6, Fig 7 and Fig 8. It has been observed that annual addition of organic manure (5 t FYM ha^{-1}) maintained the organic carbon and available status of P, K and S. The maximum buildup of organic carbon was observed in 100% NPK + FYM treatment (9.96 g kg^{-1}) from its initial values (5.7 g kg^{-1}). It has been observed that major proportion of added P from fertilizer is known to fix in black soil, hence, the continuous additions of P fertilizer for the last four decades indicated a considerable buildup of P against its initial status (7.6 kg ha^{-1}). However, continuous applications of P fertilizer along with FYM exhibited a further higher buildup (Nambiar 1994). Appreciable increase in available soil P status was recorded except in control and 100% N alone treatment. Available P was found to be increased with successive addition of applied fertilizer P from 50% NPK to 150% NPK. On the contrary, the maximum depletion of available K in soil was noted in control and imbalanced application of fertilizer. Continuous addition of fertilizer in optimal amount (100% NPK) was accounting about 280 kg of K ha^{-1} while it was further increased to 357 kg of K ha^{-1} with 100% NPK+FYM application as against its initial status (370 kg ha^{-1}). Further, result also indicated a declining trend in available S status when continuous application

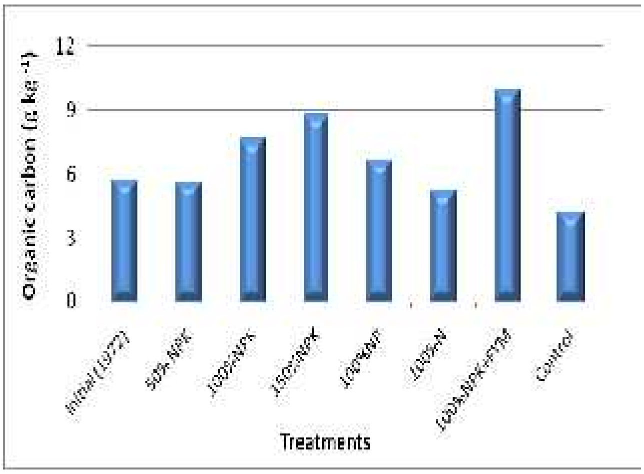


Fig 5. Status of soil organic carbon content over its initial value

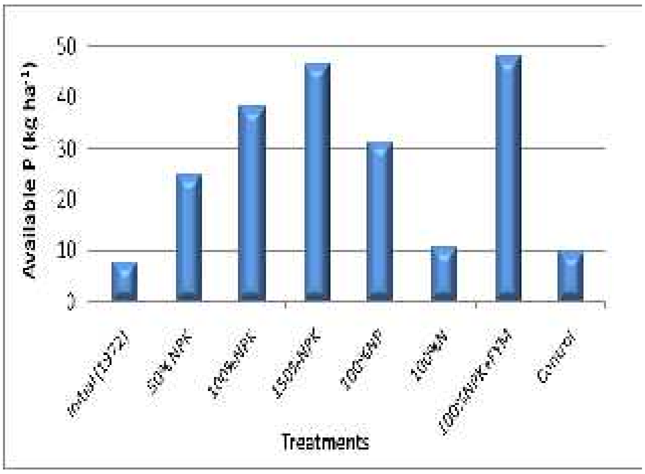


Fig 6. Status of soil available phosphorous content over its initial value

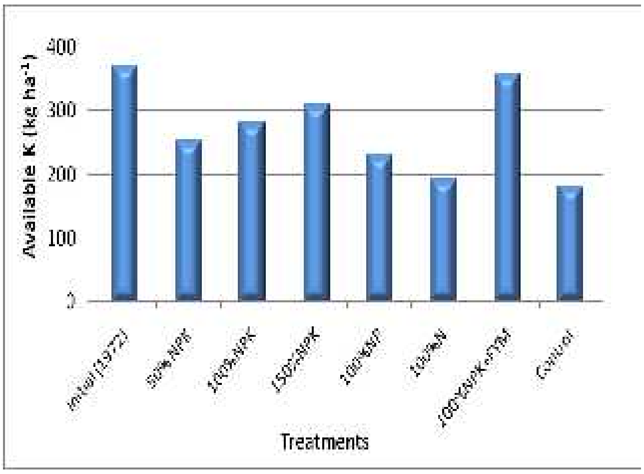


Fig 7. Status of soil available potassium content over its initial value

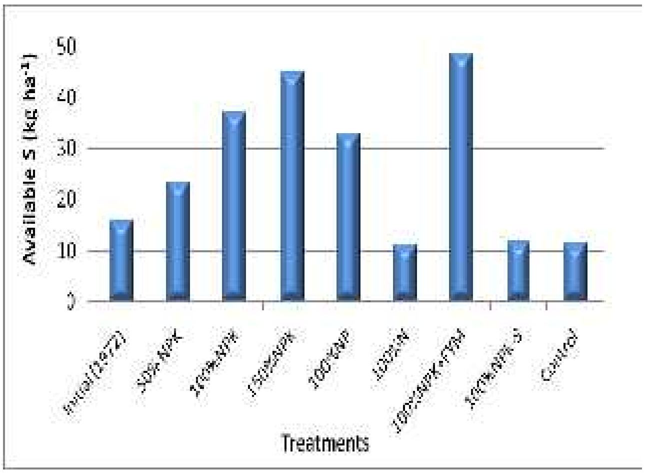


Fig 8. Status of soil available sulphur content over its initial value

of sulphur free fertilizers (DAP) was practiced. Balance application of fertilizer (100% NPK through urea, SSP and MOP) maintained the available S status in soil, however, integrated use of organic manure with optimal use of fertilizer resulted in enrichment of the S status in soil to a considerable extent (Thakur et al. 2009,Thakur et al. 2010, Dwivedi et al. 2015c).

Therefore, these findings clearly indicated that the continuous use of imbalance fertilizers for four decades adversely affected the soil fertility. However, the integrated use of optimal fertilizers with organic manure addition maintained the fertility of soil and subsequent productivity of soybean-wheat cropping sequence grown on a black soil of Jabalpur.

It has been observed that a significant response to applied N (Table 3) only during first few years (1973-1982) and later on soybean did not response to applied N. Response of soybean during first few year is probably due to less number of cells of N-fixing rhizobia and N requirement in the initial stages of growth before nodule formation (Singh et al. 2012). Continuous growing of soybean might have resulted in rhizobia population built up, and N added by soybean fulfills the initial N requirement of soybean. Contrary to N, soybean also responded to applied P during the whole experimental period, but response to K, noted after the 20th year, which was also not statistically significant, might be due to less demand of K because of decline in productivity of soybean and high status of soil K. Similar to N, soybean responded to applied FYM in the first decade and thereafter subsided because of organic carbon built up in soil. Soybean-wheat is a carbon sequestering system and application of FYM further enhances carbon sequestration (Rawankar et al. 2001).

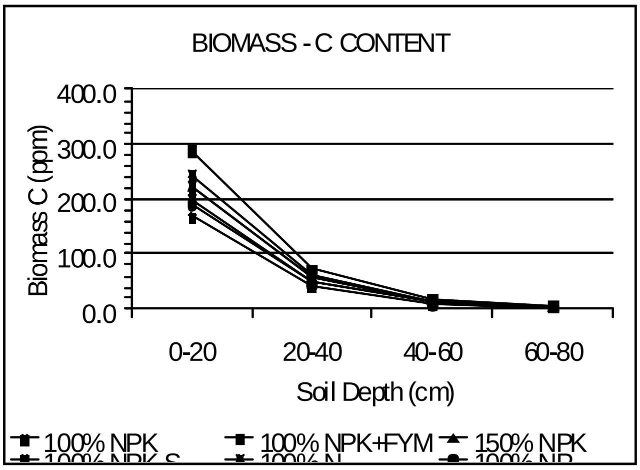
Impact of nutrient management on changes in microbiological environment of the soil

Soil analysis after 32 years revealed that the data on biomass carbon and nitrogen clearly indicate that cultivation of crops without addition of fertilizers and manure resulted in lower amount of biomass C and N while the highest population of nitrosomonas, nitrobacter, azatobacter, actinomycetes and fungi has been noticed where organic manure (FYM) has been used. The contribution of higher bio mass carbon and bio mass nitrogen (Fig 9) due to use of optimal and super optimal fertilizer use resulting from higher yields of crops due to improving microbial population (Dwivedi et al. 2007).

Conclusion

The long term fertilizer experimental studies have yielded valuable information on sustainability, yield responses and soil fertility maintance aspects.

- Imbalanced use of fertilizers i.e. application of N alone or NP had adverse effect on yield sustainability and responses.
- Since, phosphorus appears to be one of the most important yield controlling factors and since it has a typical behavior in soil, farmers need be encouraged to use bio fertilizers like PSB/PSM etc. so as to harness effectively the added and native phosphorus. Similarly use of nitrogen fixing bio fertilizers need be encouraged to bring economy in agricultural production or the state.
- Based on soil test values, inclusion of S and micronutrients in fertilizer schedule has come out



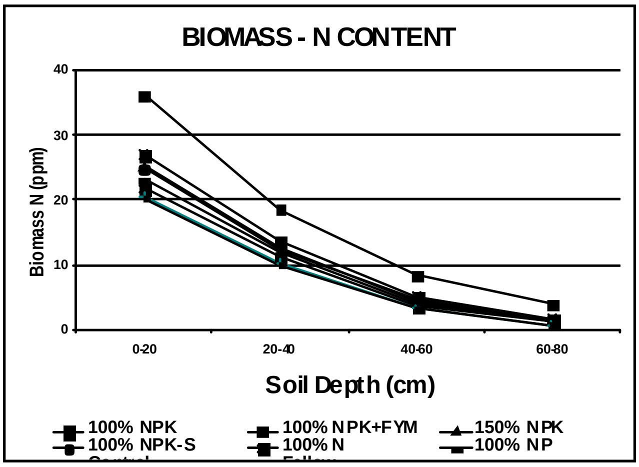


Fig 9. Effect of different treatments in Long Term Fertilizer experiment on biomass C and N content

as an important factor for obtaining sustainability and yield responses.

- The notion that continuous application of fertilizers decreases the organic matter in soil is disapproved by the experiment as organic carbon content in the soil has been found to be increased when treated with optimal dose of NPK. As expected inclusion of FYM had further strengthened the organic carbon content.
- The use of optimal dose of fertilizer based on soil test values has proved to be the key input for yield sustainability
- Application of organic manures in conjunction with chemical fertilizer has proved to be beneficial in terms of sustainability in production system under intensified cultivation not only sustained the yield at higher level but also helped in maintaining the soil fertility by increase in availability of other nutrients.

Recommendations

Promotion and dissemination of effective and ecofriendly suitable nutrient management practices

- The balanced and efficient use of plant nutrients from organic, biofertilizers and inorganic fertilizers, at the farm and community levels, should be emphasized; the use of local sources of organic matter and other soil amendments need to be promoted; and successful cases of integrated plant nutrient management should be analyzed, documented, and disseminated.
- Encouragement should be given on the effective and environmentally sound management of plant nutrients, for dissemination at both international and national levels.
- Improvement in research and monitoring for suitable nutrient management practices for increasing productivity of crops
- Participatory forms of design, testing, and extension of improved plant nutrient management strategies to train the farmer groups, should be promoted.
- A network of benchmark sites on representative farmers' fields in major farming systems should be developed to monitor the soil health status especially with respect to availability and reserves of plant nutrients.
- A comprehensive suitable data base needs to be developed for all chemical and organic sources of nutrients, including their amount, composition, processing techniques, their economic value, and their availability.
- The impact of micro- and macro-economic policies on plant nutrient management should be evaluated.
- Ways and means need be sought low in put management for approach to improved plant nutrition requirement.
- The recycling of pollutant-free organic waste need to be promoted, considering that such waste constitutes an increasingly significant source of plant nutrients.

Future thrust

- It is expected that there will have to be a very substantial increase in the use of chemical fertilizers to meet the food needs of populations by the year 2050, especially in the developing countries, even though organic sources may make a larger contribution to supply plant nutrients.
- There is a lack of prioritized and strategic problem-solving agricultural research in relation to the management of plant nutrition and the integrated use of chemical and organic sources of plant nutrients into the soil.
- Fertilizer uses by most of the farmers are based on general recommendations. However, fertilizer use on soil test is essential to breakout of the constraint of low production.
- There is an imbalance in the supply of N, P, and K, which resulted in deficiencies of secondary nutrients and micronutrients beginning to appear; there is an overall decrease of soil organic matter and an increase in soil degradation in general; and
- Adverse effects from pests and diseases are increasing, hence, environmental considerations, relating to pollution and degradation of natural resources, need intensive attention.

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Challenges and opportunities for carbon sequestration in vertisols: An overview

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Abstract

Carbon is functional building block of life and an important component for many processes on the planet earth. The term 'carbon sequestration' refers to fixing of atmospheric carbon dioxide (CO_2) by physical, chemical or biological processes in to long lived carbon pools such as ocean, soils, vegetation (especially forest) and geologic formation in a manner that is not reemitted in to the atmosphere in the near future. It is commonly used to illustrate any augment in soil organic carbon (SOC) content resulted from any change in land management, with the implication that increased soil carbon (C) storage to improve soil health in terms of physical, chemical and biological properties of soil. Carbon sequestration efficiency is commonly expressed by the relationship between annual C input and SOC accumulation rate, which is an indicator of soil C sequestration ability. However, it is factual only if the management practice causes a supplementary net transfer of C from the atmosphere to land. Challenges of C-sequestration for improving soil health include the magnitude of C stored in soil and the process of upward CO_2 flux. Transforming the traditional agriculture to conservation agriculture, degraded land to forest, grassland or perennial have great potential to remove carbon from atmospheric CO_2 and authentically contribute to sequester it in to the soil. Incorporation of organic materials to soil through heavy tillage operations in tropical and sub-tropical climatic region does not sequester much C due to heavy mineralization and no additional transfer of C from the atmosphere to soil. The climate change benefit of increased SOC from higher production of biomass (through use of fertilizers) must be balanced against GHGs emissions associated with manufacture and use of fertilizer. An over-emphasis on the benefits of soil C sequestration may detract from other measures that are at least as effective in combating climate change; including slowing deforestation and increasing N use efficiency in order to decrease N_2O emissions.

Keywords: Vertisols, carbon sequestration, carbon pools

Carbon sequestration contributes to the mitigation of greenhouse gas emissions and to the improvement of soil fertility (Lal 2004a). Net carbon sequestration is the balance of carbon inputs into the soil and upward flux of soil carbon. Carbon sequestration efficiency is commonly expressed by the relationship between annual carbon input and its accumulation rate, which is an indicator of soil carbon sequestration ability (McLauchlan 2006). Therefore, information about the carbon sequestration efficiency is useful for seeking high efficient management strategies of enhancing the soil carbon stock and soil health.

Vertisols are inherently fertile soils but are also regarded as problematic soils in light of their high clay contents, swell-shrink behavior, creaking and narrow workability. The term "Vert" in Vertisol is derived from the Latin word 'Verto' meaning invert or turn. Inversion takes place in the soil because of cracking characteristic. The soil moisture range in which the physical condition of Vertisols is suitable for tillage and planting operations is quite narrow (Virmani et al. 1989). These typical characteristics of Vertisols resists to carbon sequestration in view of high erodibility, accelerated oxidation of soil organic carbon, less biomass production, narrow workable soil moisture conditions forcing the farmers to grip the seeding of successive crops through cleaning the fields either removal or burning the crop residues. These limitations cause a negative flux of soil carbon and resulting in degradation of soil health primarily the physical and microbiological attributes.

A number of research publications on soil carbon and sequestration aspects are floating on the scientific information hubs which indicate that carbon sequestration in soil have potential to improve the soil health. Estimated global stock of SOC is in the range 684 - 724 Pg (1015 g) to a depth of 30 cm and 1462 - 1548 Pg to a depth of 1 m

(Batjes 1996). Thus the quantity of SOC in the 0 - 30 cm layer is about twice the amount of C in atmospheric carbon dioxide (CO_2) and three times that in global above-ground vegetation. It was estimated in the 4th Assessment Report of the Inter-governmental Panel on Climate Change (IPCC) that the annual release of CO_2 from deforestation (contribution from both vegetation and soil) is currently 25% of that from fossil fuel burning (IPCC 2007). The large number of publications on soil C sequestration indicates the degree of interest, at least in the scientific community of fighting climate change by increasing the extent of C stored in soil and vegetation, to some extent seeking to reverse the current trend. Freibauer et al. (2004) reported quantitative estimates of the potential for soil C sequestration through changes in the management of agricultural soils, while Smith et al. (2007) furnished global estimates for green house gas (GHG) mitigation within agriculture, taking account of wider considerations in addition to soil C sequestration.

This paper has been aimed at floating an overview on fundamental principles underlying the concept of carbon sequestration in soil and many other significant issues related to identifying the ways to decrease the upward flux of CO_2 and emission of other GHGs from agricultural practices as the estimates showed that 70% of the total GHG emissions from agriculture are associated with N fertilizer (combination of CO_2 and N_2O) from its manufacturing and direct and indirect N_2O emissions from its use (IPCC 2007). At the same time action to diminish the current rates of land-use changes, especially deforestation and drainage of wetland soils, which are leading to emissions of C from soils and vegetation, is also need to be addressed in broader prospective.

Vertisols

Vertisols are a group of heavy-textured soils, characterized by high clay content and associated shrink-swell properties depending up on the moisture status, which occur extensively in the tropics, subtropics and warm temperate zones and are synonyms as Dark Clays, Black Earths, Black Cotton soils, Dark Cracking soils in other classification systems (Dudal and Bramao 1965). The high content (40-60 %) of montmorillonitic clay present in Vertisols results in significant swelling and shrinking under moist and dry conditions. During the hot, dry post monsoon seasons the Vertisols become very hard, shrink and develop wide deep creaks, while under moist conditions during monsoon season these soils swell and have a sticky and plastic consistency. Under tropical temperature regimes, the Vertisols are generally low in organic matter, have poor hydraulic conductivity and are frequently poorly drained. The major areas of Vertisols are found in Australia, India, Sudan, Chad and Ethiopia which contains 82.1 percent of the total area (260.0 million ha) in the world. However, in India area under Vertisols accounts for 76.4 M ha (29.4 % of world's area under Vertisols), while in Madhya Pradesh it is 16.7 M ha (23.0 % of Vertisols in India). Murthy (1981) reported that Vertisols are concentrated in Central and South-central areas of Deccan Plateau spread over states of Maharashtra, Madhya Pradesh, Gujarat, Andhra Pradesh, Karnataka, Tamil Nadu, Rajasthan, Orissa and Bihar (Table 1).

Forms of carbon in the soil

Soils contain carbon (C) in both organic and inorganic (elemental and minerals) forms. Elemental form of carbon

Table 1. Distribution of Vertisols and associated soils in India

State	Total area (M ha)	Per cent of gross area	Per cent of total geographical area
Maharashtra	29.9	35.5	7.9
Madhya Pradesh	16.7	23.0	5.1
Gujarat	8.2	11.9	2.6
Andhra Pradesh	7.2	10.0	2.2
Karnataka	6.9	9.4	2.1
Tamil Nadu	3.2	4.2	1.0
Rajasthan	2.3	3.0	0.7
Orissa	1.3	2.0	0.4
Bihar	0.7	1.0	0.2

(Source: Murthy 1981)

in soil may be in the forms of geologic materials (graphite and coal), incomplete combustion of organic materials (charcoal, graphite and soot) or dispersion of these carbon forms during mining. While, mineral form of carbon present in soil is mainly carbonates of calcium, magnesium and iron. However, the organic forms of carbon in soil is associated with plant and animal materials at various stages of decomposition ranging from crop residues with size of 2 mm and particulate organic carbon with size 0.05-2 mm and humus (highly decomposed materials < 0.05 mm that are dominated by molecules attached to soil minerals). In most of the soils (except calcareous soils) the majority of C is held as soil organic carbon (SOC). The term soil organic matter (SOM) is used to describe the organic constituents in the soil (tissues from dead plants and animals, products produced as these decompose and the soil microbial biomass).

The term 'soil organic carbon' refers to the C occurring in the soil in SOM. The constituents of SOM can be divided into non-humic substances, which are discrete identifiable compounds such as sugars, amino acids, lipids, and humic substances, which are complex largely unidentifiable organic compounds. As organic compounds, both humic and non-humic substances contain carbon, oxygen (O) and hydrogen (H) and can also contain nitrogen (N), phosphorus (P) and sulphur (S). Most of the organic carbon in soils present in either labile or non labile pools. Five major soil organic pools as described in the figure are of great importance for carbon sequestration and improving soil quality.

Carbon sequestration in soils

Carbon sequestration is the long-term storage of carbon in soils, oceans, vegetations and geologic formations. Whereas, high levels of fossil fuel combustion and deforestation have transformed large pools of carbon from fossils and forests into atmospheric carbon dioxide. Carbon sequestration refers to the removal of carbon dioxide from the atmosphere into a long-lived stable form that does not affect atmospheric chemistry.

The most viable way to trap atmospheric carbon dioxide is through photosynthesis, where carbon dioxide is absorbed by the plants and turned into carbon compounds for plant growth. Carbon is considered sequestered if it ends up in a stable form, such as wood or soil organic matter. Carbon sequestration in soil is an imperative and instantaneous sink for removing atmospheric carbon dioxide and slowing global warming. Direct carbon sequestration in soil occurs by inorganic chemical reactions that convert carbon dioxide into soil inorganic carbon compounds such as calcium and magnesium carbonates. Direct plant carbon sequestration occurs as plants photosynthesized atmospheric carbon dioxide into plant biomass (Gupta and Sharma, 2010). Subsequently, some of this plant biomass is indirectly sequestered as soil organic carbon (SOC) during decomposition processes. The amount of carbon sequestered at a site reflects the long-term balance between carbon uptake and release mechanisms. Numerous management practices including agronomic, forestry and conservation leads to a beneficial net gain in carbon fixation in soil. It has been estimated that carbon sequestration to the extent of 7.2 to 9.2 $TgCyr^{-1}$ (Table 2) can be achieved by arresting land degradation in India (Lal 2004b).

Table 2. Soil organic carbon (SOC) sequestration through restoration of degraded soils

Degradation Process	Area (M ha)	SOC sequestration rate (kg ha^{-1} yr^{-1})	Total SOC sequestration potential (Tg C yr^{-1})
Water erosion	32.8	80-120	2.62-3.94
Wind erosion	10.8	40-60	0.43-0.65
Soil fertility decline	29.4	120-150	3.53-4.41
Water logging	3.1	40-60	0.12-0.19
Salinization	4.1	120-150	0.49-0.62
Lowering of water table	0.2	40-60	0.01-0.012
		Total	7.20-9.82

(Source: Lal 2004b)

Process of carbon sequestration in soils

Through the process of photosynthesis, plants assimilate carbon and return some of it to the atmosphere through respiration. The carbon that remains as plant tissue is then consumed by animals or added to the soil as litter when plants die and decompose. The primary way that carbon is stored in the soil is as soil organic matter (SOM) which is a complex mixture of carbon compounds, consisting of decomposing plant and animal tissue, microbes (protozoa, nematodes, fungi, and bacteria), and humus - carbon associated with soil minerals.

The density of carbon is highest near the soil surface and most recently added SOM decomposes rapidly, releasing CO_2 to the atmosphere. Some carbon becomes stabilized, especially in the lower part of the soil profiles while the balanced rates of input and decomposition determine steady state carbon fluxes. However, in many parts of the world, agriculture and other land-use activities have upset the natural balance in the soil carbon cycle, contributing to an alarming increase in carbon release from soils to the atmosphere in the form of CO_2. Carbon sequestration in soils is a climate-change-mitigating strategy based on the assumption that movement or flux of carbon from the air to the soil can be increased while the release of carbon from the soil back to the atmosphere is decreased. In other words, certain activities can transform soil from a carbon source into a sink. This transformation has the potential to reduce atmospheric CO_2, thereby slowing global warming and mitigating climate change.

Challenges of carbon sequestration in vertisols

The key challenges associated with Vertisols are more clay content, swell-shrink behavior, high water holding capacity, poor drainage and creaking on drying which result in narrow workability and high erodibility causes soil and nutrients loses. Whereas, high CEC and inter-layer spacing in minerals (Montmorillonitic) resulted in nutrient cations fixation and self inversion nature resulted in low organic carbon in Vertisols. Swell and shrink properties invert the soil structure which offers poor workability. It is estimated that 16.7 M ha area of Madhya Pradesh is covered under Vertisols (Tomar et al. 1996a) which are vulnerable to erosion and high runoff losses and cropped only during post rainy season on profile stored moisture and remains fallow or poorly utilized during rainy season (Tomar et al. 1996b; Painuli et al. 2002). Madhya Pradesh in central India is predominantly a rainfed state. The practice of fallowing the Vertisols in the state during rainy season (kharif) where farmers harvest rainwater (0.2 to 1.2 m depth depending upon the field size and slope) by constructing embankments along the field boundary (termed as 'Haweli' system). The impounded water is then drained out from the field during September-October and winter crops (wheat, pea and chickpea) are grown on stored moisture. Impounding of rain water for about three months followed by drainage sequester significant amount of carbon (1800 mg kg-1 soil) and add nitrogen (87.5 mg kg-1) corresponding to an increase of 30.5 and 20.1 per cent, respectively. Microbial biomass carbon also gets improved by 23.5 per cent (31 mg microbial C kg-1) in Vertisols (Sahu et al, 2015). The soil moisture range in which the physical condition of Vertisols is suitable for tillage and planting operations is quite narrow (Virmani et al. 1989). In light of these challenges carbon sequestration in these soils need greater attentions with potential land use practices of reducing creaking, erosion losses, oxidation of SOC and increasing crop biomass production per unit area and their in-situ recycling for promoting inward carbon flux in soils.

Opportunities for carbon sequestration in vertisols

In-spite of diverse limitations Vertisols offers immense opportunities for carbon sequestration in soil with improved land use practices (Benbi et al., 2011). It is well known that Vertisols are inherently fertile soils which are related to chemical and mineral composition of parent materials from which they are developed (Ahmad, 1996). The dominant smectitic clays can be formed by the alteration of base-rich minerals and there stability is favoured by a high concentration of basic cations and monosilicic acid. Vertisols reflect shrink-swell properties depending upon the moisture status which also regulates the nutrients requirement and the use efficiency of applied fertilizers. It shows a potential importance of moisture-nutrient interactions that can be exploited, particularly for nitrogen and to a smaller extent for phosphorus. Nitrogen deficiency (N) is wide spread; particularly in tropical Vertisols (Katyal et al. 1987) whereas the levels of total and exchangeable potassium (K) are usually high and thus deficiencies in crops are rare (Finck and Venkateswarlu 1982). Integrated application of organic nutrient sources with inorganic fertilizers could be one of the key management practices for enhancing carbon sequestration and nutrient use efficiency in Vertisols (Behera et al. 2007).

Therefore, carbon sequestration in Vertisols could be optimized through accelerated adoption of those agro-techniques and land use practices which are able to minimize soil erosion, water runoff, creaking, oxidation of soil carbon and enhance the biomass production and biological activities per unit area and time. Important among these are conservation agriculture and integrated nutrient management (Lal 2009). There have been ample number of reports on the effect of various tillage and residue management practices in modifying the physical, chemical and microbiological environment of soil (Tomar et al. 1996b, Hobbs 2001, Painuli et al. 2002, Malik et al. 2004 and Sidhu et al. 2004). All of these are considerably diverse and contradictory owing to their dependence on regional soil and climatic variability and the duration of the experimental study.

Studies conducted by Sengar (1998) showed that the graded broad bed and furrow (BBF) system of land configuration improves the surface drainage and induces more water infiltration in the soil and reduces the soil erosion. Soil erosion could also be reduced by promoting the formation of macro aggregates and aggregate stability through addition of organic matter in soil which produces organic macromolecules by action of microorganisms that bind primary particles and micro aggregates to form macro aggregates (Benbi and Senapati 2010).

Conservation agriculture (CA) is one of the most important resource conservation technologies which includes minimum disturbance of soil by adopting no-tillage, leaving and managing the crop residues on soil surface and adopt spatial and temporal crop sequencing/ crop rotation to derive maximum benefits from inputs and minimize adverse environmental impacts. CA has extreme potentials for arresting carbon in soil as no-tillage practice reduces the rate of oxidation of soil carbon, surface cover with crop residues minimizes the creaking and erosion and promotes the infiltration and steady buildup of organic carbon, biodiversity in soil, while crop diversification provides the higher biomass for accelerated carbon sequestration.

No-tillage system is a technically viable, sustainable and economic alternative to current crop production practices especially in Vertisols. No-tillage system has great potential for carbon sequestration through storage of soil organic matter in the soils (Bayer et al. 2006). Under conventional tillage soil layers invert, mixes air and dramatically increases soil microbial activity over baseline levels which resulted in faster oxidation and breaking of organic matter and carbon is lost from the soil into the atmosphere. In addition to keeping carbon in the soil, no-till system also reduces nitrous oxide emissions by 40-70%, depending on rotation (Omonode, et al. 2011). In addition to these, conservation tillage (no-tillage) also improves soil properties and facilitates soil carbon buildup in soil. Study conducted by Singh et al (2013) clearly showed that conservation tillage significantly reduce the bulk density and enhance the organic carbon and infiltration rate in rhizosphere (Table 3).

With conventional tillage (turning over of the soil), the bare soil is exposed to the Vertisols are prone to erosive action of water and wind, which, in many areas is

Table 3. Effect of tillage practices on soil properties in pigeon pea-wheat

Treatment	Bulk Density (Mg m^{-3}) 0-15 cm	15-30 cm	Organic Carbon (g kg^{-1})	Infiltration Rate (mm hr^{-1})
Conventional tillage	1.56	1.60	3.24	5.36
Minimum tillage	1.50	1.61	3.25	5.36
Zero-tillage	1.49	1.59	3.30	6.60
CD (p=0.05)	0.01	NS	0.04	0.07

(Source: Singh et al. 2013)

Table 4. Possible cropland strategies for maintenance or increase of soil organic carbon

Reduction in carbon losses	Increase in carbon input in soil
Conservation-tillage	Organic manures/Composts
Cover crops	Cover crops
Erosion reduction strategies (mulching, contour cultivation on sloping land)	In-situ crop residue recycling
Minimization of fallow periods	Higher crop biomass production
Reduced burning of crop residues	Crop diversification

the major route of soil loss and conventional tillage frequently expose the soil to these factors, while under conservation tillage, the crop residue buffers the raindrops' energy, so water has less erosive force when it reaches the soil. This protection by residue, along with the rougher surface provided by the residue facilitates infiltration and decreases runoff that carries soil and nutrients with it. In addition, macro-pores, which are the major route for water movement through soil, get disrupted in the surface layer (0-20 cm) by conventional tillage, but remain intact under conservation tillage hence, enhances water infiltration and decreases runoff and conserve water and fertilizers. Schertz (1988) observed that amount of soil loss through water erosion was directly regulated by residue retained on the soil surface (Figure 1). Management of soils to increase carbon content therefore involves strategies that reduce losses and/or increase inputs as given in Table 4.

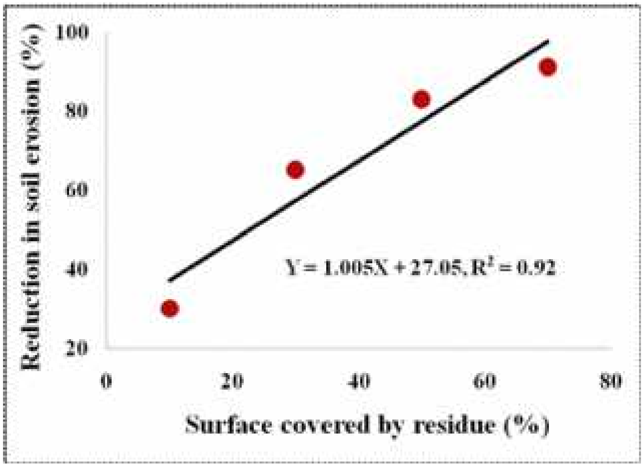

Fig 1. Relationship between residue cover and soil erosion by water

Conclusion

Enhancing sequestration of atmospheric carbon dioxide (CO_2) either into the soil or trees is an important strategy which has multiple benefits. Carbon sequestration in Vertisols is a challenging task in light of self turning and creaking behavior which offers accelerated decomposition of added organic matter and higher oxidation rate of organic carbon, narrow workability resulting fallowing and less biomass production per unit time. Adoption of suitable management practices including conservation agriculture, integrated nutrient management, erosion control measures, judicious resource utilization can facilitate the potential base for carbon sequestration in Vertisols.

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Status of ravines of Madhya Pradesh

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Abstract

Research work was carried out at Aisah village of Morena district of Madhya Pradesh during the year 2012-13 to 2015 -2016 with major objectives of mapping of ravines, causes of formation, control measure and soil health management.. These soils are alluvial in nature and are very poor in organic matter, all available nutrients, highly dispersed, poor binding capacity and very high infiltration rate (7- 8 cm hr^{-1}). The advancing of Chambal ravines is very typical in nature which starts only as deep ravine (>10m) without any prior sheet erosion, rill or gully formation and way of formation is quite unique in nature due to various reasons. The area of ravine land was estimated through ERDAS Imagine 10 (2013) and Arc GIS 10 which clearly indicated that areas under shallow ravines on other river are shrinking while it is still increasing on Chambal River due to its unique physiography. The results recorded in project got success in blocking advancement of deep ravine by modification in slopes on advancing front along with suitable soil water conservation techniques. Reasons for unsuccessful control during past was also explored and major causes noticed were human, animals and poverty of farmers. Very innovative way of site specific soil and water conservation was developed through. A very innovative, simple and practical methodology for reclamation of deep Chambal ravine has been developed by the centre. This technology involves use of heavy earth machine (Hitachi 110 or 220) only for cutting of top edge and uses this soil for chocking of drainage gullies at specified distance with appropriate strength. Construction of peripheral bunds and partial modification of slope at every leveled piece of land is mandatory. The reclaimed flat land is usable for crop cultivation (35 to 50%), modified slopes can be used for medicinal/ fruit trees/grasses/ silvi-pastoral system (30 to 45%) and plugged deep gullies are good for water storage. This is most cheapest and practical methodology to make ravines usable. The reclamation cost varies only Rs 35,000 to 40,000 depending on depth of ravine. The system is eco-friendly, remunerative and takes care of all aspects sustainability to human being. To evaluate nutrient use efficiency of major nutrients (N, P, & K) in ravineous soil an experiment was conducted during the year 2013-14 and 2014-15. The experiment comprises seven treatments (RDF, 150% RDF, and other integrated approaches of nutrient managements).The maximum nutrient (N, P, & K) use efficiency was recorded either in 100% RDF or integrated (inorganic, micronutrients, organic & biofertilizers) method of nutrient management while, yield and restoration in soil health was maximum under the treatment of 150% RDF during these two years as compared to any other treatment.

Keywords: Ravineous land, soil water conservation, mapping of ravines, technology and soil health

Cultivable land in our country continues to shrink and its long term effect could be disastrous with the country needing more and more food grains to support its growing population. As many as 20 states reported decrease in cultivable land to the extent of 7,90,000 hectares in four years from 2007-08 to 2010-11. The decrease is mainly attributed to diversion of cultivable land to construction, industries and other developmental activities. Besides diversion, about 20.6 lakh ha area is under ravines-unsuitable for agricultural production. Gullies and ravines form an extensive net work along Gomati, Yamuna, Chambal, Betwa, Sindh, Ken and Mahi rivers and their tributaries in Uttar Pradesh, Madhya Pradesh, Rajasthan and Gujarat states. These result not only in loss of non-renewable land and soil resources but also lead to other processes destructive to National Economy such as floods in rivers, siltation of water reservoirs and consequent loss in their storage capacity, damage to railway lines, roads and other public properties. Ravines also encroach upon inhabited villages which have to be shifted to new sites to avoid loss of lives. Besides these economic losses, an important socio-economic problem created by deep ravines is providing shelter to dacoits and consequently making the area dacoit-infested. Thus, management of ravinous land so as to control ravine formation, and to reclaim the ravines already formed, is necessary for the survival of present and future generations.

Land degradation has emerged as a major constraint in raising agricultural output and attaining food self sufficiency in a number of developing countries. But its sad repercussions are much more widespread. Land degradation not only adversely affects agricultural productivity but other sectors of the economy and the environment by the upsetting water regimes and causing floods or the silting up of rivers, dams and ports. Thus, the land degradation is posing a serious threat to the survival and welfare of people.

The point needs to be stressed that there is a symbiotic relationship between land, water, plants, animals and human beings which together constitute an integrated system. When one component of the system is disturbed the other components are bound to be affected. The problems of deforestation, soil erosion, sedimentation of reservoirs, floods, water loggings, soil salinity are closely interrelated (Singh et al. 1991). Out of 329.0 million ha geographical area of the country, nearly 147.75 million ha is subjected to various types of degrees of degradation. Of this about 93.68 million ha is severely eroded (NBSS & LUP 2004, Trivedi 2010).

The ravines are not static, but are increasing in their spread every year. The average rate of encroachment into the table lands is estimated at 0.008 million ha. The available data show that the average soil loss is about 16.35 mg ha^{-1} yr^{-1}, which is a total soil loss of 5.3 billion Mg yr^{-1} (Dhruvanarayana and Rambabu 1983). Moreover, in areas where ravines advance at faster rate, the soil loss is as high as 100 Mg ha^{-1} yr^{-1}.

Tomar (2009) has provided a detailed review on Chambal ravines in Madhya Pradesh and the management strategies for productive/socio-economic uses. He hypothesized that with only minor reclamation (half-moon levelling) these revines can be utilized for mong productive purposes and that can bring greenery and hapiness in the area. The Chambal region of Madhya Pradesh has provided huge number of warriors to the Nation and is a major producer of oilseeds, pulses and the milk. Even maximum productivity of wheat is achieved under limited irrigations. Soil and water quality is very good. But the precious land has been converted into ravines. Here, therefore, an effort has been made to assess the situation of ravines of Chambal in Madhya Pradesh, review the efforts made to control, reclaim and eliminate the ravines and to utilize them properly for improving the ecology, social and economic conditions of the people.

In Madhya Pradesh, nearly 0.683 million hectare area under ravines lie mostly along the rivers Chambal, Sindh, Betwa, Kunwari and other tributaries of river Yamuna. These are mainly north flowing peninsular rivers in the State.

And out of this, nearly 0.57 M ha is in Chambal and Gwalior divisions of the state (Table 1) showing that the Chambal basin suffers most severely from the problem of land degradation due to ravine formation (Chambal

Table 1. Ravines affected districts in Madhya Pradesh

Division	District	Ravine area (lakh ha)	Division	District	Ravine area (lakh ha)
Chambal	Morena & Sheopur Bhind	1.92 1.19	Sagar	Tikamgarh	0.05
				Chhatarpur	0.40
				Panna	0.20
				Sagar	0.25
				Damoh	0.05
Gwalior	Gwalior	1.08			
	Datia	0.26			
	Guna &Ashok	0.97			
	Nagar Shivpuri	0.26			
Total	6.83				

Table 2. Drop in the slope of the Chambal river bed

Distance from the source km	Slope/ drop in river bed m/km
0 to 16.1	19.97
230.2 to246.3	2.00
386.4 to 429.87	1.59

CADA 1997). An abrupt fall in altitude between the main Vindhyan hill ranges, situated in South-West and Western part of the state and the course of the Chambal in the North-West, together with alluvial deposition in between, results in heavy soil erosion in this area. The bed level of river Chambal controls the maximum depth of ravine erosion for its tributaries whereas, for other rivers like Betva, it is river Yamuna which decides the depth and base level of erosion.

The Chambal is inter-state river and part of its catchment lies in Rajasthan and Uttar Pradesh. Chambal originates from the northern slopes of the Vindhyan mountains, about 14.4 km south-west of Mhow, district Indore, Madhya Pradesh, at an elevation of 854 m above MSL. At first, it flows in a northerly direction in Madhya Pradesh for a length of about 320 km and after passing by the historic fort of Chaurasigarh, it flows north-east for about 286 km through Rajasthan. Later, it forms the border between Madhya Pradesh and Rajasthan along Morena district for a length of 216 km continuing in the same direction, it then forms the boundary between Madhya Pradesh and Uttar Pradesh along Bhind district for a distance of about 112 km before finally joining the river Yamuna in U.P. after flowing for another 64 km. The drop in the slope of river bed is gentle except in three reaches, two in the upper reaches before the Chaurasigarh gorge and the third below it (Table 2).

In the third reach, the drop in the river slope is 1.59 m per km. Formation of ravines is maximum in this reach. This situation shows that river bed has a very gentle slope whereas, the table lands from where tributaries originate, are at a much higher level. The differences in the two elevations really initiate the process of active erosion which is aided by the climate and soil type and other related factors.

The vertical fall between bank and the river bed are 10-15 m at places and range up to 20m. The vertical drop of the tributaries is a highly influencing factor for gully and ravine development. In general, Chambal river is in the degradation stage, and so depth of the river bed is likely to increase with time in order to achieve a dynamic equilibrium with the vertical drops. The phenomenon of gully erosion tries to expand in the lateral direction all along river courses. Gullies and ravines flank for about two km along the banks.

Current scenario of ravine lands in Gird region

Sebastian (2001) reported that there have been programmes galore in the past for reclamation of ravines in the troubled intersection of Madhya Pradesh, Rajasthan and Uttar Pradesh, however, nothing has worked. Jha (2004) reported that a series of ravine reclamation and soil erosion control schemes launched from time to time by the central and state governments - such as the Ravine Erosion Control Scheme, the various afforestation programmes and the Dacoit Prone Area Development

Table 3. The purchased data details are as below

Data Type	Date	Row/Path	Scale
IRS-ResourceSat-2 LISS-III	29.04.2013	53/97	23.5 m
IRS-ResourceSat-2 LISS-III	29.04.2013	52/97	23.5 m
IRS-ResourceSat-2 LISS-III	04.05. 2013	54/98	23.5 m
IRS-ResourceSat-2 LISS-III	04.05.2013	53/98	23.5 m

Table 4. Area (ha) and Percentage coverage under different LULC classes of northern part of Madhya Pradesh

Class Name	Morena		Bhind		Sheopur		Gwalior		Datia	
	Area	%	Area	%	Area	%	Area	%	Area	%
Ravine/Waste Land	72144	14.38	19532	4.38	18848	2.84	13900	3.00	3945	1.3
Water body	5810	1.45	953	0.47	2128	0.31	4144	0.90	1316	0.4
Forest	59566	11.88	4596	1.00	310000	46.52	112100	24.55	29344	9.9
Fallow/Barren/ Open	180421	35.16	215569	48.40	179095	26.87	123769	27.14	64899	21.9
Built-up	2127	0.42	2277	1.12	100	0.02	4045	0.88	586	0.2
Agriculture	181305	36.16	202446	45.45	156136	23.43	198586	43.49	195721	66.2

Programme - have not helped. To evaluate current status of ravines in Gird region, remote sensing data were purchased from National Remote Sensing Agency (NRSA) Hyderabad. To get recent information about ravineous land in Gird region of Madhya Pradseh Land Use land cover map of five districts those suffer maximum in Madhya Paradesh (Bhind, Morena, Gwalior, Sheopur and Datia) affected by ravine problem has been completed.

Land use and land cover classification of ravine affected districts

Land use land cover classification of five district of northern part of Madhya Pradesh, which is severely affected by land degradation problem was performed for estimation of ravinous/ Wasteland in the districts. The classification was completed in ERDAS Imagine 10 (2013) and Arc GIS 10. For the present study IRS- Resource Sat-2 LISS-III data full scene of Morena, Bhind, Sheopur, Datia, and Gwalior Districts was purchased from National Remote Sensing Center, ISRO, Hyderabad (Table 3). In the preparation of LU/LC the ancillary data in the form of topographic maps, existing land use /land cover data of the district and Google earth. Ground truth required for the study was carried out with GPS and Google earth.

Land Use and Land Cover Map: Morena district covers an area of 5.013 lakh. Table 4 shows the status of Land Use Land Cover of all five district (Bhind, Datia, Gwalior, Morena and Sheopur). It is found that there three major classes, they are Agriculture, fallow, ravine and Forest of the total area, which varies district to district (Figs 1-6), however other classes such as water body and Built up in these districts. The continuous increase in area of ravine was recorded during the period 1943-44 to 1975-76 and it decreased drastically in recent years particularly last three years (2012-14) due to decreasing land availability and escalating land prices, farmers are forced to reclaim ravines on the river bank where it is shallow or medium in nature (example: Bhind district where it is now only 19000 ha instead of 119000 ha).

The area under ravine land in Gird region has been estimated at different time space (Table 5) right before independence (1943-44) to till date and there was continuous increase up to 1972 when it was 4.45 lakh

Table 5. Changes/reduction observed in ravine area (ha)

Name of District	1943-44	1950-51	Planning commission 1972	1975-76	Project (2013)	Reduction in area
Morena	138000	147700	192000	191300	72144	-100308
Sheopur					18848	
Bhind	90300	86400	119000	119400	19532	-99868
Datia			26000		3945	-2255
Gwalior			108000		13900	-95100
Total	228300	234100	445000	310700	128369	-297531

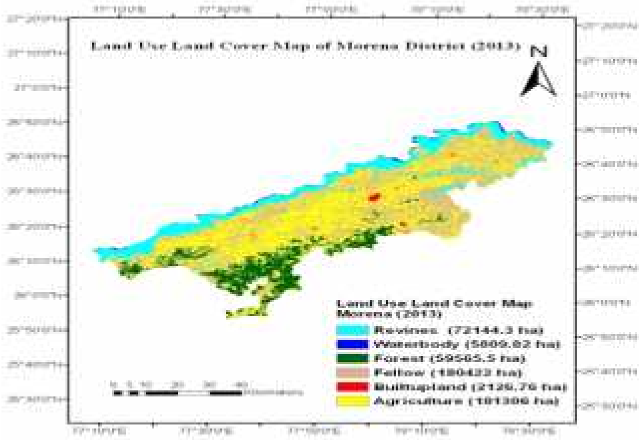

Fig 1. Land Use Land Cover of Morena district

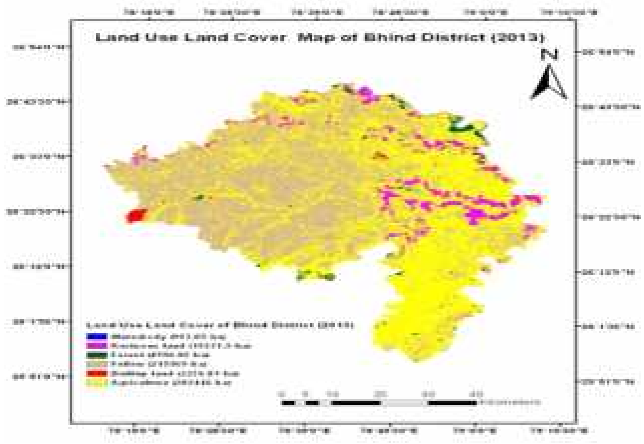

Fig 2. Land Use Land Cover of Bhind district

and since then it is showing a decrease. The area estimated through remote sensing data and ground true thing during last year (April/ May, 2013) showed a very marked reduction probably due to population pressure and very high escalation in land price, that forced farmers to reclaim shallow ravines on rivers Kunwari and Asan rivers of the region.

Land use and land cover classification of Gird region

A complete map for gird region was generated for recent estimation of ravine lands.

Actual mechanism of ravine development on Chambal river

The mechanism of Ravine Development on Chambal River is quit different as compared to any other river of the area. The formation of Chambal ravines do not follow the ways described in theories and it is always deep (more than 10 meter) in nature right from adjoining table land. The data shows that the Chambal ravines are still advancing at the rate of about 0.0008 mha/yr. The major role in its formation is played by soil water energy balance and accelerated by profile's soil texture, elevation difference between river bed and adjoining table land, low particle binding energy and high water transmission properties. Some times elevation difference from river bed to table land is more than 30 meter. The soil profile is alluvial in nature and sand content increases with depth (reaches 95% at a depth of six meter) with very high water intake rate (more than 1.25 m/ day). The soil is very poor in organic matter content (less than 0.2%) and particle binding energy (less than -40 mV) and this causes very high dispersion in fine sand particles with the moving water in saturated and transient water flow. The infiltrating water achieves a very high hydrodynamic energy after reaching a certain depth and it further accelerated with depth causes displacement of soil along with horizontally passing waters. The water column near to vertically exposed profile has horizontally a very high hydraulic head drop and dispersed phase of sandy texture causes pit hole formation in adjoining area of recently formed ravine makes a path for its further advancement. The formed pit hole further becomes big to bigger in continuously dizzling water and makes a larger cavity at lower depth and the whole profile collapses and dispersed soil get lost with flowing subsurface water. The continuous horizontal sub surface water flow with relatively higher rate and energy accelerates the formation of deep ravine. Normally four stages of Ravine development are generally recognized by Geomorphologists, (Fig.7) namely.

In this initial stage, parallel pot holes are formed along the river below the flat ground by the mutual action of water and soil particles.

Tunneling Stage

A further stage in the development is the deepening of pot holes and formation of a tunnel from the pot holes to the adjoining ravine. With continuous corrosion these tunnels enlarge in size.

Collapsing Stage

In this stage the roofs of tunnels collapse when rain is drizzling and the profile get wet slides in the water channel and are carried away to the river, therefore formation of ravines takes place.

Recession Stage

The side and head scarps of ravines recede continuously. With the continuous recession of side scarps alluvial bluffs are disconnected and thus begin to shatter into conical blocks. In this last stage, maximum width of ravine bottom takes place.

Soil conservation strategies for control measures of Chambal ravines

The technologies developed by various researchers are not suitable for Chambal ravines due to its different nature and posing a serious challenge to check its further advancement and gobbling some other new villages. Some new approaches have been started by the project for various stages.

Management of upper reaches of ravine

The major issue that needs attention of worker is checking of gully advancement. Some work has initiated in the project which includes native as well as innovative

Indigenous technology

After consultation with thousands of villagers the fact emerged that peoples are trying since hundreds of years to check the advancement and save their village but it never worked permanent solution only delayed the situation for some years. Among many methods the shaping of advancing gullies (Fig 1A) and planting of shelterbelts of trees are quite impressive. Shaping was done manually and on individual basis by making the edge in slanting condition (say 120? rather than 90?angle) and planting of Sachrum munja as vegetative barriers on the slopes. These two methods can be very effective if made on community basis and with the help of modern machineries.

Soil conservation and protection of village Aisah from advancing ravine

The villagers of village Aisah practices soil conservation measures for protecting the village from ravine development. The Aisah was shifted approximately 1.5 Kilometer from its original location due to advancement of ravines and this is ongoing process. The villagers planted the acacia (Babool) at the ravine formation site. The strip of 20 meter babool plantation approximately 70 meter in length acts as vegetative barrier. Fig 8, shows the vegetative barrier encircled green and Fig. 9 depict the vegetative barrier which protect the village from advancement of ravine.

Innovative techniques

Two methods i.e. terracing in advancing area (Fig 10 C &D.) and slopping the vertical fall (> 2: 1(Fig. 10C) has been introduced under this project and it may give a permanent solution to the problem. A strong vegetative barrier at suitable intervals is provided on slopes of terrace and diagonal surface of slanting face of the slopes. The results are to be confirmed only after few years of observations.

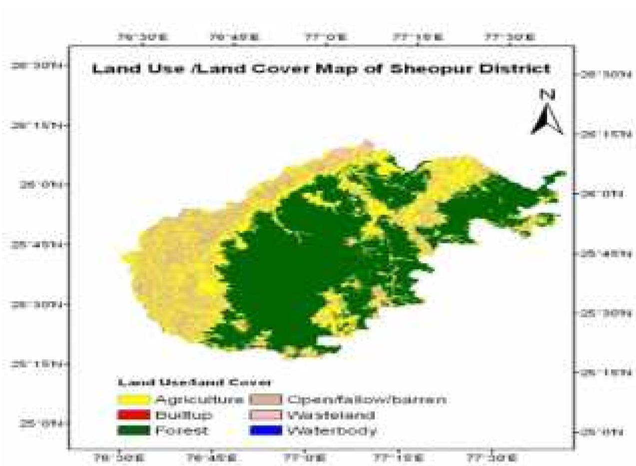

Fig 3. Land use land cover map of Sheopur district

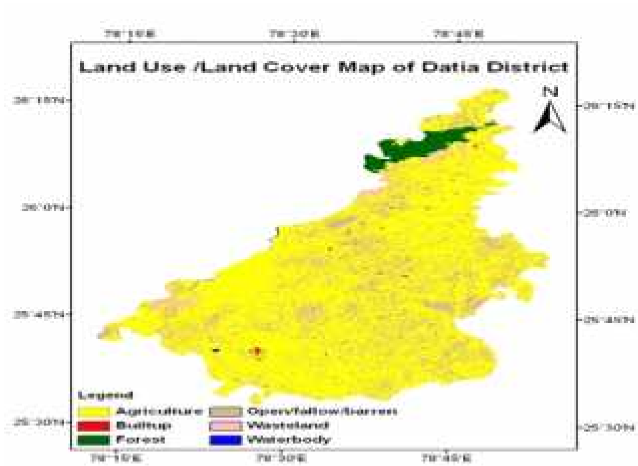

Fig 5. Land use Land Cover map of Datia

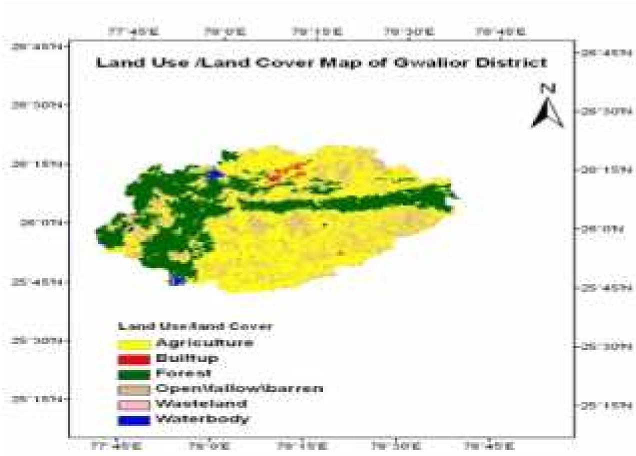

Fig 4. Land use land cover map of Gwalior district

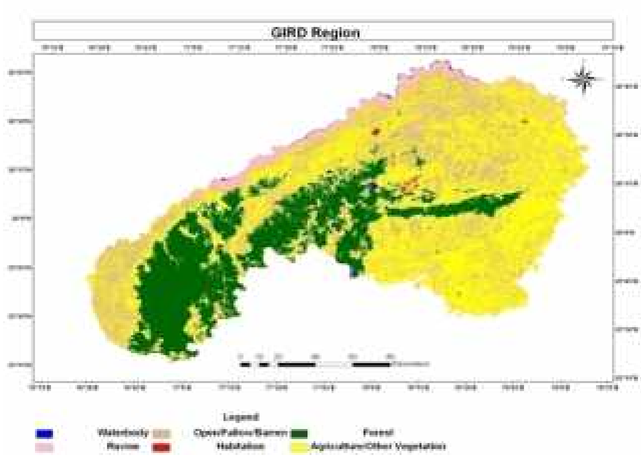

Fig 6. Land use Land Cover map of Gird region

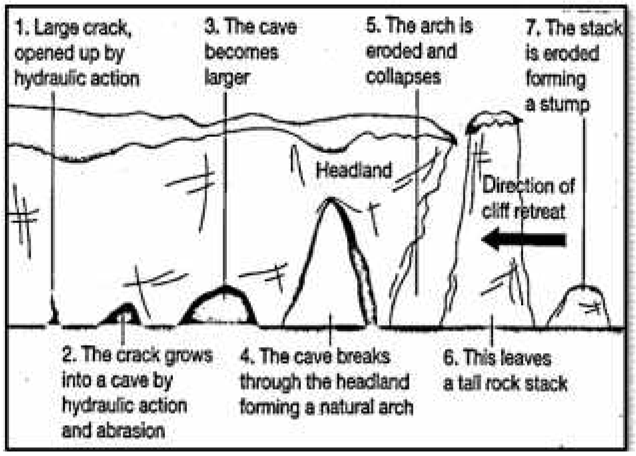

Fig 7. Schematic diagram of ravine development stages (pot hole stage)

Management of gullies

Many options has been introduced by the project to manage the gullies and conserve the natural resources, it includes masonry structures, gabions, submersible dams, earthen dams (Fig.10 B), plugging of gullies and temporary bunds (bori bandhan). All the measures normally got failed due to leakage from side or gushing of water under the structures. The submersible dam has some edges over others structures provided it has been built at least at a depth of 1.00 to 1.25 meter. A modified form of submersible dam plus gabion was introduced to check runoff, reduce the cost and it is working satisfactorily.

Management of deep ravine

Deep ravines can manage by introducing submersible dams with sufficient arms and putting earthen dams over it. These structures are also useful in making water harvesting / recharging tanks that will contribute in raising ground water.

Multi-step levelling system or zero loss technology

A very innovative, simple and practical methodology for reclamation of deep Chambal ravine has been developed by the centre (Fig 11). This technology involves use of heavy earth machine (Hitachi 110 or 220) only for cutting of top edge and uses this soil for chocking of drainage gullies at specified distance with appropriate strength. Construction of peripheral bunds and partial modification of slope at every levelled piece of land is mandatory. The reclaimed flat land is usable for crop cultivation (35 to 50%), modified slopes can be used for medicinal/ fruit trees/grasses/ silvi-pastoral system (30 to 45%) and plugged deep gullies are good for water storage. This is most cheapest and practical methodology to make ravines usable. The reclamation cost varies only Rs.35,000 to 40,000 depending on depth of ravine. The system is eco-friendly, remunerative and takes care of all aspects sustainability to human being.

Soil health management and crop production in reclaimed ravine

To improve the soil health and crop production in reclaimed

Fig 8. Vegetative barrier for protection of village Aisah

Fig 9. Vegetative barrier which protect the village from advancement of ravine

Fig 10. Different options for checking ravine advancement

A. View of reclaimed valley

B. Water harvesting tank in valley

C. Agro-forestry on side of ridge

D. Crops on flat land and plantation on slopes

Fig 11. Multistep minimum leveling system or zero loss technology soils of ravine land, several programs have been initiated as under.

Soil physical and chemical properties

Some soil properties like aggregate size, zeta potential, particle size, total carbon content & dispersion ratio at the start of experiment were estimated for ravine profile excavated to a depth of 5.0 m and samples were collected at each 50cm layers.

The initial properties of soil clearly indicated that these soils are very poor in aggregation (Table 6) very low binding capacity (lower Zeta potential) (Table 7), low to very low in organic carbon (0.08 to 0.12%), very fine particle size and highly dispersed (Table 8).

For achieving up gradation in soil health the integration of organic and inorganic treatments were imposed from last two years and the effect has been assessed. The treatment consisted following management practices which includes farmers practice (100 kg/ha DAP), 100% RDF, 150% RDF, 50% RDF + 5 ton FYM/ ha + PSB + $ZnSO_4$ 25 kg/ha, 75% RDF + 2.5 ton FYM/ ha + PSB + $ZnSO_4$ 25 kg/ha, FYM @ 10 ton/ha + PSB + Azotobacter, and NPK application on the basis of STCR equations (developed by IARI)

The changes in physical (Tables 9 & 10), chemical (Table11) and biological(Table 12) properties due to

Table 6. Cumulative aggregate size analysis for two profiles and its (average value)

	Average value of two profiles				
Soil depth (cm)	>2 mm	>1 mm	>500 mic	>250 mic	>125 mic
0-50	2.676	6.93	14.37	38.62	67.35
50-100	7.87	13.17	18.42	30.18	50.91
100-150	3.33	7.49	14.53	39.37	69.88
150-200	3.82	8.73	18.15	45.73	74.03
200-250	7.13	16.75	27.84	43.37	66.28
250-300	7.67	13.61	18.38	21.49	32.29
300-350	3.606	8.61	14.05	27.97	54.39
350-400	2.708	9.50	18.07	29.97	48.63
400-450	4.72	14.31	24.74	37.81	58.04
450-500	2-7	8-14	14-18	25-40	50-70

Table 7. Soil samples analyzed for Zeta potential, particle size and total carbon content (%) (average of five profiles)

Profile	Zeta potential (mv)	Particle size (nm)	Total carbon %
P1S1-S10	41.91	166.5	1.05
P2S1- s10	43.59	252.58	1.18
P3 S1-S10	45.89	246.47	1.14
P4S1-S10	41.75	165.66	1.30
P5S1-S10	43.1	150.4	1.24

Table 8. Dispersion ratio calculated for samples collected from five profiles

Profile	Silt (%)	Clay (%)	Total silt + clay (%)	Water dispersible silt + clay (%)	Dispersion ratio
P1S1	23.3	29.8	53.1	43.983	0.824
P2S1	23.7	32.188	55.888	49.32	0.885
P3S1	25.02	28.21	53.13	45.846	0.866
P4S1	25.02	29.4	54.62	47.208	0.864
P5S1	22.1	32.44	54.54	45.778	0.844

Soil physical conditions

Table 9. Soil moisture content, bulk density (g/cc) and organic carbon content (%) as affected by treatments

SN	Treatments	Moisture (%)	B.D. (g/cc)	OC(%)
T_1	Farmer practices (100 kg/ha DAP) as control	14.76	1.47	0.14
T_2	100% RDF	12.61	1.48	0.15
T_3	150% RDF	14.16	1.44	0.17
T_4	50% RDF+5 ton FYM/ha+PSB+$ZnSO_4$ 25 kg/ha	13.70	1.42	0.12
T_5	75% RDF+2.5 ton FYM/ha+PSB+ $ZnSO_4$ 25 kg/ha	14.75	1.42	0.18
T_6	FYM @ 10 ton/ha+PSB+Azotobacter	14.72	1.38	0.13
T_7	NPK application on the basis of STCR equation	21.58	1.31	0.16

Table 10. Soil moisture content at different suctions(only for selected treatments)

Treatments	Suction (Bars) applied for 0-15 cm soil				
	0.33	1.00	5.00	10.00	15.00
Farmer practices (100 kg/ha DAP) as control	12.891	11.822	4.345	6.152	5.334
50% RDF+5 ton FYM/ha+PSB+$ZnSO_4$ 25 kg/ha	21.187	7.709	7.771	8.830	8.817
75% RDF+2.5 ton FYM/ha+PSB+ $ZnSO_4$ 25 kg/ha	16.161	10.612	5.709	6.820	7.423
FYM @ 10 ton/ha+PSB+Azotobacter	12.088	21.921	3.572	5.840	4.926

Soil chemical conditions

Table 11. Changes in soil chemical parameters due to various nutrient management options

Treatments	pH	EC (dSm^{-2})	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})
Farmer practices (100 kg/ha DAP) as control	8.58	0.51	73.17	4.04	324.68
100% RDF	8.42	0.52	87.81	8.64	295.19
150% RDF	8.42	0.49	117.08	6.04	287.72
50% RDF+5 ton FYM/ha+PSB+$ZnSO_4$ 25 kg ha^{-1}	8.35	0.43	109.76	29.80	468.42
75% RDF+2.5 ton FYM/ha+PSB+ ZnSO– 25 kg ha^{-1}	8.31	0.47	142.69	10.87	360.52
FYM @ 10 ton ha^{-1} +PSB+Azotobacter	8.48	0.49	146.35	13.55	289.96
NPK application on the basis of STCR Education	9.06	0.61	76.10	7.03	449.08

Soil biological conditions

Table 12. SMBC & Dehydrogenase activities (DHA) in wheat at 75 DAS during 2014-15

Treatment	SMBC (µC g^{-1})	DHA (microgram TPF/gm soil/day)
Farmer practices (100 kg/ha DAP)	58.38	94.501
100 % RDF	58.18	58.564
150 % RDF	60.46	74.536
50% RDF+5 ton FYM/ha + PSB+ $ZnSo_4$ 25 kg/ha	61.25	57.233
75% RDF+2.5 ton FYM/ha+ PSB+ $ZnSo_4$ 25 kg/ha	65.47	47.916
FYM @10 ton /ha +PSB + Azotobactor	62.72	74.536
NPK application on the basis of STCR Equation	59.61	39.930

imposition of different fertility managements applied to pearl millet- wheat cropping system, clearly indicated that soil health of ravine soil can be improved either 150% RDF with micronutrients or 75% RDF+2.5 ton FYM/ha+ PSB+ $ZnSO_4$ 25 kg/ha are most appropriate. There was better improvement in physical and biological properties due to application of FYM @10 ton /ha +PSB + Azotobacter has been recorded.

The introduction of various modules in ravine also improved physico- chemical properties (Table 13) . There was tremendous improvement in organic carbon content and nutrient contents while introduction of silvi- pastoral (M5) and silvi - medicinal module (M4) have shown marked improvement in soil aggregation.

Dynamics of major nutrients (N, P & K) in ravineous watersheds under different land use system

Nutrient use efficiency under different nutrient managements

To evaluate nutrient use efficiency of major nutrients (N, P, & K) in ravineous soil an experiment was conducted during the year 2013-14 and 2014-15. The experiment comprises seven treatments (RDF, 150% RDF, and other integrated approaches of nutrient managements). The maximum nutrient (N, P, & K) use efficiency was recorded either in 100% RDF or integrated (inorganic, micronutrients, organic & biofertilizers) method of nutrient management.

Nitrogen dynamics in ravineous soil under different nutrient managements

The different forms of nitrogen (total, available, ammonical and nitrate forms) were estimated under inorganic and integrated nutrient management. The recorded value clearly indicated that these soils are very fragile in nature

Table 13. Changes recorded in soil properties under different modules

Module	pH	EC (dSm^{-2})	O.C.(%)	Nutrient content (kg ha^{-1}) N	P_2O_5	K	Aggregate% (>500 mic)
M_0	8.52	0.42	0.09	90.2	5.50	309.4	14.37
M_1	8.42	0.52	0.38	137.9	5.33	375.2	16.54
M_2	8.42	0.49	0.36	150.4	4.04	328.0	18.64
M_3	8.35	0.43	0.34	112.8	3.90	292.6	24.87
M_4	8.31	0.47	0.36	100.3	3.50	287.8	32.41
M_5	8.48	0.49	0.37	125.4	4.08	320.3	37.45
MSL	8.22	0.40	0.12	99.7	8.25	410.4	16.43

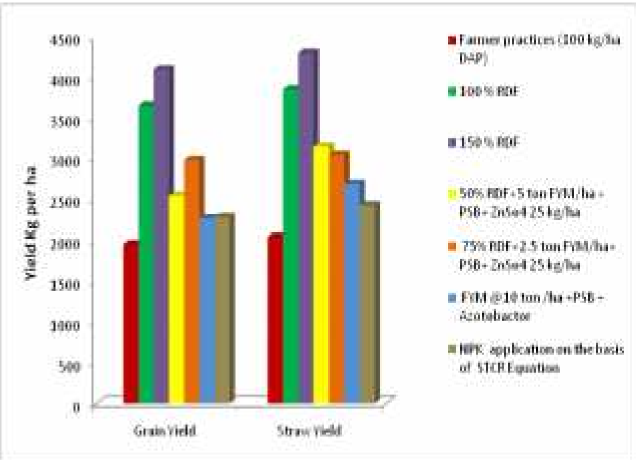

Fig 12. Grain and straw yield under different nutrient management practice in wheat

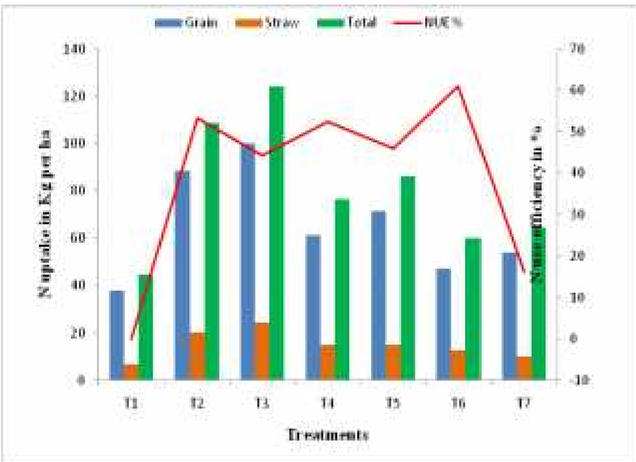

Fig 13. Nitrogen uptake under different nutrient management practice in wheat

Table 14. Yield and nitrogen concentration, uptake and use efficiency under different nutrient management in wheat crop

Treatment	GY	SY	Grain N	Straw N	Grain uptake	Straw uptake	Total uptake	NUE	NUE %
Farmer practices (100 kg/ha DAP)	1953.75	2043.46	1.95	0.33	38.16	6.68	44.84	0.000	-0.01
100 % RDF	3648.31	3846.12	2.42	0.53	88.29	20.51	108.80	0.533	53.30
150 % RDF	4093.23	4295.08	2.44	0.57	100.01	24.34	124.35	0.442	44.17
50% RDF+5 ton FYM/ha + PSB+ ZnSo4 25 kg/ha	2539.50	3143.63	2.42	0.47	61.37	14.88	76.25	0.524	52.35
75% RDF+2.5 ton FYM/ha+ PSB+ ZnSo4 25 kg/ha	2977.57	3042.40	2.40	0.49	71.36	14.91	86.27	0.460	46.03
FYM @10 ton /ha +PSB + Azotobactor	2260.94	2684.58	2.10	0.47	47.48	12.62	60.10	0.610	61.03
NPK application on the basis of STCR Equation	2277.64	2422.84	2.39	0.42	54.36	10.18	64.54	0.164	16.41

Table 15. Yield andphosphorus concentration, uptake and use efficiency under different nutrient management in wheat crop

Treatment	GY	SY	Grain N	Straw N	Grain uptake	Straw uptake	Total uptake	PUE	PUE %
100 % RDF	3648.31	3846.12	0.36	0.048	13.13	1.86	14.99	0.182	18.20
150 % RDF	4093.23	4295.08	0.35	0.059	14.33	2.52	16.85	0.142	14.20
50% RDF+5 ton FYM/ha + PSB+ ZnSo4 25 kg ha^{-1}	2539.50	3143.63	0.30	0.059	7.62	1.84	9.46	0.180	17.98
75% RDF+2.5 ton FYM/ha+ PSB+ ZnSo4 25 kg ha^{-1}	2977.57	3042.40	0.37	0.053	11.02	1.60	12.62	0.190	19.00
FYM @10 ton ha^{-1} +PSB + Azotobactor	2260.94	2684.58	0.51	0.065	11.61	1.75	13.36	0.186	18.58
Farmer practices (100 kg ha^{-1} DAP)	1953.75	2043.46	0.17	0.033	3.39	0.68	4.07	0.000	-0.01
NPK application on the basis of STCR Equation	2277.64	2422.84	0.45	0.059	10.17	1.44	11.61	0.126	12.57

Table 16. Yield and potash concentration, uptake use efficiency under different nutrient management in wheat crop

Treatment	GY	SY	Grain N	Straw N	Grain uptake	Straw uptake	Total uptake	KUE	KUE%
100 % RDF	3648.31	3846.12	0.47	3.15	17.15	121.15	138.30	2.108	210.77
150 % RDF	4093.23	4295.08	0.43	2.77	17.60	119.12	136.72	1.379	137.88
50% RDF+5 ton FYM/ha + PSB+ $ZnSO_4$ 25 kg ha^{-1}	2539.50	3143.63	0.50	2.79	12.78	87.81	100.59	2.330	233.02
75% RDF+2.5 ton FYM/ha+ PSB+ $ZnSO_4$ 25 kg ha^{-1}	2977.57	3042.40	0.55	3.17	16.38	96.34	112.72	1.958	195.76
FYM @10 ton /ha +PSB + Azotobactor	2260.94	2684.58	0.47	3.16	10.70	84.83	95.53	1.662	166.18
Farmer practices (100 kg ha^{-1}DAP)	1953.75	2043.46	0.34	2.32	6.58	47.41	53.99	-0.004	-0.42
NPK application on the basis of STCR Equation	2277.64	2422.84	0.51	2.57	11.69	62.19	73.88	0.497	49.72

Table 17. Nitrogen dynamics as affected by integrated nutrient management in wheat during 2013-14

Treatment	Total-N (kg ha^{-1})	NH_4-N (mg kg^{-1})	NO_3-N (mg kg^{-1})	Available-N (kg ha^{-1})	Total N (kg ha^{-1})	NH4-N (mg kg^{-1})	NO_3-N (mg kg^{-1})	Available-N (kg ha^{-1})
100 % RDF	3211.26	30.45	0.30	129.62	2960.38	31.05	0.55	175.62
150 % RDF	4306.77	31.93	1.47	154.71	3144.36	44.18	43.13	200.70
50% RDF+5 ton FYM/ha + PSB+ ZnSo4 25 kg ha^{-1}	3754.84	31.37	0.14	167.25	3976.45	29.15	0.84	121.26
75% RDF+2.5 ton FYM/ha+ PSB+ ZnSo4 25 kg ha^{-1}	3177.81	31.12	2.33	125.44	2801.49	30.18	17.00	167.25
FYM @10 ton ha^{-1} +PSB + Azotobactor	3261.44	34.18	5.48	146.35	3073.28	31.02	7.17	188.16
Farmer practices (100 kg ha^{-1} DAP)	2333.19	32.23	0.36	125.44	1814.70	30.32	1.16	108.71
NPK application on the basis of STCR Equation	2642.60	31.92	0.15	158.89	1923.41	32.90	2.98	125.44

and all the nitrate nitrogen is lost while only some ammonical nitrogen is retained by the soil. Application of either 150% nitrogen fertilizer dose or integrated approach can retain some available nitrogen for crop use. Total nitrogen was in the range of 1815- 3976 kg/ha while available was found 109 to 201 kg/ha. The condition of nitrate nitrogen was very poor before sowing of crop while there was some increase after the crop harvest. There was very little change in ammonical nitrogen during both the years. The observations suggest the nitrogen is needed to be applied in split dose and in integrated manner to achieve better crop.

Popular crops of Chambal division were tried to grow in ravine land with all the recommended practices followed in this region. Five crops viz. pearl-millet,

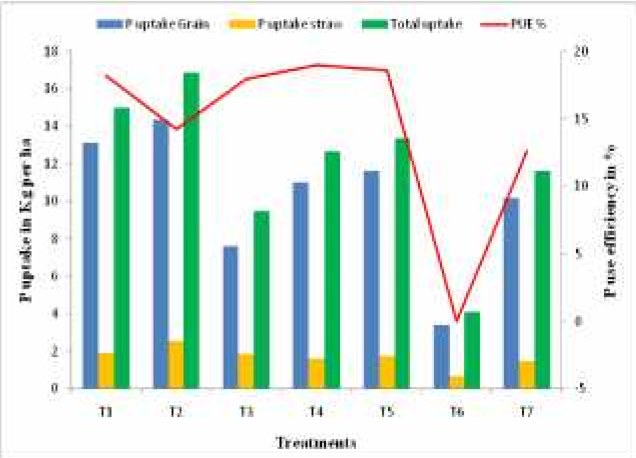

Fig 14. Phosphorus uptake under different nutrient management practice in wheat

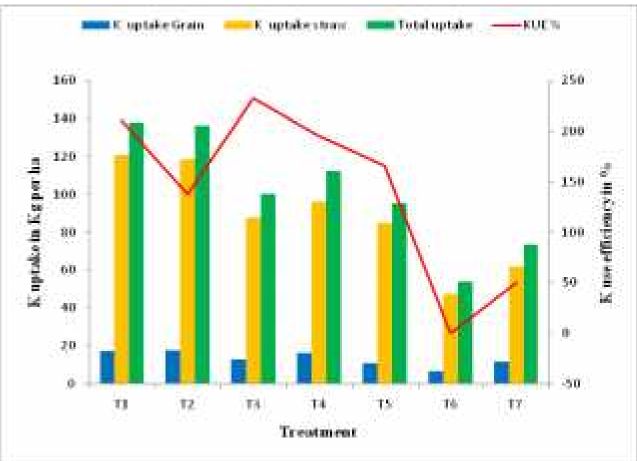

Fig 15. Potash uptake under different nutrient management practice in wheat

Table 18. Nitrogen dynamics as affected by integrated nutrient management in wheat during 2014-15

Treatment	Initial				Final			
	Total-N ($kg\ ha^{-1}$)	NH_4-N ($mg\ kg^{-1}$)	NO_3-N ($mg\ kg^{-1}$)	Available-N ($kg\ ha^{-1}$)	Total N ($kg\ ha^{-1}$)	NH4-N ($mg\ kg^{-1}$)	NO_3-N ($mg\ kg^{-1}$)	Available-N ($kg\ ha^{-1}$)
100 % RDF	3211.26	30.45	0.29	129.62	2920	15.69	9.73	87.81
150 % RDF	4306.77	31.93	1.47	154.71	3840	23.10	10.14	117.08
50% RDF+5 ton FYM/ha + PSB+ ZnSo4 25 kg ha^{-1}	3754.84	31.36	0.14	167.25	3320	13.07	4.04	109.76
75% RDF+2.5 ton FYM/ha+ PSB+ ZnSo4 25 kg ha^{-1}	3177.81	31.11	2.32	125.44	2920	15.04	23.55	142.69
FYM @10 ton /ha +PSB + Azotobactor	3261.44	34.18	5.48	146.34	2920	14.96	7.43	146.35
Farmer practices (100 kg ha^{-1}DAP)	2333.18	32.23	0.36	125.44	2080	12.84	13.35	73.17
NPK application on the basis of STCR Equation	2642.60	31.91	0.15	158.89	2260	9.35	2.52	76.10
CD	253.8	0.93	0.032	NS	300			

sesamum, black gram, cluster bean and soybean in kharif and mustard, tara-mira, wheat and gram during rabi season were grown. To work out most suitable and profitable cropping system the system productivity of different system were computed on the basis prevailing support / market price during the season/ year.

The recorded yield (Table 19) showed that yield of pearl-millet during kharif was almost equally good as in normal soil of the area while other crops were totally failed. The system productivity computed on the basis yield recorded durin year 2013-14 (Table 20) indicates that maximum system productivity was recorded for pearl-millet-wheat and was closely followed by cluster bean-gram and next was pearl millet - mustard while black gram, taramira, soybean, sesamum crops were totally damaged by very poor rains during kharif.

The research works carried out under Niche Area of Excellence financed by ICAR, New Delhi have given complete solution of the problem by identifying formation process, procedure for complete checking its advancement, an innovative an very practical multi-step leveling reclamation and maintenance of soil health in degraded land. Improvised gabion given an economical and effective way of soil & water conservation in deep ravines. Multi step leveling reclamation (cheapest reclamation) has facility for crop production from first year in a sizeable area while rest can be used for agro-forestry for making ravines green. Minimum shifting of soil provides natural looks of ravine that gives more cultivable area (140-150 % of actual area) due to utilization of slopes and gives 100% relief from soil, water and nutrient losses. The cropping system of pearlmillet- wheat, pearlmillet-mustard and cluster bean - gram are better option for maximum return from such soils. For improving soil health, nutrient use efficiency and better crop production fertilizer application @ 150% RDF or 75% RDF along with FYM and other sources (INM) are found best for ravineous soil.

Table 19. Grain & straw yield (kg/ha) of kharif and rabi crops during 2014-15

Kharif Crop	Grain	Straw	Rabi Crops	Grain	Straw
Pearl-millet	1500	5424	Mustard	1200	4720
Sesamum	55	200	Tara-mira	-	-
Black gram	-	-	Wheat	1574	3250
Cluster bean	-	-	Gram	-	-
Soybean	-	-			

Table 20. Cropping systems followed and computed system productivity (equivalent to pearl millet-mustard) on the basis of market prices (2013-14)

System	Kharif season		Rabi season		Total
	Grain	Straw	Grain	Straw	
Pearl-millet- Mustard	41612	16638	33916	7231	99397
Pearl-millet-Wheat	41612	16638	28110	20784	107144
Pearl-millet-Taramira	41612	16638	8476	1681	68407
Clusterbean- Gram	65415	4827	29223	2496	101961
Clusterbean- Taramira	65415	4827	8476	1681	80399
Black gram- Wheat	18490	1667	28110	20784	69051
Black gram-Mustard	18490	1667	33916	7231	61304
Soybean- Wheat	10931	1139	28110	20784	60964
Soybean- Mustard	10931	1139	33916	7231	53217
Sesamum- Wheat	9225	891	28110	20784	59010
Sesamum- Mustard	9225	891	33916	7231	51263

Note: The cost (in Rs) of grain is for pearl milet-1062, sesamum-4500, black gram-4300, clusterbean -5250, soybean-2560, wheat-1150, mustard- 3000, taramira-2600and gram-3100,
The cost (in Rs) of straw is for pearl milet-200, sesamum-100, black gram-100, clusterbean - 150, soybean-100, wheat-600, mustard-150, taramira- 150 and gram-200.

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Dynamics of soil microbial diversity in Vertisols: A review

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Abstract

Madhya Pradesh is one of the agricultural growing states in the country and dominant crops are soybean, wheat, maize, cotton, rice, chickpea etc. Factors responsible for crop growth and yields are both biotic and abiotic. Soil microbial communities exert important biotic factors in maintaining the health of soil and productivity of crops, and in turn, their population dynamics are influenced by agricultural systems. Plant growth promoting rhizobacteria are the soil bacteria inhabiting around/on the root surface and are directly or indirectly involved in promoting plant growth and development via production and secretion of various plant growth regulatory substances in the vicinity of rhizosphere. This review accentuates the perception of the beneficial soil microorganisms under the current perspectives. However, legume-cereal crop rotation along with application of organic sources of plant nutrients indicates that significant changes occur in the diversity of important microorganisms involved in nutrient transformations, antibiosis and growth promotion in response to various soil managing practices which are part of intensive cropping systems.

Keywords: Cereal-legume rotation, microbial community and management strategies.

Cropping system is a kind of sequence and arrangement of crops grown on a given area of land over a period of time. Cropping systems are the outcome of the technological innovations, household needs, reflection of government policies, availability of production inputs, market forces and socio-economic compulsion. An ideal cropping system should use natural resources efficiently, provide stable and high returns and do not damage the ecological balance. Cropping system is broadly grouped into sequential cropping and intercropping. Other cropping systems may include different crops but lack definite or planned order in which crops follow one another or growing of two or several crops mixed together. Cropping systems based approach of agricultural research received little attention, except some considerations for utilizing the beneficial effect of growing crops of dissimilar nature in mixed/ intercropping (Aiyer1949) or sequential cropping and role of legumes in green manuring (Singh1972). Gomez (1968) found that maize in rotation with soybean maintained high yields similar to those of sequential maize fertilized with nitrogen.

Madhya Pradesh has numerous agro-ecological systems, with diversity in crops and cropping systems, climate, agronomic and resource management inputs and socio-economic aspects. In the state, legumes including soybean are usually grown in rotation with non-legumes particularly maize, wheat, rice, cotton and sunflower. Many agricultural practices, such as crop rotation, continuous cropping and tillage, induce changes in microbial communities in soil (Lupwayi et al. 1998, Alvey et al. 2003) but specific microbial groups may respond differently. In Madhya Pradesh, soybean is mainly grown during kharif in Malwa plateau, part of Deccan plateau and Central Highlands in the state (Tamgadge et al. 1996). The state grows soybean largely on Vertisols and associated soils. The soybean rhizobia in surface of 0-15 cm depth in 40 districts of Madhya Pradesh surveyed were less than 100 cells g^{-1} (Rawat et al. 2008).

Studies of the influence of intensive agriculture on soil microbial communities are one of the modern frontiers of soil quality research. Numerous studies have shown that fertilizers and crop rotations affect the bacterial community structure in soil (Hai et al. 2007, Karin et al. 2007).Soil microorganisms play a critical role in maintaining soil health (Doran and Zeiss 2000) and thus biologically sustainable strategies of crop production have assumed a central priority in the current scenario. In addition, soil microorganisms also influence plant health by suppressing plant pathogens, inducing systemic resistance in plants, and improving plant growth (Garbeva et al. 2004, Jennifer et al. 2004). Therefore, the rhizobacteria are the dominant derivingforces in recycling the soil nutrients and consequently, they are crucial for soil fertility (Glick 2012).Soil organisms control the decomposition of plant and animal residues, and are involved in biogeochemical cycling of elements, including nitrogen fixation; contribute to the formation of soil structure; transform the organics and inorganics applied to soils and regulate the production and consumption of greenhouse gases in soils. Many genera of rhizobacteria such as Rhizobium, Mesorhizobium, Allorhizobium, Azorhizobium, Bradyrhizobium and Sinorhizobium are known for their potential to fix nitrogen for their host plants (Gualtieri and Besseling 2000). Aparna et al. (2014) reported that the improvement of soil biological condition due to microbial inoculation, and the usefulness of associative nitrogen fixers and acid phosphatase activity as indicators of soil microbial health. Kumar Rao et al. (1987) quantified the nitrogen fixation in pigeonpea under sole and intercropped with sorghum in a Vertisol. Sole crop fixed 88% of the total N and intercrop fixed 96% of its total N uptake.

Factors that influence role of microorganisms in nutrient building and cycling in soil and organic matter decomposition are of unique interest. Microorganisms affect soil fertility and hence the functioning of ecosystems, measurement of the nutrients held in the soil microbial biomass has attracted considerable attention in recent years (Smith and Paul 1990). Some rhizospheric bacteria have been reported to produce siderophores which bind with ferric (Fe^{+3}) ions to form Fe^{+3}-siderophore complexes that can be easily absorbed by the root system of a number of plant species (Bar-Ness et al. 1991).In practice, crop rotations have been explicitly used to disrupt disease cycles (Curl 1963).

Table 1. Microorganisms species at 0-15cm depth of soil

Microorganisms	Number (g^{-1} of Soil)	Biomass ($g^{-1}m^{2}$)
Bacteria	108- 109	40-500
Actinomycetes	107- 108	40-500
Fungi	105- 106	100 -1500
Algae	104- 105	1 -50
Protozoa	103- 104	Varies
Nematode	102- 103	Varies

Source: Hoorman and Islam (2010)

However, it is unknown how cropping systems affect the composition and structure of rhizosphere microbial communities.

Microbes in soil fertility

The agriculturally beneficial microorganisms are plant growth promoting, N-fixing, plant disease suppressive beneficial bacteria, stress tolerance entophytes and bio-degrading microbes. Bacteria are the important soil microorganisms responsible for many enzymatic transformations like nitrification, ammonification etc. Azospirillum is micro aerobic that fixes the nitrogen in association with roots of grasses. Inoculation of Azospirillum to the grass crops have positive hormonal effect on roots and plant growth. Rhizobium alone in symbiotic association with legume fixes about 50-200 kg of N_2 ha^{-1}. Most Rhizobium species have been shown to produce IAA which is involved in multiple processes including cell division, differentiation and vascular bundle formation, these three processes are also essential for nodule formation. The microorganisms population also varies with the depth and crop rhizosphere. The microorganisms population also varies with the depth and crop rhizosphere which is maximum at 0.15 cm depth (Table 1).

Impact of different crop rhizospheres on microbial population

The rhizosphere microflora include bacteria, fungi, nematodes, protozoa, algae and microarthrops (Raaijmakers and Weller 2001). The presence of a large and diverse soil microbial community is crucial to the productivity of any agro-systems. This diversity is influenced by almost all crop and soil management practices, including the type of crops grown. Plants and their exudates influence soil microorganisms and the soil microbial community found near roots (Duineveld et al.1998, Ibekwe and Kennedy 1998, Ohtonen et al. 1999). Decaying root systems also function as a source of nutrients for the surrounding microorganisms (Swinnen et al. 1995). Compared with mono-cropping, crop rotation can improve conditions for diversity in soil organisms because of variability in type and amount of organic inputs, and allow for time periods, or when there is no host available for a particular pest (Altieri 1999).Several in vitro studies have indicated the capacity of *R. japonicum* to survive flooded conditions (Osa-Afiana and Alexander 1979, Hunter et al.1980). From a glasshouse study, Wu et al. (1968) concluded that submersion of the paddy field does not affect the survival of *R. japoniucm*, but when soybeans were re-inoculated following flooding in a soybean-rice-soybean cropping system, they observed significant increases in plant weight, plant nitrogen and nodule numbers.

Roots and rhizospheres

There is a hypothesis that the plant species cultivated as a major determinant of the soil microbial population since plants provide nutrients. The narrow zone of soil directly surrounding the root system is referred to as rhizosphere (Walker et al. 2003), while the term 'rhizobacteria' implies a group of rhizosphere bacteria competent in colonizing the root environment (Kloepper et al. 1991).Plant roots secrete a wide variety of compounds to attract microorganisms, including sugar, ethylene, amino acids, organic acids, vitamins and enzymes. Composition of plant species can influence the microbial community because of different in chemical composition of root exudates (Christensen 1989). Peas and oats exude different amounts of amino acids (Rovira 1956). Ibekwe and Kennedy (1999) showed that wheat (*Triticum aestivum* L.) barely (*Hordeum vulgare* L.) and pea (*Pisum sativum* L.) grown in two soil types had different rhizosphere microbial communities. Barely cultivars differed in the abundance of fungi and bacteria present in their rhizoplanes and rhizospheres, and these differences were sustained over different stages of plant growth (Liljeroth and Baath 1988).Some Pseudomonas spp secrete some volatile and antimicrobial compounds which reduce the density and activity of deleterious microorganisms (Benziri et al. 1995).

Some endophytes including *Beaveria bassiana, Trichoderma koningii, Alternaria alternate, Phoma spp and Acremonium strictum* isolated from maize roots have been found to be of immense benefit to the plant as a promoter of plant health improving growth potentials and act as biological control agents against fungal and bacterial disease of plants (Kirkpatrick and Wilhelm 2006). *Azotobacter chroococcum, Enterobacter agglomerans, Pseudomonas chlororaphis and Pseudomonas putida, Rhizobium sp., Bradyrhizobium japonicum* etc. residing respectively, in the rhizospheres of wheat (Kumar and Narula 1999), soybean (Cattelan et al. 1999) and radish (Antoun et al. 1998) have been reported to solubilize the phosphates and promote the growth of these plants.

Management strategies

During the colonization of plant roots by soil bacteria, microorganisms from the bulk soil undergo selective enrichment in the plant rhizosphere in response to different root exudate components. When examined at the community level, crop rotations can cause changes in substrate utilization patterns, which suggest that soil bacterial communities under crop rotation have greater species diversity than under continuous cultivation with the same crop (Lupwayi et al. 1998). Following agricultural management practices can improve the diversity of beneficial soil microbial communities under different crop rhizospheres:

Cereal-legumes crop rotation

Pulses are known to improve the microbial environment in the soils. They are known to release a part of unused nitrate fixed through symbiotic nitrogen fixation to the soil.

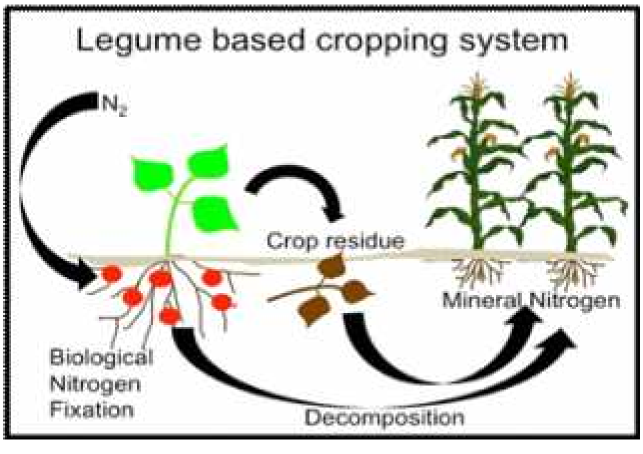

Fig 1. Response of intercropping legume crop on cereal and their diagrammatically representation show the indirectly benefited to maize crop.

Also low molecular weight organic compounds are released to the soil as exudates. Rhizobium-soybean symbiosis is of comparable importance to other Rhizobium-cereal associations with respect to nitrogen economy to the succeeding crop (Fig 1).

Fields which receive consistent fertility management and legume cropping were also found to host higher rhizobial numbers and diversity (Zengeni et al. 2006). This serves as a substrate to soil microorganisms resulting in the population is buildup. In maize based system, maize-wheat-mungbean recorded highest soil microbial biomass carbon as compared to maize-wheat. Diversity in crop rotation can allow for higher C inputs and diversity of plant materials added to soils, depending on the residue level and carbon quality of the crops in rotation (Table 2).

These increases in microbial activity which in turn influence mineralization and immobilization of nutrients like N, P and S depending upon the environment. These results indicate that inclusion of pulses in crop rotation improves soil microbial biomass and their activity that could be vital for long-term soil health and productivity. The maximal value of microbial biomass N (7 mg N g^{-1} soil) was observed in soybean-sorghum cropping system when no N has been applied to post rainy season sorghum (Patil el al. 1996).Higher activities of beneficial microbes and diversity under Bt-cotton than non Bt cotton cropping system which includes soybean, red gram, wheat and vegetables under Vertisol might be due to greater rhizodeposition, leaf fall and root biomass accumulation serving as source of bio-energy for native microbes (Mandal et al. 2015).

Arbuscular mycorrhizal (AM) fungi mobilize phosphorus and other minerals from the soil and exchange these nutrients for carbon with their plant hosts. Significant cultivar variability in the response to AM fungi has been measured in faba bean, pea, alfalfa, corn, wheat?peach palm and pearl millet (Clement and Habte 1995, Bradbury et al. 1991). Plant breeding can affect AM fungal associations with plants. Hetrick et al. (1993) found that modern wheat cultivars are less responsive to mycorrhizal symbiosis.

Green manuring/Cover crops

Cover crops have multiple uses, providing several opportunities for inclusion in crop rotation. Cover crops may be used as green manures, living mulches, residue mulches, catch crops and forages. Cover crop residues furnish a carbon or food source to microorganisms. When a green manure crop is incorporated into the soil, microbes multiply to break down the fresh plant material, resulting in a rapid increase of microorganisms by 2-6 fold. The roots can liberate a range of molecules (e.g., sugars, amino acids etc.) during the growing period (Borner 1960), although the amount of these substances is too small to directly affect soil fertility, they can directly influence the community composition and biomass of soil microorganisms (Ladygina and Hedlund 2010). Cover crops have been shown to influence the soil microbial biomass and composition more than soil temperature, moisture, pH, and texture in a tomato cropping system (Buyer et al. 2010). An increased microbial activity and diversity induced by preceding (rotational) crops such as canola, rapeseed, and barley (Larkin et al. 2010).

Cover crops, such as autumn-sown cereals or vetches, increase the AM inoculation potential for subsequent crops (Boswell et al. 1998). Cover crops aid in maintaining a viable mycelium network. Incorporation of crop residue of mungbean in rice-wheat system not only added 100 kg N ha^{-1} to the soil but also maintained high availability of N during various growth stages of rice. Rekhi and Meelu (1983). Changes in biological properties

Table 2. Microbial biomass carbon in maize based cropping system

Cropping systems	Microbial biomass carbon (mg g^{-1})		
	Control	CRB + BFs +FYM	NPKSZn B
Maize-Wheat	247	298	291
Maize-Wheat- mungbean	327	350	338
Maize -wheat -maize -chickpea	310	338	334
Pigeonpea-wheat	295	305	301
Source:Kushwaha et al. (2007-08)			

Note: CRB = Crop Residues Based, BFs = Biofertilizers and FYM = Farm Yard Manure after 7 years of cultivation of rice-rapesesame cropping sequence in an inceptisol showed that soil health attributes were superior under IPNS/INM as compared to balanced fertilization (Basak 2011). Inclusion of cover crop of peanut and FYM in Bt cotton, increased bacteria, fungi and actinomycetes population by 60%, 14%, and 10%, respectively, over Bt cotton alone, which can mask any negative effect of the Bt toxin on microbial activity and thus on enzymatic activities (Singh et al. 2013)

Soil manipulation

Biological properties of soil may change because of the changing physical and chemical properties of soil by soil manipulation/tillage methods. No-tillage with residue application was proved to increase the soil microbial community. In many cases, both bacteria and fungi were more abundant under no-tillage than conventional tillage (Helgason et al. 2009). In no-tillage systems, fungi domination was frequently found and the residue was mainly decomposed by the fungal community (Gouaerts et al. 2007). Bacteria were generally considered to be the predominant decomposers of incorporated crop residues under conventional tillage (Nicolardot et al. 2007).

Integrated nutrient management approaches

Manuring and fertilizer applications also have a significant impact on the species diversity of bacteria and fungi. They cause significant changes in the microbial populations which are largely mediated through changes in soil pH. Application of nitrogen fertilizers like ammonium sulphate increased the fungal population whereas FYM and NPK application increased the population of fungi, bacteria and actinomycetes (Sharma et al. 1983).Microbial population changes occur with added fertilizer crop rotation. Nitrogen fertilization increased numbers of fungi and gram-negative bacteria in rhizosphere of rice (Emmimath and Ranaswami 1971).

Changes in chemical and biological properties of soil after 3 years of experimentation, receiving organic nutrient management either fully (100% organic) or partially (INM) exhibited improvement in organic carbon content and microbial population (viz. total fungi, bacteria, Azotobacter, PSB and Actinomycetes) of the soil and the effect of 100% organic nutrient management was more pronounced in this respect (Table 3). Maurya et al. (2012) found that maximum diversity of microbial population density of both Azotobacter and Azospirillum microorganisms are present in Agro-forestry based crop

Table 3. Effect of nutrient management and cropping system on growth of microbial populationafter harvest

Treatment	Fungi (10^4xcfu g^{-1} soil)	Bacteria (10^4xcfu g^{-1} soil)	Azatobacter (10^4xcfu g^{-1} soil)	PSB (10^3xcfu g^{-1} soil)
Nutrient Management				
M_1-Organic	71.00	292.5	72.08	32.96
M_2-Inorganic	71.10	289.5	73.33	35.12
M_3-INM (50% organic + 50 % inorganic)	69.00	291.8	73.00	33.19
SEm±	1.47	1.12	0.08	0.51
CD at 5%	5.78	4.43	0.30	2.01
Cropping System				
CS_1-Rice-wheat-GM	71.81	286.1	73.11	34.78
CS_2-Rice-chickpea-sesame	68.91	292.4	72.22	34.45
CS_3-Rice-berseem (fodder + seed)	70.95	292.1	71.44	33.12
CS_4-Rice-vegetable pea-sorghum (fodder)	69.82	294.4	74.44	32.67
SEm±	0.78	0.95	0.18	0.76
CD at 5%	2.73	3.27	0.64	2.63

Source:Dubey et al. (2013)
Note:PSB- Phosphorus Solubilizing Bacteria,CS_1- Green manuring sunhemp-Rice-Wheat, CS_2-Rice-Chickpea-Sesame, CS_3-Rice-Berseem, CS_4-Rice-Veg.pea-Sorghum and three nutrient managements M_1- 100% Organic (1/3 N through each of FYM, Vermicompost and Neem oil cake), M_2 -100 % Inorganic (100% NPK through fertilizers), M_3-INM (50%NPK through fertilizer+50% N through organic sources)

rotation. Higher numbers of all groups of analyzed cultivable microorganisms were observed in organic agriculture fields in comparison to conventional fields, e.g., the number of bacteria had increased by 70%, actinobacteria by 290%, cultivable filamentous fungi by 110%, yeasts and maltose fermenting bacteria by 190% (Grantina et al. 2011). In a 4 years study on maize + cowpea-berseemrotation in Vertisol (fertiliser N @ 60 kg N ha^{-1} applied in kharif, 20 kg N ha^{-1} in rabi) leaching loss of NO_3-N ranged from a low of 37 kg ha^{-1} yr^{-1} to a high of 140 kg ha^{-1} yr^{-1} in two years; it was 80-90 kg in another 2 years (Patra et al. 2001) showing that biologically fixed nitrogen is equally susceptible to loss if managed improperly.

In a soybean-wheat rotation in a Vertisol in Madhya Pradesh (Table 4) showed (Rao et al. 2008 unpublished) that the microbial numbers and enzymatic activities during wheat growth were higher in integrated nutrient management as compared to chemical farming or farming without addition of fertilizers

Table 4. Microbial populations and soil enzymes in a Vertisol in various nutrient management options in soybean-wheat rotation

Treatments	Organic C (%)	Bacteria (106/g)	Fungi (104/g)
Farmer practice	0.44	8.6	2.9
Chemical	0.47	9.3	1.6
Organic	0.50	8.4	1.5
Integrated	0.54	13.0	2.1
LSD	-	2.3	0.9
P=0.05	-	-	-

Conclusion

Received information show that the changes in soil microbial diversity occurring response to agricultural practices viz. crop rotation, root rhizosphere, nutrient, soil management practices. Legume-cereal crop rotation and organic carbon source designate that significant changes occur in the diversity of important microorganisms involved in nutrient transformations, antibiosis, plant disease control and growth promotion in response to various soil managing practices which are part of intensive agriculture. Therefore, there is need to understand the aspects of microbial diversity in order to soil health and sustain the soil productivity on a long term basis, particularly in Vertisols.

"Healthy soil, Healthy plant, Healthy people and Healthy planet"

“स्वस्थ मृदा, स्वस्थ पौधे, स्वस्थ मनुष्य एवं स्वस्थ ग्रह”

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Integrated resource management: A key to improve soil health

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Abstract

Soil health is one of the integrative property that reflects the capacity of soil to respond to agricultural intervention, so that it continues to support both the agricultural production and the provision of other ecosystem services. The major challenge within sustainable soil management is to conserve ecosystem service delivery while optimizing agricultural yields. It is considered that soil health is dependent on the maintenance of four major functions: carbon transformation; nutrient cycle; soil structure maintenance; and the regulation of pests and diseases. Each of these functions is manifested as an aggregate of a variety of biological processes provided by a diversity of interacting soil organisms under the influence of the abiotic soil environment. Nutrient management practices have a significant effect on soil physical, chemical and biological properties and also sustain the crop production. The conjunctive use of organic and inorganic fertilizers along with biofertilizers and micronutrients gave lowest bulk density, improved infiltration rate and better aggregation as compared to other input treatments. The optimum moisture regime shows significant difference in case of physical parameters. The resource management practices significantly improve soil enzymatic and microbial activities under conservation tillage and optimal water supply which reduce the dependence on chemical fertilizers. Soil organic carbon (SOC) is the important factor for improving soil health and organic carbon content is significantly influenced by nutrient management practices. The conjoint use of inorganic fertilizers with organic manure and biofertilizers improves the organic carbon content in soil and also builds up other nutrients like N and P. Therefore, maximum nutrients use efficiencies and benefits could be obtained by integration. Recent studies have revealed superiority of INM over fertilizer NPK alone in improving microbial biomass C and N (MBC and MBN) and activities of enzymes like dehydrogenese, urease and alkaline phosphatase. Application of FYM along with recommended NPK proved the best nutrient management strategy to enhance accumulation and sequestration of C in the effective root zone.

Keywords: Integrated Resource Management A Key to Improve Soil Health

Soil Quality is simply how well soil does what we want it to do. More specifically, soil quality is the capacity of a specific kind of soil to function, within natural or managed ecosystems, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation. Soil Quality is the integration of the physical, chemical and biological properties of the soil. The diversity and productivity of living things depends on healthy soil. The minerals and microbes in soil are responsible for filtering, buffering, degrading, immobilizing, and detoxifying organic and inorganic materials, including industrial and municipal by products and atmospheric deposits. Carbon, nitrogen, phosphorus, and many other nutrients are stored, transformed, and cycled through soil (Soil Health Fact Sheet 2011).

The profitable production of agronomic crops is nearly impossible without healthy soil. The reason for this is that all of the trademarks of a healthy soil viz. good soil organic matter levels, good water holding and infiltration capacity, earthworms and soil fauna, nutrient levels, and a proper pH level, which play into conditions that optimize crop production. Crops need water, air, and nutrients, all present in the proper amounts and in the proper chemical balance in order to thrive. It does not matter the crop is tomato or wheat, soybeans or pumpkins; these soil quality parameters must be present. There are several good, common methods to greatly improve the soil quality (Soil Health Fact Sheet 2011).

Organic matter is very important to healthy soil. A healthy soil erodes less because it can absorb and infiltrate more rainfall, and it is also more resistant to raindrop impact and runoff. A good soil should have 3 to 5 percent organic matter by dry weight. Important measurable soil characteristics are pH, soil organic matter level, bulk density, and cation exchange capacity. Soil management is fundamental to all agricultural systems, yet there is evidence for widespread degradation of agricultural soils in the form of erosion, loss of organic matter, contamination, compaction, increased salinity and other harms (European Commission 2002). This degradation sometimes occurs rapidly and obviously. For this reason, research has been directed to devising measures of the health of soil, which could be used to monitor its condition and inform its management so that degradation is avoided.

There are two ways in which the concept of soil health (or the closely related concept of soil quality) has been considered, which can be termed either 'reductionist' or 'integrated'. The former is based on estimation of soil condition using a set of independent indicators of specific soil properties-physical, chemical and biological (Doran et al. 1994; Doran & Jones 1996; Van-Camp et al. 2004). This reductionist approach has much in common with conventional quality assessments in other fields, such as material science. The alternative, integrated, approach makes the assumption that the health of a soil is more than simply the sum of the contributions from a set of specific components. It recognizes the possibility that there are emergent properties resulting from the interaction between different processes and properties. Harris et al. (1996) said that the reductionist approach is an accessible and practical means of assessing soil condition, progress in understanding the interactions between management interventions and the capacity of the soil to respond depends on insights into its functioning as an integrated subsystem of the agro ecosystem. Soil health is derived from a context which we accept as an essential feature of sustainable agriculture, namely that agricultural production should not prejudice other ecosystem services that humans require from agricultural landscapes. Thus, our working definition is that a healthy agricultural soil is one that is capable of supporting the production of food and fibre, to a level and with a quality sufficient to meet human requirements, together with continued delivery of other ecosystem services that are essential for maintenance of the quality of life for humans and the conservation of biodiversity'.

Integrated Approach

Sustainability of agriculture is the major concern for food security, nutritional security and environmental safety. Population of India is continuously increasing and the availability of land for agricultural use is shrinking every day. Therefore, the country needs 5 to 6 million tons annually as additional food to meet the requirement. To attain the same we have to produce more food and other agricultural products too. During the past four decades the use of high yielding varieties of crops and inorganic fertilizers has helped in a rapid increase of agricultural production. Fertilizers is the key to increasing agricultural production by enhancing the land productivity, but it must be realized that their cost and other constraints frequently deter farmers from using them in recommended quantities and balanced proportion. In view of national food security demands, sustenance of soil fertility is important through balanced and integrated plant nutrient use. Primarily INM refers to combining old and modern methods of nutrient management into ecologically sound and economically optimal farming system that uses the benefits from all possible sources of organic, inorganic and biological components/substances in a judicious, efficient and integrated manner (Janssen 1993). It optimizes all aspects of nutrient cycling including N, P, K and other macro- and micronutrient inputs and outputs, with the aims of synchronizing nutrient demand by the crop and its release in the environment (Fig 1). Under INM practices, the losses through leaching, runoff, volatilization, emissions and immobilization are minimized, while high nutrient-use efficiency is achieved (Zhang et al. 2012). Moreover, it also aims to optimize the soil conditions by improving its physical, chemical, biological and hydrological properties to enhance farm productivity and minimize land degradation (Esilaba et al. 2004). There is now a greater awareness that INM can not only increase crop productivity but also simultaneously and almost imperceptibly preserve soil resources. Its practices to use

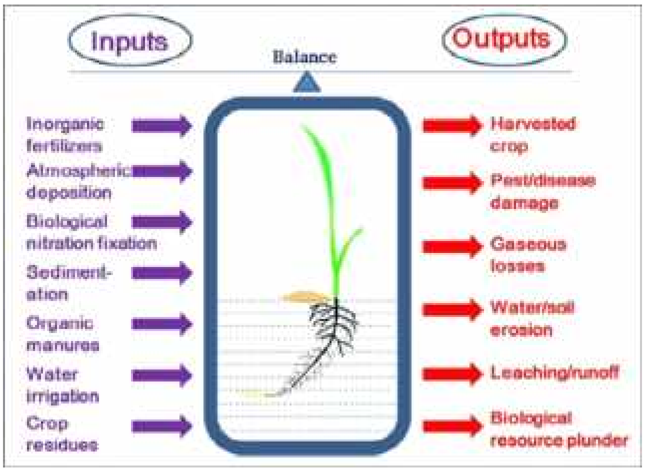


Fig 1. Nutrient cycling with input and output balance

farmyard manures, farm wastes, soil amendments, crop residues, natural and chemical fertilizers, green manures, cover crops, intercropping, crop rotations, fallows, conservation tillage, irrigation and drainage to conserve available water and to boost plant nutrients (Janssen, 1993). This strategy also includes new techniques, such as deep placement of fertilizers and the use of inhibitors or urea coatings that have been developed to minimize nutrient losses and improve plant uptake (Zhang et al. 2012). Such practices encourage farmers to focus on long-term planning and have greater consideration for environmental impacts, rather than only focusing on yield-scaled profit.

Resource integration is not only to supplement the need for fertilizer nutrients but also to derive maximum benefits of positive interactive effect of the various nutrient resources applied to the soil to restore depleted / depleting soil fertility. It also involves the integration of the contributory role of soil process with the other factor regulating ecosystem functions including those determining resources availability and access, and farmer's decision-making processes. Further, a wide gap exists between quantities of nutrients being removed by crops and quantities supplied by all sources of nutrients to the crops. Integrated nutrient management is the maintenance of soil fertility and supply of plant nutrients at an optimum level for sustenance of desired crop production as well as minimizes nutrient losses to the environment (Singh and Balasubraman 1986). Soil productivity declines through leaching, erosion and crop harvests. These losses are even exacerbated by tropical rainfall and anthropogenic forces. Unless the soil nutrients are replenished through use of organic wastes, crop residues, fallow and reconstruction of soil organic matter, soil fertility loss would continue unabated (Donova and Cassey 1998). In Nigeria research interest had diverted to use of organic wastes source of nutrients (Uyovbisere and Elemo 2000). This is due to scarcity and high cost of inorganic fertilizer. Intensification of use of mineral fertilizer has been reported to cause soil acidity and environmental health hazard. This situation renders use of inorganic fertilizer in sustainable soil productivity.

Resources integration and physical health of soil

Soil bulk density, aggregation and water intake rate were evaluated in the present reviw considering them as the most sensitive soil physical parameters that should reflect the impact of any change in the soil physical constituents, which may dominantly affect soil productivity. Soil physical properties is improved by organic matter additions which vary with climate, soil type and texture and rate and type of organic matter addition.

Bulk density and Penetration resistance

The impact of addition of organic manures (FYM) along with the inorganic fertilizers does have its impact on the soil bulk density values of both the soil layers. Sahu et al. (2011) reported that the bulk density of surface layer was low and that of the sub-soil was marginally high. Further, the bulk density values in both soil layers were relatively higher under moderate soil moisture conditions with medium fertility levels. The minimum values were observed in low input conditions. The highest value was recorded if the nutrients source was only the inorganic fertilizers and minimum if the inorganic source and FYM were applied simultaneously. A quite similar trend was recorded from the sub-soil layer under study. Bazoffi et al. (1998) showed that urban refuse compost increased soil bulk density although Chang et al. (1983) and Giusquiani et al. (1995) found that bulk density was reduced by municipal sludge compost and urban waste compost respectively. Zebarth et al. (1999) applied six different organic amendments including biosolids and food waste compost and found that all the materials reduced bulk density. A decrease in bulk density might be expected when soil is mixed with less dense organic material, but there may also be associated changes in soil structure. The magnitude of change for bulk density and other soil properties is likely to differ with soil texture as noted by Aggelides and Londra (2000). Reduced penetration resistance as a result of compost use is also commonly reported (e.g. Aggelides and Londra 2000). Low soil penetrometer readings indicate more favorable conditions for root growth. Edwards et al. (2000) observed that compost decreased penetration resistance in the subsoil under potatoes, possible reflecting improved soil structure. Similarly, Bazoffi et al. (1998) found that compost could prevent increased penetration resistance under heavy trafficking. Similarly, use of organic manures and blue green algae (BGA) either alone or in combination significantly reduced the soil bulk density. The highest reduction in bulk density was observed under FYM + BGA treatment.

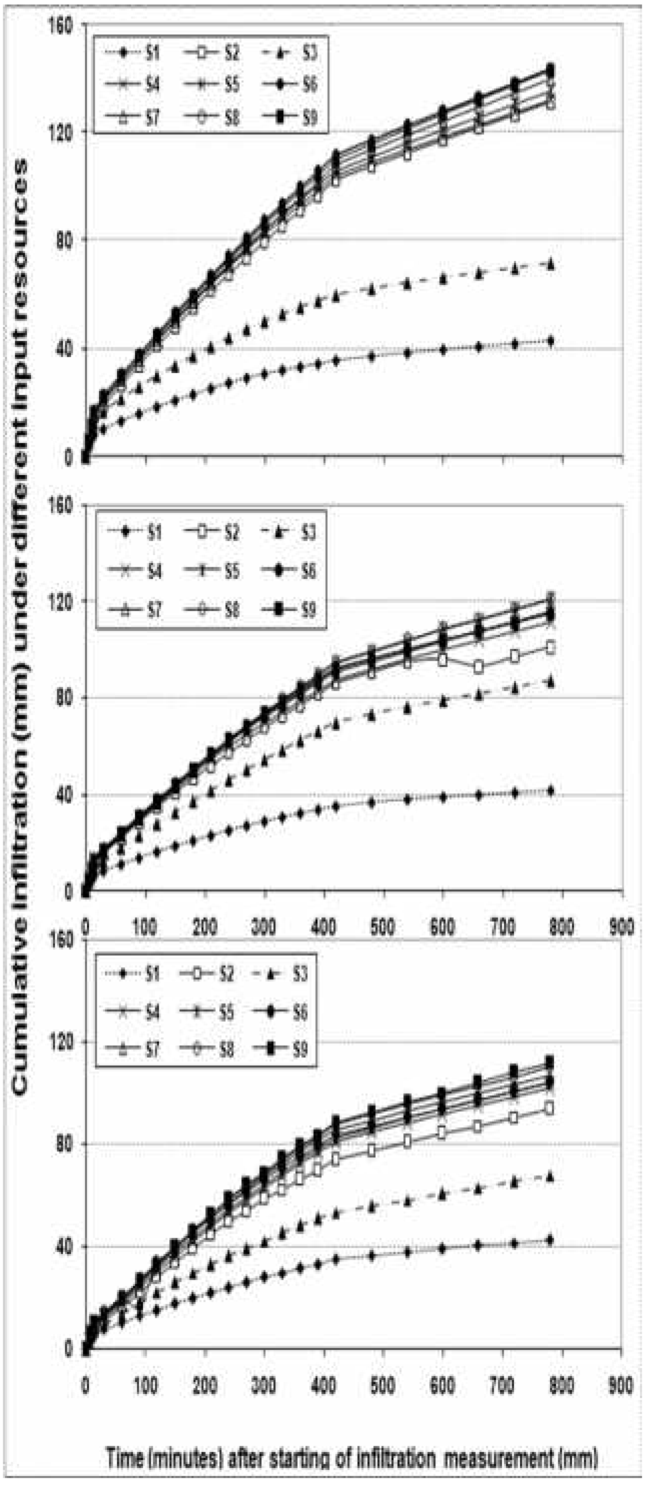
Water holding capacity and porosity

Increased water holding capacity of soils provides more available water to plants and can also help in resistance to drought. In a non-aggregated soil any effects on water retention are likely to be due to the properties of the compost material itself. However, in a more structured soil changes in both aggregation and pore size and continuity may affect the water holding capacity. Baziramakenga et al. (2001), Chang et al. (1983), Giusquiani et al. (1995) and Hernando et al. (1989) have all found increased soil water holding capacity after application of urban wastes. Chang et al. (1983) also noted increased hydraulic conductivity. When compost made from a mixture of potatoes, sawdust and manure increased soil moisture over untreated soil (Edwards et al. 2000). Urban waste compost has also been shown to increase total porosity (Aggelides and Londra 2000, Giusquiani et al. 1995, Pagliai et al. 1981).

Porosity is a measure of the size and arrangement of voids in the soil matrix, and thus affects both aeration and water movement. In addition to increasing total porosity, compost application can change pore size distribution. Pagliai et al. (1981) observed an increase in the number of small and medium sized pores in compost amended soils, indicating a better structure and potential plant growth. Using thin sections Giusquiani et al. (1995) also found that stability of the pore system was improved in treated soils. They also observed that total porosity increased linearly with compost application rates. The infiltration rate as well as its cumulative values got raised from 2.7 to 5.4 mm hr^{-1} when the organic sources were used in combination to the inorganic sources (Sahu et. al. 2011) However, the impact of bio-inoculants over the treatments receiving organic manures was not prominent. The lowest values of cumulative infiltration (Fig 2) registered if only inorganic sources for the addition of nutrients were used. It was attributed to the partial degradation of bigger size soil aggregates with the impact of inorganic fertilizers as also supported from the soil aggregation size distribution (Sahu et al. 2011). The initial infiltration rate increased in clay soils due to applications of FYM along with the inorganic fertilizers (Rasende 1987; Tiwari 1991).

Aggregate stability

The changes in soil bulk density were minimum and least consistent due to its dependence predominantly on soil moisture content. However, the impact was quite apparent on soil aggregation and infiltration rate. Further, reduction in bigger size aggregated in to finer aggregates noted if the nutrients are applied through only inorganic source. Inclusion of FYM, bio-inoculants and micronutrients significantly improves the soil aggregation due to formation of bigger aggregates at the expense of finer aggregates. The most predominant soil aggregation is obtained if all input resources were integrated judiciously (Sahu et al. 2011). The change in soil aggregation also contributes to the water intake rate and its transmission through the soil profile. Therefore, the constant water infiltration is the highest in treatments with highest degree of integration.



S_1 = 100% NPKS; S_2=75% NPKS + FYM @ 5t ha^{-1}; S_3 = 50% NPKS + FYM @ 5t ha^{-1}; S_4=S_2 + BGA @ 10 kg ha^{-1}; S_5 = S_2 + PSB @ 1.5 kg ha^{-1}; S_6= S_2 + PSB +BGA; S_7 =S_6 + Zn @ 2.1 kg ha^{-1} S_8 =S_6 + Mo @ 260 g ha^{-1}; S_9 =S_6 + Zn + Mo

Fig 2. Impact on cumulative infiltration rate

Subsequently, there are also significant variations in the cumulative infiltration values recorded under different level of inputs and their combination. The surface soil indicated that the changes in soil aggregation due to different levels of resources were marginal in case of high fertility (100% dose) and optimum moisture conditions. However, the impact on aggregate size distribution was more pronounced when the level of input resources were moderate to low (75% or 50% level, of the required dose). A quite similar behavior was also noted for the aggregate size distribution of sub-soil [Fig 3(a&b)]. The improvement was attributed to the formation of bigger size aggregates at the expense of smaller aggregates by the decomposing organic matter under these treatments as apparent from the percent of aggregates 0.5 mm, which was recorded relatively higher. Zhu and Yao (1993) also recorded similar results. They noted decrease in percent of bigger size aggregates only if inorganic sources of nutrients were used. It was attributed to the degradation of coarse aggregates by the impact of inorganic fertilizers, as also reported by Sengar (1990) and Singh (2002). Similarly, Rao and Burns (1990) reported the improvement of surface soil properties due to inoculation with a cynobacteria (BGA) in rice. They observed that due to inoculation with BGA culture, initially there was increase in BGA growth that subsequently declined and the soil aggregation improved significantly. Mishra and Sharma (1997) also reported improvement in soil aggregation due to application of organic manures.

Paper sludge has generally been shown to have a positive effect on aggregation (Gagnon et al. 2001, Nemati et al. 2000). Studies on the effect of sewage sludge and composted municipal wastes on aggregate stability have shown positive (Aggelides and Londra 2000, Albiach et al. 2001, Pagliai et al. 1981) and neutral effects (Guidi et al. 1988). Effects may be limited in stable soils as in the study of Guidi et al. (1988). An interesting study by Pare et al. (1999) compared the effects of fresh and stockpiled cattle manure on aggregate stability.

However, regular additions of organic matter will have long-term effects (Haynes and Naidu 1998). Tisdall and Oades (1980) stated that quality is more important than quantity in relation to effects of organic matter on aggregate stability. It has also been observed that a greater quantity of organic material is needed to improve soil structural properties than is necessary to supply the nutrient requirements of a growing crop. Thus economic and environmental impact must be accounted for in quantifying the value of use of organic materials. Debosz et al. (2001) noted an instantaneous effect on aggregation of sewage sludge, where the effect of municipal compost was slower. They attribute this to the extracellular polymeric substances accumulated during anaerobic storage of sewage sludge. The extraction of humic acids from composted wastes for use as commercial soil conditioners has also received some interest. Canarutto et al. (1996) found that micro aggregation was improved by the addition of humates from green waste compost. Such substances are also known to have beneficial effects on plant growth and microbial populations so may be of interest in high value horticultural crops if economic methods of extraction can be developed. For use in organic farming systems, there would be a need to find out whether such materials are acceptable within the organic standards. This is likely to depend on both the original material and the method of extraction.

Resource integration and chemical health of soil

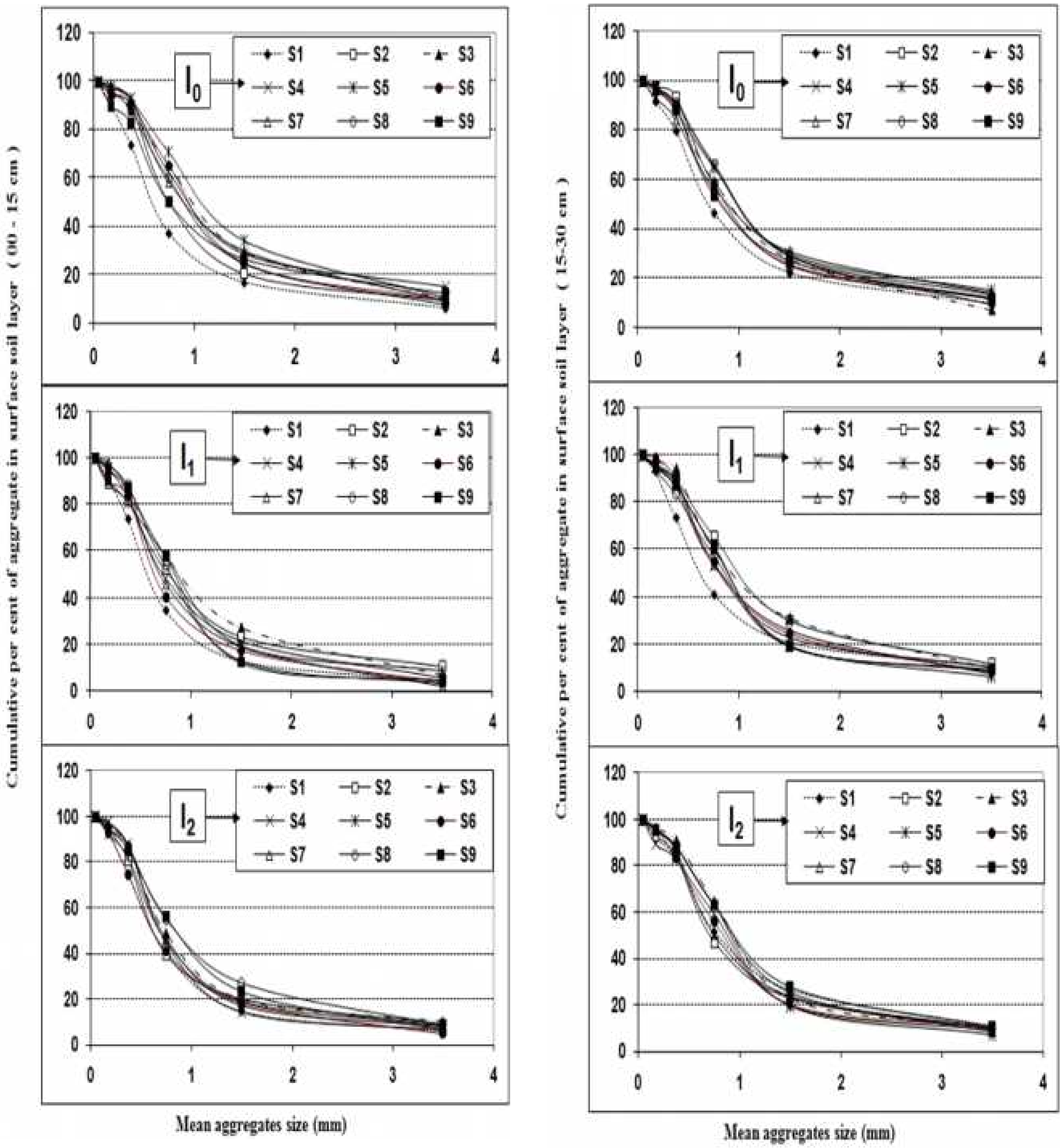
The present day agriculture is dependent on chemical (i.e. N, P, K) fertilizers and energy intensive processes (Bosede 2010). It has been established that chemical fertilizers cause many problems like soil alkalinity, acidity, yield stagnation, etc., and are the major source of environmental pollution. So the emphasis of research has been shifted towards exploring the alternative organic options for inorganic N, P, K fertilizers (Mahajan & Gupta 2009). Soil pH is also critical to maintain an optimum soil pH for the crops being produced. Proper pH maintenance provides benefits ranging from increased soil aggregation to better pesticide efficacy (Soil Health Fact Sheet 2011).

Soil pH and EC

Soil pH, electrical conductivity (EC) and available nutrients contents in the soil profile etc. were recorded to study the impact of any change occurred in these soil parameters due to the applications of the external inputs which may affect to modify the soil health and its productive potentials (Sahu et al. 2012). The soil pH is a barometer of soil health. Since, the net residual acidity or alkalinity of the applied inputs is negligible in view of the high buffering capacity of these soils. Therefore, no significant changes were found. Thakur et al. (2011) also reported that there is no perceptible change in soil reaction (pH) and electrical conductivity under continuous application of inorganic fertilizers and organic manure in a Typic Haplustert after 38 years of on soybean-wheat cropping system.

Cation exchange capacity

Cation Exchange Capacity (CEC) describes the ability of



S_1 = 100% NPKS; S_2=75% NPKS + FYM @ 5t ha^{-1}; S_3 = 50% NPKS + FYM @ 5t ha^{-1}; S_4=S_2 + BGA @ 10 kg ha^{-1}; S_5 = S_2 + PSB @ 1.5 kg ha^{-1}; S_6= S_2 + PSB +BGA; S_7 =S_6 + Zn @ 2 I1= 75%NPKS with one irrigation;.1 kg ha^{-1} S_8 =S_6 + Mo @ 260 g ha^{-1}; S_9 =S_6 + Zn + Mo; I_0 = 50%NPKS with come up irrigation; I_1= 75%NPKS with one irrigation; I_2= 100%NPKS with two irrigation

Fig 3(a&b). Impact of integrated resource management on cumulative aggregation of soil (0-15 and 15-30 cm) a soil to retain cations on soil colloids as a result of negative charges. CEC is thus important for retaining nutrients and making them available to plants. Soil organic matter and clay minerals are the two most important constituents that influence soil CEC. Thus increasing soil organic matter through compost addition is likely to increase CEC. McConnell et al. (1993) in a review of MSW compost concluded that applying compost at normal agronomic rates (38 to 75 Mg ha^{-1}) would increase the CEC of most mineral soils used for agriculture by a minimum of 10%. However, in a sandy soil in British Columbia, Zebarth et al. (1999) found CEC to be unaffected by a range of composted and non-composted organic amendments. In a pot experiment over a 7-years period Jakobsen (1996) found that on average CEC was reduced by mineral fertilizers but unchanged by compost amendments. The significant increase in exchangeable Ca, Mg, K and ECEC could be attributed to release of these exchangeable bases upon mineralization of added organic wastes in the soil. Agboola and Fagbenro (1985) and Mbagwu (1992) in their studies reported that application of organic wastes in soil increased exchangeable properties which enhanced CEC.

Soil organic matter

The energy that drives soil systems is derived from reduced carbon that is ultimately derived from net primary productivity. Carbon is the common currency of the soil system, and its transfer with associated energy flows is the main integrating factor. The benefits of increased soil organic matter content in terms of crop yield and nutrient uptake have been demonstrated by the long-term experiments at Rothamsted (Johnston 1986). McConnell et al. (1993) reported that compost applied at rates varying from 18 to 146 t ha^{-1} produced a 6 to 163% increase in soil organic matter. A study by Zebarth et al. (1999) over a three-year period showed that increases in soil organic matter from 5 different organic sources including bio-solids, food waste and composted pig manure. Effects on soil organic matter will differ between one-off and regular applications. The long-term experiments at Rothamsted demonstrate the buildup of organic matter over time. Experiment showed increases in percent C from 0.87% to 1.46 % from FYM additions and 2 % from composted FYM additions over a 25 year period (Johnston et al. 1989). Eghball (2002) reported that 25% applied manure C remained in the soil after a four year period compared with 36% applied compost C suggesting that compost may have greater benefits for C sequestration than manure. Soil organic carbon content was significantly influenced by nutrient management practices. The increase in SOC content was the highest under NPK and FYM followed by NPK. The plots receiving N alone witnessed only marginal change in SOC (Manna and Ganguly 2003).

Soil available nutrients

The maximum nutrient (N, P, K, S and Zn) availability was found associated to the surface soil and decrease with soil depth (Fig 4, 5 & 6). The availability of nutrients in all soil layers improved by integration of inorganic sources in combination with organics along with bio-inoculants and micronutrients, particularly at optimum level of inputs in rice crop (Sahu et al. 2012). The nutrients (N, P, K, S & Zn) content profiles indicated that, the higher values of any nutrient was found associated with higher moisture regime which also received higher level of nutrients application and vice versa. Further, with the increasing level of integration of resources also, the nutrients content was higher at similar level of application. In case of N, P and S contents (Fig 4 & 5), in general, the higher values of nutrients were recorded from surface layer and it continued to drop with increasing soil depth. Also, the highest nutrients content values were recorded in surface layer (126.7, 16.9 & 24.8 mg kg^{-1}, respectively) were all input recourses are integrated irrespective of the highest production under any level of irrigation. Other treatments occupied the intermediate positions. Such a behavior clearly indicated that integrated applications helps in protecting nutrients losses and better nutrients use efficiencies, thus the higher contents in the profiles, in conjunction of higher production from those plots where resources were integrated.

The changes in N contents of different soil layers amongst the various sources might be attributed to the nutrient use efficiency due to the variable biochemical activities within the soil. The higher values of available N, P & S at lower soil depths in differential combinations and levels of inputs indicated the impact of differences in the internal soil activities, conservations and leaching, with this level of application (Murugappan et al. 1998). Similar findings were also reported by Nand Ram (1998) who observed that the organic carbon and / or available N content was maintained from its initial values by integrated use of NPK fertilizers with FYM. The differences amongst the sub treatments were more apparent in case of P & S content profiles (Fig 5 & 6). Tyagi and Bharadwaj (1994) who recorded maximum P content in top (0-15 cm) soil layer and the minimum in deeper layer (75-90 cm). Similarly, Kabeerathamma and George (1993) reported that 70% of P retained in upper layer (0-30 cm). Tembhare et al. (1998) reported that the soil available sulphur progressively declined with depth and the highest accumulation of soil available S was noted from the top soil. The residual of Mo enhanced the microbial activities in soil environment that metabolized the bulk of soil S present in organic form. Presence of Mo ions enhances the activity of micro-organisms in the soil and thus improved the availability of S to plants.

The nutrients content profiles related to K & Zn (Fig 7 & 8) also recorded similar trends, however, in case of K content profiles; the K content values registered an increasing trend with soil depth after 50 cm soil layer. The actual values of K contents at 10, 50 and 90 cm soil depths of 'S_3' were 122.3, 89.9 & 107.2 mg $^{k}g^{-1}$, respectively, and 'S_9' 133.4, 102.7 & '119.7 mg $^{k}g^{-1}$, respectively, under 'I_2'. Such behaviour was due to higher uptake of K as well as soil moisture (Kauraw 1982) only from upper half meter soil layers and the continuous release of unavailable K in to available form during crop growth period. Similar trend of reduction in K content with increasing soil depth also reported by Tyagi and Bharadwaj (1994) and Rehman & Mukhopadhyay (1999).

In case of Zn content profiles the values were much higher for the upper half-meter profile indicating the movement of applied Zn within the soil profile (Sahu et. al. 2012). A significant increase of Zn availability was also recorded by the application of FYM with 75% recommended fertilizer dose. Enhanced availability of Zn was also reported by Nand Ram (1998) & Raman (1984). Integration of biofertilizers further improved the availability of Zn; which was attributed to the enhanced microbial activities in these plots. A further enhancement in the availability of Zn was recorded after the application of Mo. It indicated that better availability of Mo stimulated the soil microbial activities thereby increased the availability of native elements for the growing plants. Swarup and Rao (1999) emphasized that the deterioration in productivity factor was associated with deficiencies of zinc.

Rawat et al. (2013) reported in a long-term field experiment that was conducted for 8 years on a Vertisol in central India to assess quantitatively the direct and residual N effects of soybean inoculation with *Bradyrhizobium* and wheat inoculation with *Azotobacter* in a soybean-wheat rotation. After cultivation of soybean each year, its aerial residues were removed before growing wheat in the same plots using four N levels (120, 90, 60 and 30 kg ha^{-1}) and *Azotobacter* inoculation concluded that there was always a positive balance of soil N after soybean harvest; an average of +8 kg N ha^{-1} yr^{-1} in control (nodulated by native rhizobia) plots compared with +41 kg N ha^{-1} yr^{-1} in *Rhizobium*-inoculated plots. Residual and direct effects of *Rhizobium* and *Azotobacter* inoculants caused a fertilizer N credit of 30 kg ha^{-1} in wheat. Application of fertilizers or microbial inoculation favored the proliferation of rhizobia in crop rhizosphere due to better plant growth. Additional N uptake by inoculation was 14.9 kg N ha^{-1} by soybean and 20.9 kg N ha^{-1} by wheat crop, and a gain of +38.0 kg N ha^{-1} yr^{-1} to the 0- 15 cm soil layer was measured after harvest of wheat. So, total N contribution to crops and soil due to the inoculants was 73.8 kg N ha^{-1} yr^{-1} after one soybean-wheat rotation. There was a total N benefit of 13.8 kg N ha^{-1} yr^{-1} to the soil due to regular long-term use of microbial inoculants in soybean-wheat rotation.

Resource integration improves the biological health of soil

The direct effects of inorganic fertilizers on the nutrient cycling function are exacerbated by the reduction in organic matter inputs which often accompanies high rates of fertilizer use. Although fertilizers are highly effective in increasing crop production, integrative practices of combining them with organic inputs are commonly abandoned in the interests of efficiency, and above-ground residues are often removed or burned. Inorganic fertilizers have been shown to increase the rate of decomposition of 'low-quality' organic inputs and soil organic matter (Vanlauwe et al. 1994, 2001; Recous et al. 1995). This effect is usually attributed to the enhancement of microbial decomposer activity previously limited by low nutrient concentrations in the organic resources. It should be noted, however, that the results of experiments on this effect are equivocal: although a majority of results indicate the above effect, in a significant minority added inorganic nitrogen has either a neutral or even an inhibitory effect on the decomposition of low-N plant materials (Hobbie 2005). This is probably indicative of the interaction with secondary rate-limiting factors, but makes the point that the addition of a single 'simple' source of nitrogen can have complex interactive effects on carbon transformations in the soil. The commonly observed overall effect of continuous inorganic fertilization with diminished input of carbon and energy is continuing decline in soil organic matter content. Finally, it should be noted that although each of the three substitutive practices have been considered separately, they are commonly used in concert. Comparative studies of soil food webs and functions in such multiple substitution systems and low substitution integrated agriculture confirm the improved soil health in the latter (Brussaard 1994)

The path of decomposition may be supplemented or diverted by the intervention of larger detritivorous fauna, such as earthworms and other macro arthropods (such as termites in tropical soils) which consume both organic matter and microbes, often together with soil. The rate of decomposition is shown as being regulated by climate

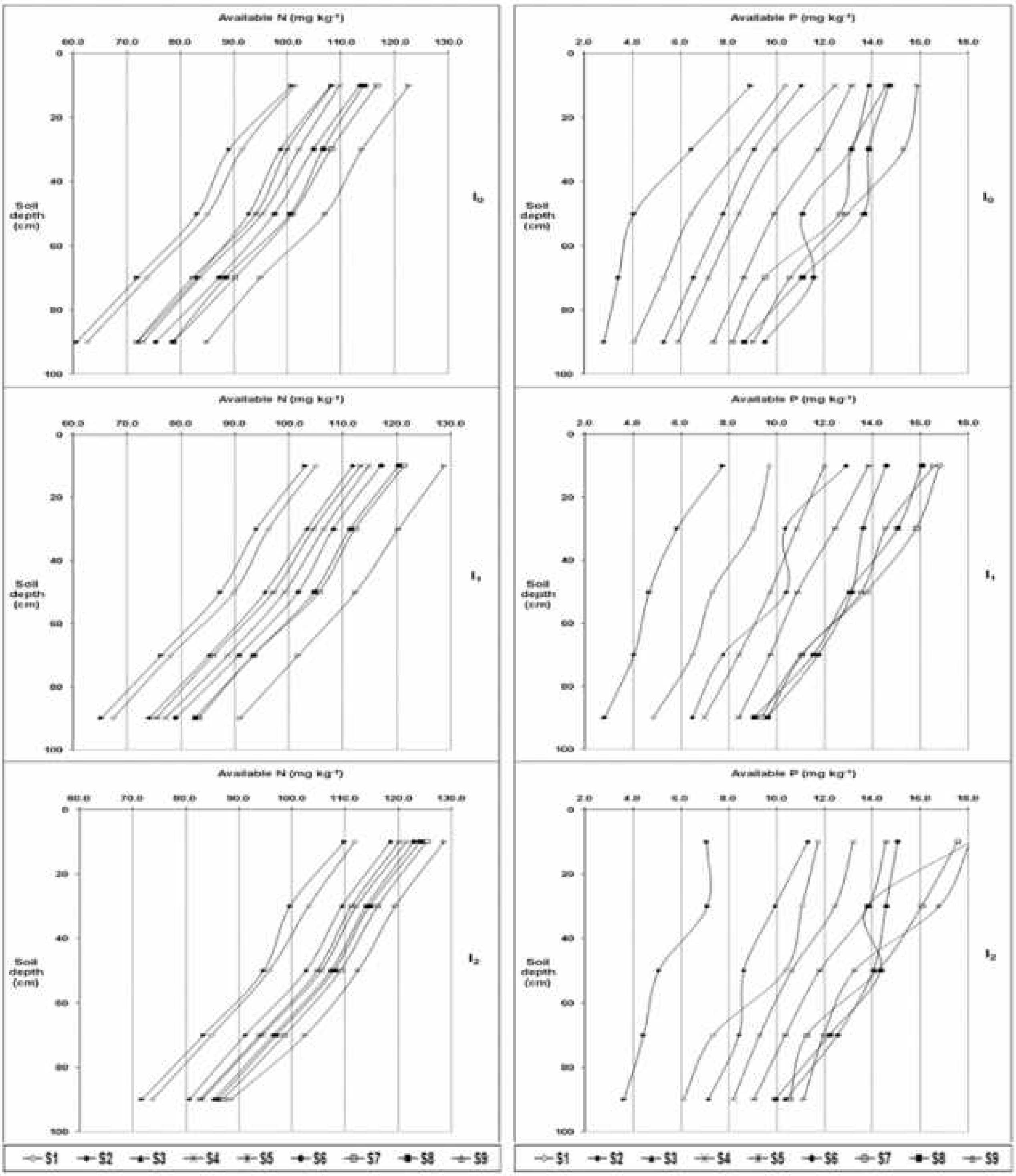


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Fig 4. Available N & P content in soil profile after harvest of rice

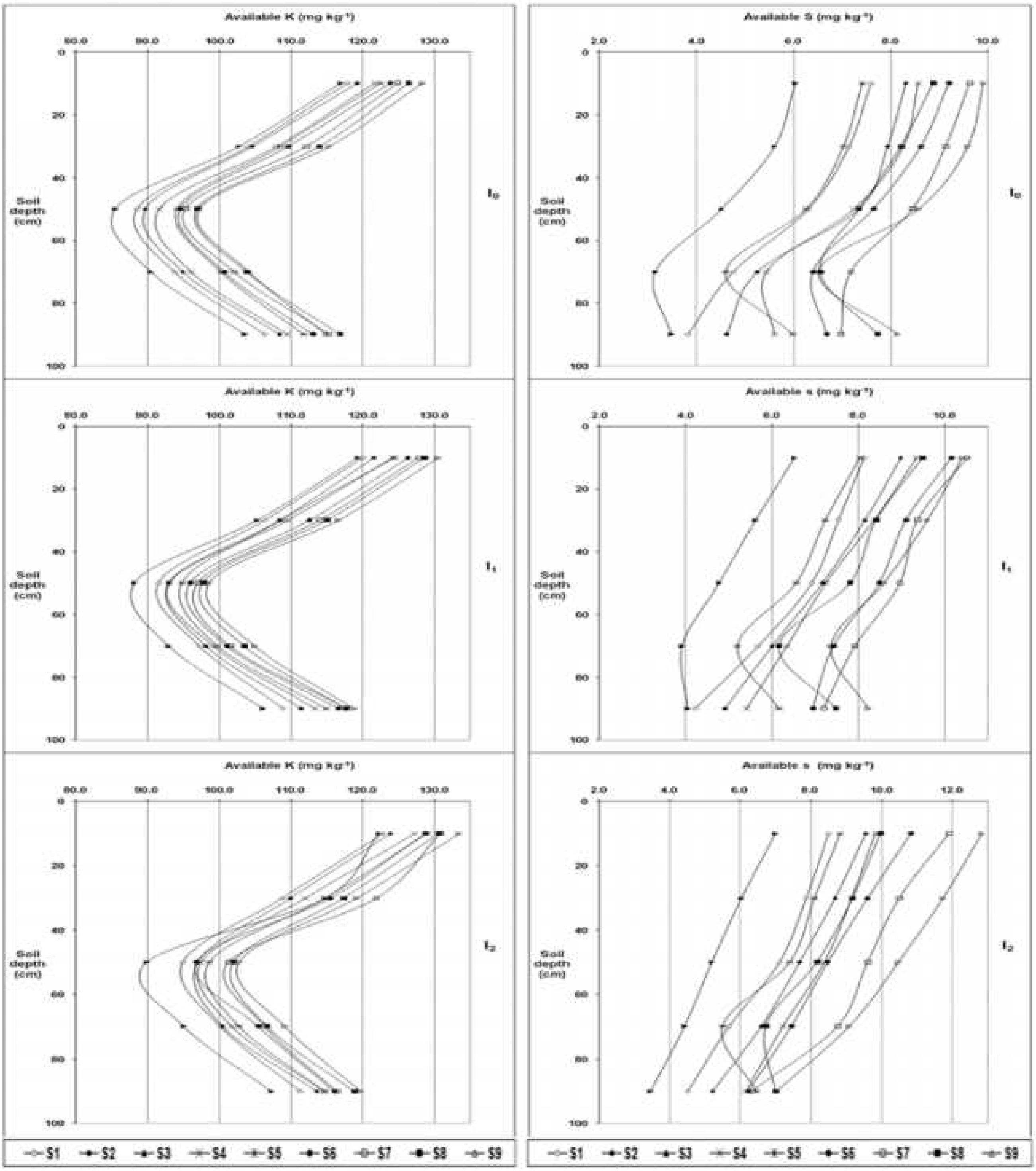

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Fig 5. Available K & S content in soil profile after harvest of rice (particularly soil moisture content and temperature), soil conditions (pH and particularly habitat structure) and resource quality (particularly in relation to organic matter and the content of nutrients, lignin and polyphenols (Swift et. al.1979; Lavelle et al. 1997).

Microbial biomass C and N

Inclusion of organic manure (FYM) significantly improved microbial biomass C and N contents over rest of the treatments. Where the balance applications are practiced, the soil conditions are favorable for microbial biomass C and N contents (Table 1). Microbial C/N ratio of surface soil (0-20 cm) ranged between 7.45 to 9.82 (Table 34). The highest value of ratio (Table 1) was recorded in T9 treatment (without S) and lowest value (7.45) obtained in fallow plot. The most appropriate values of C/N ratio at different depths of profile (between 10 to 12) was found associated with 100% NPK+FYM. Recent studies also revealed superiority of INM over fertilizer NPK in improving microbial biomass C and N (MBC and MBN) contents and activities of enzymes like dehydrogenese, urease and alkaline phosphatase (Manjaiah and Dhyan Singh 2001; Masto et al. 2007).

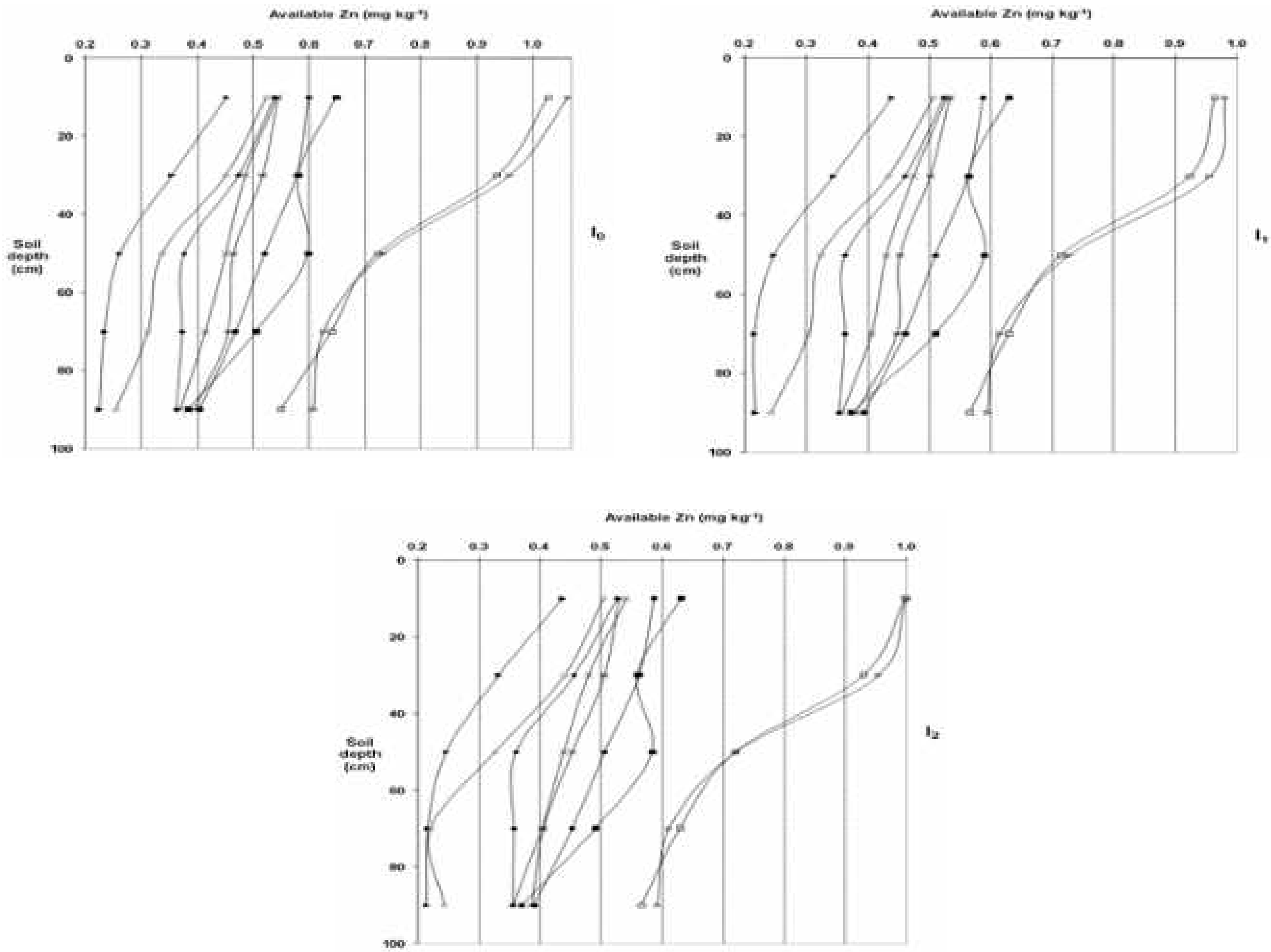

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Fig 6. Available Zn content in soil profile after harvest of rice

Table 1. Distribution of microbial biomass C and N (mg kg^{-1}) in soil

Treatments	Microbial biomass C				Microbial biomass N Soil depth (cm)				Microbial C/N ratio			
	0-20	20-40	40-60	60-80	0-20	20-40	40-60	60-80	0-20	20-40	40-60	60-80
100% NPK	224.5	136.5	43.8	14.8	26.96	13.53	5.20	1.52	8.36	10.11	8.45	9.80
150% NPK	222.7	119.8	45.1	10.4	25.21	12.45	4.51	1.47	8.85	9.62	9.98	7.06
100% NP	186.5	97.0	39.9	6.2	23.03	11.76	3.92	1.21	8.11	8.31	10.16	5.12
100% N	199.9	110.2	29.6	10.5	21.86	11.25	3.83	1.19	9.19	9.82	7.71	8.91
100% NPK+FYM	291.4	196.6	93.8	39.9	35.99	18.40	8.33	3.85	8.11	10.69	11.27	10.34
100% NPK - S	244.0	143.3	47.9	11.9	24.89	12.10	4.65	1.20	9.82	11.85	10.31	10.22
Control	170.3	94.3	17.5	2.4	20.62	10.25	3.24	0.79	8.26	9.27	5.42	3.02
Fallow	150.4	93.8	14.8	1.9	20.20	10.02	3.20	0.68	7.45	9.50	4.62	2.77
CD (P=0.05)	16.1	11.9	7.9	2.6	2.307	1.053	0.241	0.162				

Table 2. Effect of different treatments on organic matter decomposition [CO_2 (mg) g^{-1} soil 72hr^{-1}] and dehydrogenase activity (TPF µg 24 hr^{-1}g^{-1} soil)

Treatments	At Initial stage		At flower initiation stage		At harvest stage	
	CO_2-C	DHA	CO_2-C	DHA	CO_2-C	DHA
50%NPK	0.09	4.42	0.10	6.41	0.09	5.45
100%NPK	0.11	5.54	0.11	6.48	0.11	6.00
150%NPK	0.15	6.00	0.18	6.73	0.15	6.29
100%NPK+HW	0.10	5.56	0.12	5.60	0.11	5.80
100%NPK+Zn	0.12	5.65	0.14	6.68	0.12	6.23
100%NP	0.10	5.88	0.14	6.62	0.12	6.10
100%N	0.10	5.51	0.13	5.98	0.11	5.85
100%NPK+FYM	0.18	6.29	0.23	7.02	0.19	6.35
100%NPK-S	0.09	5.56	0.11	5.87	0.10	5.75
Control	0.08	4.32	0.09	4.98	0.08	4.61
CD (P=0.05)	0.01	0.37	0.01	0.53	0.01	0.39

Table 3. Effect of different treatments on microbial population (CFUx10^{4}g^{-1} soil)

Treatments	Before sowing of Soybean				After harvesting of Soybean			
	Azo.	PSB	NM	NB	Azo.	PSB	NM	NB
50%NPK	30.34	12.04	15.98	13.97	39.25	13.30	18.60	17.80
100%NPK	42.10	14.95	22.58	15.88	52.42	17.85	25.15	18.57
150%NPK	54.27	20.64	26.11	20.18	68.11	25.07	34.61	25.32
100%NPK+HW	44.41	13.41	20.92	15.18	50.74	16.46	23.03	17.71
100%NPK+Zn	45.23	13.81	24.70	17.73	54.31	19.02	26.11	21.15
100%NP	43.28	17.25	24.11	17.20	51.57	19.40	30.12	20.05
100%N	35.73	13.24	23.93	18.87	41.03	15.11	28.01	22.19
100%NPK+FYM	60.03	23.08	28.14	23.08	78.76	30.23	39.07	32.34
100%NPK-S	49.20	14.37	18.07	17.01	51.17	16.13	21.63	18.77
Control	25.50	8.96	11.39	10.58	26.49	10.03	14.12	13.85
CD (P=0.05)	7.44	2.57	2.60	2.21	6.50	2.82	3.88	2.96

Enzymatic properties

Conservation tillage, three-irrigation regime, and nutrient treatments, where 50% FYM + 25% GM + 25% biofertilizer had been used as a replacement for RDN (as urea) or where urea was replaced with 25% FYM or 25% GM or 25% biofertilizer or 25% sewage sludge, improved activities of important soil enzymes (glucosidase, urease, and phosphatase), and overall microbial activity, e.g. SR, SMBC, and DHA, following rice cultivation (Sharma et al. 2015). Among the various treatments dehydrogenase activity and organic matter decomposition (Table 2) was found maximum in 100% NPK+FYM. The maximum activity was observed at flowering stage as compared to initial and harvest stage.

The improvement in enzymatic activity could lead to improvement in mobility of nutrients in the soil. Sharma et al. (2015) reported in rice crop, a significantly greater soil alkaline phosphatase activity (105%) was noted in zero-tillage plots compared to conventional-tillage plots Among the INM treatments, the highest rate of soil alkaline-phosphatase activity was recorded for the treatment where 25% N requirement was met through FYM of N (i.e. 135.54 µg PNPP g^{-1} soil h^{-1} soil), followed by the treatment where urea was used (i.e.134.36 µg PNPP g^{-1} soil h^{-1} soil), which was further followed by the treatment where whole organic source of N was used as RDN (i.e.134.03 µg PNPP g^{-1} soil h^{-1}). Significantly ($p < 0.05$) higher soil alkaline-phosphatase activity in treatments with organic amendments was detected than in the control plots. For any given nutrient-management practice, the three different water regimes significantly increased the soil alkaline phosphatase activity. Soil receiving RDN as urea in the three-irrigation treatment recorded 8 and 24% higher soil alkaline-phosphatase activity compared to two- and five-irrigation treatments, respectively. The use of sole organic source for N with three irrigation regimes gave statistically similar result as that from the plots where urea was used as the source of RDN. The use of RDN as urea caused a 9% increase compared to the control. Other plots receiving RDN in various forms also had higher soil alkaline-phosphatase activity compared to control plots.

Microbial Population (CFUx$10^4$$g^{-1}$ soil)

The primary agents of decomposition are fungi and bacteria which, in their turn, provide a food source for a variety of microbivorous predators occupying the lower row of the larger box. A wide range of experimental studies have shown the importance of these organisms in regulating the rate of decomposition through the release of nutrients and by stimulating microbial population turnover through their feeding activity (e.g. papers in (Coleman & Hendrix, 2000). Microbial population (*Azotobacter*, PSB, *Nitrosomonas* and *Nitrobacter*) was significantly improved with increasing level of fertilizers. Further, maximum microbial population was found in 100% NPK+FYM treatment and minimum was in control (Table 3).

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Soil test based fertilizer recommendations for targeted yield of crops in MP

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Abstract

Innovated technology adopted by the developed countries for bagging higher yields with high inputs have forgotten the adverse effect on soil and environment ultimately proving hazardous to human health. This is all because of indiscriminate use of chemical fertilizers under intensive production system. Fertilizer recommendation based on soil test has now been well recognized as one of the scientific way of finding out fertility status of soil and predicting the nutrient requirement of crops. Soil test based fertilizer recommendation for farmers of varying capabilities is the basic concept of STCR. Targeted yield approach has been found beneficial which recommends balanced fertilization or soil available nutrient status and crop need. Works on four decades of STCR have been summarized the work done on different soils with different crops generating various fertilizer adjustment equations for fixed targeted yield of crops of M.P. has been discussed.

Keywords: Balance fertilization, fertilizer adjustment equations, nutrient requirement, STCR, targeted yield.

Feeding the growing population is a challenge to the agriculture scientist because of the shrinking arable lands to cope up with the traditional farming practices. Developed countries for adaptation of modern innovated technology bagging higher production have been adopted forgetting the long run curse of the blessing. Now the modern agriculture technology is addicted to the agriculture chemicals like fertilizers, pesticides, growth promoting hormones etc., which have adversely effected environment and proved hazardous to human health and animals with unbalanced ecology.

Indiscriminate and imbalanced use of chemical fertilizers has caused the problems like lowering the yield, depletion and degeneration of soils, contamination of water nutritional deficiency, increase in pests and insects. Under intensive production system though it helping increasing crop productivity, but adversely affects the soil health and environment. It is essential that the nutrient demand of a crop to produce a target yield replenishes the amount of nutrients removed from soil. Fertilizer is one of the costliest, most important agricultural inputs for increasing crop production and the use of right amount of fertilizer is fundamental for farm profitability and environmental protection (Kimetu et al. 2004). It plays a crucial role to meet the nutrient requirement of the crop, hold great promise in securing high level of crop productivity and persistent depletion in posing a greater threat to the sustainable agriculture.

Fertilizer recommendation based on soil testing is well recognized as one of the scientific means for quick characterization of the fertility status of the soil and predicting the nutrient requirement of crops. Soil testing is now accepted as a procedure for the recommendation of doses and kind of fertilizer. But the soil testing becomes a useful tool only when it is based on intimate knowledge of soil-crop-variety-fertilizer-climate-management interaction for a given situation (Kanwar 1971). Soil test based fertilizer recommendations for farmers of varying capabilities is the basic concept of STCR which is considered practically useful. The targeted yield approach is unique in developing fertilizer recommendation for desired targeted yield based on the farmers resource availability and the farming community as this practice leads to balanced use of fertilizer for better crop yield and sustainable soil health. One of the reasons for lower production of crops is imbalanced fertilization of N, P and K nutrients. Targeted yield approach (Ramamoorthy et al. 1967) has been found beneficial which recommends balanced fertilization considering the soil available nutrient status and the crop need.

Balanced nutrition does not mean the application of N, P and K alone in certain proportion through fertilizer, but it should ensure that the nutrients in available forms are in adequate quantity and is required in proportion in the soil to meet the requirement of the crops for obtaining desired levels of yield. Nutrients available in soil are rarely present in adequate amount and in balanced proportion to meet the nutrient requirement of the crops. This requires intervention by application of external sources of nutrients i.e. fertilizers and manures. Soil test provides the requisite information about the amount of nutrients available in the soil and their imbalances, while a fertilizer recommendation aims at correcting the imbalances in nutrients according to crop requirements. The fertilizer recommendations based on qualitative / quantitative approaches do not give expected yield responses. Therefore, a refined method of fertilizer recommendation for varying soil test values has been developed by JNKVV, Jabalpur centre of AICRP on Soil Test Crop Response Correlation for some field crops.

Soil testing was accepted long back as a tool for farmers through practicing balanced use of the nutrient management favourably affects the physical, chemical and biological environment of soil thus ultimately increases the soil fertility. The use of inorganic fertilizers has received considerable attention in the past with a hope of meeting the farmer's economic need as well as maintaining favourable ecological conditions on long-term basis (Kumar et al. 2007). It is also a great promise in securing high level of crop productivity and also to protect soil health from deterioration and pollution hazards. The impact of increased inorganic fertilizer use on crop production has been large, but ever increasing cost of energy is an important constraint for increased use of inorganic fertilizer. Nitrogen, phosphorus and potassium are major essential plant nutrients and prove key input for increasing crop yield (Dastan et al. 2012).

In 1947 Stewart in India was first to attempt in relating the knowledge of soil testing to the judicious use of chemical fertilizers, having initiating the soil fertility and fertilizer use project in 1953. The soil testing laboratories in1955-56 was established under Indo-US Operational Agreement and in 1965, five of existing laboratories were strengthened. Soil test helps in segregating nutrient deficient areas and marking them capable of supplying the adequate nutrients for plant growth optimum crop production.

During the last Four Decades

The project was initiated at Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur during the year 1967 with the key mandate of establishing a significant relationship between soil tests and crop response to fertilizer on representative soils in different soil and agro-climatic regions of the state and thus provided a basis for fertilizer recommendations based on soil testing for enhancing the productivity, profitability and soil health in sustainable manner and provided a basis for fertilizer recommendations for fertilizer availability and/or credit facilities to the farmers. Crop studied with the objectives during period are:

1. Cereals: Rice, Wheat, Maize, Jowar and Bajra
2. Pulses: Chick pea, Pigeon pea, Urid, Lentil and Field pea
3. Oilseeds: Soybean, Linseed, Niger, Safflower, Mustard and Sunflower
4. Cash crops: Sugarcane, Cotton, Onion and Garlic
5. Medicinal crop: Chandrasur

Work for STCR project mainly focused on screening of various soil test methods for available N, P and K to find out suitable methods which give best correlations with uptake of nutrient and grain yield was done. Among the various methods used for available nitrogen by alkaline permanganate (Subiah and Asija 1956), organic carbon by potassium dichromate (Walkley and Black 1934), NO_3-N, NH_4-N, $Ca(OH)_2$ -N and total-N. Organic carbon by potassium dichromate and available nitrogen by alkaline permanganate methods were found best correlated with yield. Olsen's method for determination of available P in medium black, deep black and alluvial soils was found to be most suitable, while Bray's 1 method for available P was best suited for red and yellow soils. Ammonium acetate, Nitric acid, Hanway and Heidal (1952) methods were estimated in available K for suitability. However, ammonium acetate method was found best for the determination of available potassium in soils.

Assessment of rice, wheat and maize productivity under pot and field experiments on soil test based fertilizer application were conducted in alluvial, medium black and deep black soils having contrast fertility gradients in terms of available N, P and K and to evolve a basis for making specific fertilizer recommendation.

The STCR research work in India gained popularity because of the pre set yield targets stating "The genesis, rational methodology and applicability of this inductive approach for adjustment of fertilizer dose according to the soil test value for different purpose has been detailed out in various reports Ramamoorthy et al. (1967), Ramamoorthy (1975), Ramamoorthy and Velayutham (1971, 1973 and 1974), Velayutham (1979) and Randhawa and Velayutham (1982) with the purpose for including fertilizer doses for maximizing yield and profit on investment on fertilizer nutrients for desired targeted yield for maintain soil fertility under multiple cropping, compilation of reports by Subba Rao and Srivastava (2001) and Dey (2014).

Development of basic data

Application of fertilizers according to the need of the situation also helps in maintenance of soil fertility and ensures sustainability of crop production. The data sets generated to develop the soil test based fertilizer adjustment equations (STBFAE) for targeted yield of major crops were:

(i) Nutrient requirement (NR) in kg q-1 of economic produce (grain)

(ii) Per cent contribution from soil available nutrients (% CS)

(iii) Per cent contribution from applied fertilizers (% CF)

Fertilizers alone

(i) Nutrient requirement (NR) of N, P and K for grain production

$$NR = \frac{\text{Total uptake of nutrient (kg)}}{\text{Grain yield (q)}}$$

$$\% CS = \frac{\text{Total uptake in control plots (kg ha}^{-1}\text{)}}{\text{Soil test values of nutrients in control plots (kg ha}^{-1}\text{)}} \times 100$$

Calculation of fertilizer dose

To calculate the fertilizer dose for the major nutrients in the Vertisol with the help of fertilizer adjustment equations developed for Typic Hapluster. The basic module used for developing the transfer function to calculate nutrients dosing at variable soil test value for targeted yield of selected crop and above basic data are transformed into workable adjustment equation as follows:

Nutrients through fertilizer alone

$$\text{Fertilizer Dose (FD)} = \frac{NR \times 100}{\% CF} \times T - \frac{\%CS}{\% CF} \times STV$$

= a constant × yield tearget (q ha^{-1}) - b constant × soil test values (kg ha^{-1})

Nutrients through FYM alone

$$FD = \frac{NR \times 100}{\% CF^*} \times T - \frac{\%CS}{\% CF^*} \times STV - \frac{\% CFYM}{\% CF} \times$$

$$\times \text{ Nutrients in FYM} \times \text{FYM}$$

where,

NR = Nutrient requirement in kg q^{-1} of grain production

%CS = Per cent contribution of nutrients from soil

%CF = Per cent contribution of nutrients from fertilizer

%CFYM = Per cent contribution of nutrients from FYM

%CF* = Per cent contribution of nutrients from fertilizer with FYM

TUN = Total uptake of nutrients (kg ha^{-1})

STV = Soil test values (kg ha^{-1})

FD = Fertilizer dose (kg ha^{-1})

The targeted yield approach on soil test based cropping system presides appropriate advice to farmers promoting FUE for balanced use of fertilizer for better utilization soil fertilizer recommendation for different crops has been verified for various situations having similar soil type and agro-eco regions. The target fixed with different crops and the range of experimental yield produced which must be based on the crop yield potential limits. The soil test values cannot be extrapolated there needs to be corrections of secondary micronutrient deficiencies which should be done separates following the good agricultural practices for increasing for the productivity of crops.

The calculation of fertilizer dose through fertilizers alone and in integrated plant nutrient supply can easily

$$CF = \left(\frac{\text{Total uptake of nutrient in fertilizer treated plots (kg ha}^{-1})}{} - \text{Soil test value of nutrients in fertilizer treated control plots (kg ha}^{-1}) \times CS \right)$$

With FYM

$$\%CF = \frac{CF}{\text{Fertilizer dose (kg ha}^{-1})} \times 100$$

$$\%CFYM = \frac{\text{TUN from control plots with FYM (kg ha}^{-1}) - \text{STV of nutrients from control plots with FYM (kg ha}^{-1}) \times \frac{\%CS}{100}}{\text{Total amount of nutrient (kg ha}^{-1}) \text{ added through FYM}} \times 100$$

$$\%CF^{*} = \frac{\text{TUN from treated plots with FYM (kg ha}^{-1}) - \text{STV of nutrients in treated plots with FYM (kg ha}^{-1}) \times \frac{\%CS}{100} \text{ Nutrients added Through FYM (kg ha}^{-1}) \times \frac{\%CFYM}{100}}{\text{Fertilizer nutrient applied (kg ha}^{-1}) \text{ in treated plots with FYM}} \times 100$$

be done after substituting the values obtained from the equations, nutrient required for N, P and K divide of by response from fertilizer for example in case of soybean the equations of FAE is:

$$FN = 5.19\ T - 0.48\ SN$$

$$FP_2O_5 = 5.20\ T - 4.00\ SP$$

$$FK_2O = 3.90\ T - 0.22\ SK$$

The equation developed for prescribing fertilizer doses for soybean crops for nitrogen, phosphorus and potash have been calculated for application of NPK (kg ha^{-1}) through different farmers. To prescribe the fertilizer dose for wheat yield of a fixed target of 60 q ha^{-1} in the medium black soil of Jabalpur. The fertilizer doses required for is substituted in the fertilizer prescription equations. The fertilizer doses required is more in the flat prescription than the fertilizer doses required under IPNS.

Experiments with rice and wheat conducted under soils of 12 locations (neutral to alkaline in reaction, low to medium in available N, low in available P and medium to high in available K) across the Madhya Pradesh showed that alkaline permanganate (available N) and Olsen's (available P) methods were well correlated with yield of wheat while Olsen's P was significantly correlated with paddy field. Results clearly indicated that rice responded well up to 100 kg N ha^{-1}. It was found that requirement of N, P and K for producing one quintal of grains of wheat were 2.10, 0.45 and 4.10 kg while for paddy the values were 2.10, 0.50 and 5.10 kg, respectively. Regar and Singh (2014) reported that the nutrient requirements (kg q^{-1}) of N, P_2O_5 and K_2O for producing one quintal of rice yield in Inceptisol were found to be 2.56, 0.56 and 2.21, respectively. Similar result also found in Bhargava (2001) was observed that the nutrient requirements for the production of one quintal of rice grain were 1.57 kg N, 0.35 kg P_2O_5, and 3.8 kg K_2O in Vertisols. The per cent contribution of available N, P and K content of soils in wheat was 23.2, 67.5 and 16.1 whereas, applied fertilizers contributed 66.8, 19.1 and 98.9 per cent respectively. However, for paddy contribution were 22.4, 75.7 and 30.1 and 31.0, 13.1 and 88.5 per cent from soil and fertilizer, respectively. Bhargava (2001) reported that the fertilizer use efficiencies by rice were 37, 10, and 180% for N, P_2O_5, and K_2O, respectively and in soil those were 17, 18, and 22% for N, P_2O_5, and K_2O, respectively. Similar result also found by Rao et al., (2001) was conducted a field experiment to evolve soil test based fertilizer recommendation for N at Karimnagar district of Andhra Pradesh. It may be concluded that applied fertilizer N contribute less in rice as compared to wheat.

Based on the results of five years of experiments, soil test based fertilizer adjustment equations (STBFAE) were developed for targeted yield of Paddy and Wheat and subsequently the follow-up trials were also conducted at research farm and farmer's field for verifying the suitability of the equation developed for different crops.

Soil Test Based Fertilizer Adjustment Equations for

Rice

$FN = 4.25\,T - 0.45\,SN$

$FP_2O_5 = 3.55\,T - 4.89\,SP$

$FK_2O = 2.10\,T - 0.18\,SK$

Wheat

$FN = 4.40\,T - 0.40\,SN$

$FP_2O_5 = 4.00\,T - 4.58\,SP$

$FK_2O = 2.53\,T - 0.16\,SK$

During the next five years (1972-73 to 1976-77) follow-up trials on Rice and Wheat were conducted at research farm, Jabalpur and farmer's fields for verification and validation of STBFAEs for targeted yields of rice and wheat crops. Main and follow up trials on Soybean, Chick pea and Sugarcane were also conducted at research farm and farmer's fields for generation of basic data sets to develop STBFAE for soybean and chick pea.

Soil Test Based Fertilizer Adjustment Equations for

Soybean

$FN = 5.19\,T - 0.48\,SN$

$FP_2O_5 = 5.20\,T - 4.10\,SP$

$FK_2O = 3.90\,T - 0.22\,SK$

Chick pea

$FN = 3.73\,T - 0.18\,SN$

$FP_2O_5 = 5.00\,T - 2.50\,SP$

$FK_2O = 3.80\,T - 0.17\,SK$

Sugarcane

$FN = 0.57\,T - 1.66\,SN$

$FP_2O_5 = 0.23\,T - 11.73\,SP$

$FK_2O = 0.16\,T - 0.53\,SK$

The results of the follow up trials indicated a need of further calibration of the STBFAE as the lower yield targets were over achieved while the higher yield targets fixed were under achieved with the deviation of ± 10 per cent.

During 1977-78 to 1981-82 field experiments on Rice, Maize, Chick pea, Cotton, Pigeon pea and Linseed were conducted to generate the data sets for development/ refinement of STBFAE. However, fallow up trials on soybean, chickpea, paddy and wheat were also conducted at research farm, Jabalpur and at the farmer's field in different districts. It was found that in the beginning the per cent contribution of available nutrients from soil was more while letter on the per cent contribution of nutrients from fertilizers was more. Similar type of result was reported for finger millet by Kadu and Bulbule (2007). The results obtained from experiments are given below:

Soil Test Based Fertilizer Adjustment Equations for

Maize

$FN = 4.40\,T - 0.23\,SN$

$FP_2O_5 = 2.38\,T - 1.40\,SP$

$FK_2O = 2.07\,T - 0.08\,SK$

Pigeon pea

$FN = 4.87\,T - 0.37\,SN$

$FP_2O_5 = 5.34\,T - 3.47\,SP$

$FK_2O = 3.62\,T - 0.16\,SK$

Linseed

$FN = 8.48\,T - 0.46\,SN$

$FP_2O_5 = 7.38\,T - 5.08\,SP$

$FK_2O = 6.59\,T - 0.25\,SK$

Cotton

$FN = 11.33\,T - 0.59\,SN$

$FP_2O_5 = 6.45\,T - 4.40\,SP$

$FK_2O = 4.71\,T - 0.14\,SK$

During the years 1982-83 to 1986-87 field experiments on Niger (Jabalpur), Sorghum (Indore), Pearlmillet (Gwalior) and Safflower (Jabalpur) were conducted to generate the primary datasets for development of STBFAEs and validation of developed equations for paddy, wheat, soybean, chick pea, maize, pigeon pea and linseed crops.

Soil Test Based Fertilizer Adjustment Equations for

Niger

$FN = 11.80\,T - 0.17\,SN$

$FP_2O_5 = 11.17\,T - 3.52\,SP$

$FK_2O = 10.52\,T - 0.16\,SK$

Sorghum

$FN = 4.48\,T - 0.38\,SN$

$FP_2O_5 = 3.99\,T - 2.29\,SP$

$FK_2O = 3.51\,T - 0.16\,SK$

Pearlmillet

$FN = 10.90\,T - 0.78\,SN$

$FP_2O_5 = 5.22\,T - 4.00\,SP$

FK_2O = 4.19 T - 0.35 SK

Safflower

FN = 9.11 T - 0.53 SN

FP_2O_5 = 6.27 T - 2.19 SP

FK_2O = 9.27 T - 0.38 SK

Field experiments on Soybean, Pigeon pea, Mustard and Urid were further conducted during 1987-88 to 1996-97 for refinement in STBFAEs. Follow up trials on paddy, wheat, soybean, maize, pigeon pea, linseed and chickpea crops were also conducted at research farm, Jabalpur and farmer fields for calibration and validation of developed STBFAEs. During this period of time a total of 67 front line demonstrations on various crops were also conducted in farmer's participatory mode to disseminate and popularize the technology among practicing farmers.

Soil Test Based Fertilizer Adjustment Equations for

Mustard

FN = 9.11 T - 0.37 SN

FP_2O_5 = 3.60 T - 0.75 SP

FK_2O = 4.66 T - 0.13 SK

Urid

FN = 7.82 T - 0.39 SN

FP_2O_5 = 5.36 T - 2.62 SP

FK_2O = 10.83 T - 0.44 SK

During the years 1997-98 to 2001-02, field experiments on sunflower was initiated to generate the

Parameters	Rice kg of nutrients			Maize kg of nutrients			Chick pea kg of nutrients			Cotton kg of nutrients		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Required to produce 100 kg of grain	1.70	0.31	3.46	3.0	1.9	6.3	4.5	0.35	6.5	9.81	1.35	10.59
% Contribution from soil available nutrients	18	37	20	3.4	8.8	2.3	35	30	40	42	56	22
% Contribution from applied fertilizers nutrients	37	21	186	27.4	17.9	87.8	180	20	150	36	12	134

Crops	FN	FP_2O_5	FK_2O
Paddy	4.25 T - 0.45 SN	3.55 T - 4.89 SP	2.10 T - 0.18 SK
Wheat	4.40 T - 0.45 SN	4.00 T - 4.58 SP	2.53 T - 0.16 SK
Soybean	5.19 T - 0.48 SN	5.20 T - 4.10 SP	3.90 T - 0.22 SK
Chick pea	3.73 T - 0.18 SN	5.00 T - 2.50 SP	3.80 T - 0.17 SK
Sugarcane	0.57 T - 1.66 SN	0.23 T - 11.73 SP	0.16 T - 0.53 SK
Maize	4.40 T - 0.23 SN	2.38 T - 1.40 SP	2.07 T - 0.08 SK
Pigeon pea	4.87 T - 0.37 SN	5.34 T - 3.47 SP	3.62 T - 0.16 SK
Linseed	8.48 T - 0.46 SN	7.38 T - 5.08 SP	6.59 T - 0.25 SK
Cotton	11.13 T - 0.59 SN	6.45 T - 4.40 SP	4.71 T - 0.14 SK
Niger	11.80 T - 0.17 SN	11.17 T - 3.52 SP	10.52 T - 0.16 SK
Jowar	4.48 T - 0.38 SN	3.99 T - 2.29 SP	3.51 T - 0.16 SK
Bajra	10.90 T - 0.78 SN	5.22 T - 4.00 SP	4.19 T - 0.35 SK
Safflower	9.11 T - 0.53 SN	6.27 T - 2.19 SP	9.27 T - 0.38 SK
Mustard	9.11 T - 0.37 SN	3.60 T - 0.75 SP	4.66 T - 0.13 SK
Urid	7.82 T - 0.39 SN	5.36 T - 2.62 SP	10.83 T - 0.44 SK
Sunflower	12.54 T-0.64 SN-0.59 ON	3.60 T-1.24 SP-1.36 OP	8.09 T-0.30 SK-0.35 OK
Lentil	5.84 T-0.16 SN-0.27 ON	2.10 T-0.66 SP-0.79 OP	4.40 T-0.09 SK-0.77 OK
Field Pea	7.54 T-0.76 SN-1.04 ON	3.88 T-1.51 SP-1.48 OP	6.38 T-0.24 SK- 0.67 OK
Onion	9.28 T-0.80 SN-0.52 ON	3.03 T-0.79 SP-0.90 OP	4.34 T-0.20 SK-0.45 OK
Garlic	7.45 T-0.67 SN- 0.80 ON	2.73 T-0.65 SP-1.50 OP	5.74 T-0.28 SK-0.51 OK
Chandrasur	8.03 T-0.25 SN-0.96 ON	11.35 T-3.11 SP-0.65 OP	16.45 T-0.37 SK-1.54 OK

data set for development of STBFAEs under Integrated Plant Nutrient Supply (IPNS) mode. While another experiment on paddy-wheat and soybean-wheat sequences were also started to establish the relationship between soil tests based fertilizer application in cropping sequence. However, follow up trials on paddy, wheat, soybean, mustard linseed and chick pea crops were also conducted at research farm and farmer fields for calibration and validation of developed STBFAEs. During this period 29 front line demonstrations on various crops were also conducted at farmer's fields in Jabalpur, Narsinghpur and Seoni districts.

Soil Test Based Fertilizer Adjustment Equations for Sunflower under IPNS mode:

$FN = 12.54\ T - 0.64\ SN - 0.59\ ON$

$FP_2O_5 = 3.60\ T - 1.24\ SP - 1.36\ OP$

$FK_2O = 8.09\ T - 0.30\ SK - 0.35\ OK$

Field experiments on Lentil, Field pea; Onion and Garlic under IPNS mode were conducted during 2002-03 to 2006-07 to generate the data set on soil test crop response correlation and to develop the STBFAEs for these crops. While, follow up trials at research farm and farmer's fields were also conducted on soybean, paddy, wheat under STCR and sunflower under IPNS mode for verification of the STBFAEs. During this period a total of 36 FLDs on paddy, soybean, urid, wheat, chick pea and lentil were also conducted at farmer's fields in Mandla, Narsinghpur and Jabalpur districts.

Soil Test Based Fertilizer Adjustment Equations for IPNS mode

During the years 2007-08 to 2011-12, field experiments on Chandrasur under IPNS mode was conducted at research farm, Jabalpur to generate the data set on soil test crop response correlation and to develop the STBFAEs while, verification and follow up experiments on soybean, paddy, wheat, onion and garlic were conducted under IPNS and STCR mode to calibration of developed equations. A total of 32 FLDs on paddy, wheat, lentil, chickpea and soybean were also conducted at farmer's fields during this period to disseminate and popularize the use of soil test based fertilizer adjustment equations for achieving targeted yield of crops.

Soil Test Based Fertilizer Adjustment Equations for Chandrasur under IPNS mode

$FN = 8.03\ T - 0.25\ SN - 0.96\ ON$

$FP_2O_5 = 11.53\ T - 3.11\ SP - 0.65\ OP$

$FK_2O = 16.45\ T - 0.37\ SK - 1.54\ OK$

Ready-reckoners from fertilizer adjustment equations for all the major crops for which the calibrations among soil tests and their response to fertilizer have been prepared so that the officials in soil testing laboratories can make more efficient and judicious fertilizer recommendations. Fertilizer adjustment equations for targeted yields and economic yields based on soil test values have been worked out for major cereals, pulses and oilseeds. Thus fertilizer recommendations can be given to the farmers of all economic status. The general observation is that low targets give higher benefit/ cost ratio, yard stick value and higher profit than general recommended dose.

Since inception of the project following STBFAEs under STCR and IPNS mode have been developed and demonstrated at farmer's fields for minimization of fertilizer costs, improving the productivity of crops and sustaining the soil fertility status.

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Innovations in reclamation and management of salt-affected soils

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Abstract

Soil conditions, which do not provide a suitable medium for plant growth, are considered as degradation of soil. Some of these are either too acidic or alkaline and special measures have to be adopted to bring them in proper condition before any crop can be raised on them. In arid regions where rainfall is low and temperature is high, soils become saline or alkaline due to accumulation of salts in the surface soil. Earlier and has been widely adopted and replicated in many states of India and installed manually or mechanically at a design spacing and depth below soil surface to control water table and help in the leaching process. The technology has a benefit-cost ratio (BCR) of about 1.36 and internal rate of return (IRR) of 20%. Alkaline or saline-alkaline natured soils can be reclaimed through physical, chemical and biological processes. Climate change can be addressed by converting the coastal deserts into green belts. Plants that can survive in harsh conditions (dust storms, sand storms, and saline water irrigation) can be chosen and cultivated. They can become large sinks for carbon dioxide over a period of time. Resource conservation technologies and use of solid waste /spent wash /molasses to reclaim saline alkali soils take care of environmental issues.

Management of saline alkali soils under irrigated condition also requires micro level care such as laser land leveling activities; proper bunding and precision farming are required to be initiated on farmer's fields. Amendments like pyrites, or acid powder application on the surface followed by light irrigation to achieve field capacity moisture regime so as to have maximum oxidation of pyrites or acid powder while gypsum is mixed in plough layer made much effective and fast reclamation. Plantation of Marvel, Para and Karnal grasses for a period of three to four years are found more beneficial in amelioration of the soil. Soil ESP decreased up to tune of 15-20 unit and thus it reduced the quantity of gypsum up to about 8 to 12 t ha^{-1}. Improved surface irrigation design guidelines and use of pressurized irrigation systems including drip and sprinkler irrigation have been established to ensure light and frequent irrigations essential for the salt affected soils. The area covered by salt tolerant varieties of rice, wheat and Indian mustard has been estimated to be more than 60,000 ha.

Raised and sunken bed system, textural modification, raising of grasses, and reclamation through afforestation are very innovative approaches that can be utilized very efficiently to reclaim alkali soils even under rain fed conditions. Recent technological approaches of reclamations like, microbial reclamation and biotechnological approaches are found good tools for raising satisfactory crop production.

Keywords: Soil salinity, ESP, innovative managements, drainage, grasses, raised sunken bed

FAO (2005) estimated that globally more than 800 million ha of land are salt- affected. Consisting of 397 million ha affected by salinity and 434 million ha by sodicity. This represents more than 6% of the total land area. Most of this salinity and almost all the sodicity has been caused by natural process. But a significant portion of agricultural land has become degraded due to land clearing and injudicious use of irrigation water. It has been estimated that 32 million ha of dryland agriculture area has been affected by secondary salinity (of varying degrees) which is only 2% of the total area. However, in case of irrigated areas 20% of the area has been thus affected which amounts to 45 million ha. It is worthwhile to note that irrigated one is around 15% of the cultivated area but it produces one third of the global food production. The productivity of irrigated area is generally more than double of rain fed areas.

Agricultural production in the arid and semi-arid regions of the world is limited by poor water resources, limited rainfall, and the detrimental effects associated with an excess of soluble salts, constrained to a localized area or sometimes extending over the whole of the basin. In order to minimize vagaries of arid weather, bring more land under irrigation, and produce and stabilize greater yields per unit area, numerous water development projects have been commissioned all over the world. Extension of irrigation to the arid regions, however, usually had led to an increase in the area affected by shallow water tables and to intensifying and expanding the hazards of salinity. This is because irrigation water brings in additional salts and releases immobilized salts in the soil through mineral dissolution and weathering, and losing water volumes through evapo-transpiration and concentrating the dissolved salts in soil solution. Fertilizers and decaying organic matter also serve as additional salt sources. Atmospheric salt depositions, though varying with location, may be an important source along the coasts. The relative significance of each source in contributing soluble salts depends on the natural drainage conditions, soil properties, water quality, soil water, and agronomic management practices followed for crop production.

Salt-affected aoils and their management

Out of 329 million hectares of land in the country, about 175 million ha. (53 %) is suffering from degradation in some form or the other. There are 6.75 M ha of salt-affected soils in India. Waterlogging affects another 8.52 M ha mainly in the irrigation commands, which includes some of the saline-alkali soils also. In Haryana, parts of Punjab, Rajasthan, Uttar Pradesh, Gujarat, Maharashtra, Madhya Pradesh, Karnataka, Andhra Pradesh and Tamil Nadu, substantial areas of good irrigated lands are affected by saline-alkali and waterlogging problems.

There are several reasons for development of salinity in the soils, such as excessive and uncontrolled irrigation accumulation of salts in the top layer due to evapo-transpiration in arid conditions waterlogging conditions in perennial river basins/ irrigation sources due to seepage excessive use of chemical fertilizers containing chlorides sulfates etc. poor drainage conditions. The problem of salinity, alkalinity and waterlogging deserves special treatments based on the local conditions and soil texture, structure and topography. When water is used for agricultural purposes, in most cases more than 50 percent goes waste. There is seepage due to unlined channels, pipes, ditches and runoff fields and water percolates in to the soil and accumulates in uneven depressions. Water dissolves naturally occurring salts in the rocks and soils and carries them to the surface of the soil, where the water molecules evaporate, leaving the salts to accumulate near the surface. Excess salts, eventually will lead to alkali problem.

The growing problem of salinity-alkalinity should be minimized or eliminated as early as possible since it is growing at the rate of 10% every year. Soil salinity has become an acute problem rendering crop productivity to decline or making the soil unfit for cultivation. Irrigation has both sides of bane and boon. Unscientific irrigation has endangered many favorable environmental conditions and human health. In the absence of adequate drainage provisions, with the introduction of new irrigation projects and also the faulty water management practices on the farms, additional area will turn salty each year.

Saline soils and their management

Saline soils contain soluble salts which impair the soil productivity. Such soils can normally be identified by the presence of white crusts of salts on the surface of the land area and poor crop growth. Internal drainage of such soils will not be bad. By opening adequate drains, such soils can be improved. Drainage becomes a problem when the soil is waterlogged. In such soils, the aeration will be a limiting factor and microbial activities will be hindered and hence the removal of excess water from such waterlogged areas becomes very essential.

On the other hand, sodic soils containing excess sodium become extremely waterlogged as the soil porosity is lost and water does not percolate down easily / quickly. In case of excess sodium contents of the soil, it has to be treated with soil amendments such as gypsum, sulphur etc., and then the salts have to be drained. In summary, the basic requirement is the provision of adequate and appropriate drainage system. Black soils are worst affected as they have poor drainage due to high clay content.

Provision of subsurface drainage

In the areas of high salinity, it is essential to bring down the salinity by leaching the salts. It is also necessary to lower the water table if it is shallow and saline and maintain it below the critical depth to prevent re-salinization. Drainage of agricultural lands can be achieved through a package of the following measures:

- Intercept the flood and seepage water from above by opening sufficiently large drain (called interceptor drain) and divert the same from affecting the holding.
- Construct a good feeder drain (called vertical disposal drain) in the field, along the slope and connect it with the common drain or natural drains such as nallas.
- Construct adequate drains in the plots and crop fields and connect them to the vertical disposal drain.

- Provide drop pits and stone pitching in erodible spots.
- If the soils are alkali in nature, apply sufficient quantities of chemical and organic amendments, based on soil test results.

Management of waterlogged saline soils

Out of the various methods of drainage systems and reclamation of saline soils, subsurface drainage system will be most effective and long lasting particularly in heavy soils. This system includes laying of perforated PVC pipes underground and draining the accumulated salts along with water to a common outlets/well. The drained water will be tested for its quality and if found suitable, the same water will be recycled to the crop. There are different dimensions of perforated and un-perforated pipes (blind pipes) available with reputed plastic manufacturing companies, with BIS specification. It is an excellent system for all irrigated agriculture crops like sugarcane, yielding orchards, plantations and sensitive crops like turmeric.

Benefits of drainage

Flooding and loss of seeds and fertilizers are largely eliminated. Thus making the land ready for cultivation. It avoids permanently ponded areas and swamps etc. It removes excess water, salinity and alkalinity from the soils It keeps the soil pores open and thus increase both infiltration and permeability rates of the soil. Where underground drainage is practiced, there will be a better physical condition of the soil that permits vigorous and deeper root growth and as a result drought tolerance; and improves earthworms, soil microbes and other biological properties; thus better health of the soil. It also reduces certain crop diseases.

Management of saline-alkali soils in Indo- Gangetic plains

The concept of sustainable development implies development that meets the present needs of large population without compromising the ability of future generations to meet its own needs. The primary goal of sustainable development is to minimize any adverse impact on the quality of the atmosphere and water and the terrestrial environment. The increased awareness due to shortage of usable water and land in different parts of worlds has resulted in greater attention on water and degraded land management related issues.

Chemical reclamation

Several soil amendments viz. gypsum, pyrites, aluminum sulphate, sulphuric acid and acid powder were found to be equally effective when applied on the basis of sulphur or calcium content. If calcium carbonate content is low (1.5%), use of gypsum is advocated. Flushing out of excess soluble salts should follow the application of amendment @ 70-80 % of gypsum requirement. If finance is a constraint split dose of gypsum @ 50% of gypsum requirement followed by 25% of gypsum requirement in the following year can be adopted. Gypsum, pyrites and acid powder were recommended over other amendments on the basis of cost and handling hazards.

Biological amelioration of sodic soils

The results of several experiments suggested that planting of tolerant grass species in a sodic Vertisols for a period of more than two years could be an effective measure in conservation of soil, water and nutrient resources. Plantation of Marvel, Para and Karnal grasses for a period of three to four years are found more beneficial in amelioration of the soil. Soil ESP decreased up to tune of 15-20 unit and thus it reduced the quantity of gypsum up to about 8 to 12 Mg ha^{-1}. Application of gypsum @ 50% of GR after these grasses was found sufficient to harvest normal mustard and sorghum crops under rain-fed farming system.

Water Management

Inadequacy and reliability of canal water are well known. Studies to improve irrigation water efficiencies and system performance have been undertaken to develop on-farm and off-farm strategies.

- Improved surface irrigation design guidelines and use of pressurized irrigation systems including drip and sprinkler irrigation have been established to ensure light and frequent irrigations essential for the salt-affected soils
- Laser land leveling activities have been initiated on farmer's fields to demonstrate its potential for water conservation and high water productivity
- A pitcher irrigation technique has been developed to use saline water for vegetable cultivation
- Off-farm strategies based on lining, modification in operational schedules, auxiliary storage,

groundwater marketing from head to tail ends have been recommended to improve system efficiencies, equity and reliability of water supplies

- Methodologies to use GIS and remote sensing to assess crop productivity in irrigation commands under saline environment have been demonstrated

Crops and varieties for saline and sodic soils

Studies were conducted in artificially created saline and sodic soils for evaluation of salinity and sodicity tolerance of important economic crops of the region viz. cotton, sorghum, rice, pearl millet, maize, safflower, mustard, wheat, linseed and barley. Critical limits of crop tolerance (on the basis of 50% reduction in yield) have been found out in respect of the above crops. Screening of elite varieties / hybrids of different crops was carried out in sodic soils under field conditions at different ESP levels achieved through application of gypsum @ 0, 33, 66 and 100% GR. The best performing varieties of different crops in sodic soils are presented in table 1.

Crop improvement for salinity, alkalinity and water logging stresses

- Sustained breeding efforts at CSSRI have resulted into the release of six varieties of rice (CSR 10, CSR 13, CSR 23, CSR 27, CSR 30 and CSR 36), four varieties of wheat (KRL 1-4, KRL 19, KRL 210 and KRL 213), three varieties of Indian mustard (CS 52, CS 54 and CS 56) and one variety of gram (Karnal Chana 1) by Central Varietal Release Committee for salt-affected areas of the country

- The popularity of these varieties can be gauged from the fact that during the last five years alone (2004-2009), 56 Mg breeder seed of rice, 43 Mg breeder seed of wheat and 1.8 Mg breeder seed of mustard varieties have been distributed to different agencies

Overall, the area covered by salt tolerant varieties of rice, wheat and Indian mustard has been estimated to be more than 60,000 ha leading to the estimated monetary gain through primary spread of around Rs 560million. The expected monetary gain through secondary spread (conservative estimates) would be Rs 1700to 4000 million.

Bio-drainage for Land Reclamation

Biodrainage technology developed to prevent and reclaim waterlogged saline soils in canal command areas by raising Eucalyptus plantation. The five years old trees could lower the water table by 85 cm with an average transpiration rate of 50 litre day^{-1} plant^{-1}(Ram et al. 2011).

Farmers' harvested good rice and wheat crops in such areas besides having 36 Mg ha^{-1} of total wood

Table 1. Crops and their salinity/sodicity tolerant varieties (Anonymous 2003 and 2008)

Crop	Critical limits		Varieties
	ECe(dSm^{-1})	ESP	
Rabi crops			
Safflower	10-15	40-45	JSF-1, IC 11839
	15-20	45-58	IC 11750, JSF 144
Barley	15-20	48-56	DL4, 106, 120, 157, 165, BHS - 12
Mustard	15-20	20-45	CSN 3, 6, 13, 14, 15
	15-20	48-56	TH17,UP-70, RLM632, RIC 1012, 1013, Varuna, Pusa bold
Wheat	15-20	45-55	Kalyan Sona, NP 404, Malavraj, K - 227, WH - 157
Kharif crops			
Rice	10-15	50-55	CSR-4, Kalarata, Jhona - 349, SAR-328, Kranti, IR-36
Cotton	10-15	50-56	Maljari, Vikram. 70 - IH - 452, Khandwa - 2, KH 33 / 1146, Jwahar Tapti, G.Cot.19,
Maize	5-10	15-24	Ganga - 5
Sorghum	5-10	< 10	CSH - 1 and 3, 1584,
	5-10	50-60	61-1-1, SPV - 235, 938, 1041

biomass. The plantation could sequestered 24 MG ha^{-1} carbon during this period.

A new drainage technology (viz. multiple well point system, conjunctive use of canal water and ground water, bio-drainage system and sub surface drainage system) for salt affected waterlogged areas of south west Punjab were conceived developed, demonstrated and adopted by large number of farmers in the salt affected water logged areas reported by Shakya and Singh (2010). The performance and improvement in soil characteristics and grain yield under irrigation treatment using canal water only and cyclic use of two canal water followed by one tube well water were compared. The bio drainage system consist of raised bunds covered with polythene sheet buried at about 15 cm below soil surface on which eucalyptus plants were planted after applying soil amendment, farm yard manure etc. Presence of polythene sheet prevented capillary salinization.

Other Management Issues

Use of acidifying fertilizers

Iron is not the only nutrient that becomes unavailable to plants at high soil pH, the same problem also occurs with phosphorus, manganese, zinc, copper and boron. Many alkaline soils also contain low amounts of magnesium. The calcium levels of these soils are often very high and this can reduce the uptake of potassium and magnesium even when there is enough in the soil. Superphosphate or ammonium sulphate which increases acidity in soil and maintains fertility of soil impoverished by leaching and cropping. Calcium nitrate or calcium chloride minerals can be used to reclaim sodic soils, but they generally are more costly and are likely to produce other negative effects on plant growth or the environment. Nitrate is considered a groundwater contaminant and is not a good choice. The addition of sulphur does not directly add calcium to the soil. However, elemental sulphur oxidizes to form sulphuric acid, which dissolves lime (calcium carbonate, $CaCO_3$), which often exists in arid and semiarid zone soils. The dissolution of indigenous lime provides the calcium necessary to reclaim a sodic soil. When adequate moisture and temperatures are present, oxidation of elemental sulphur will be completed within one or two growing seasons. Further use of compost @ 5-10 t ha^{-1} provides additional benefit in improving soil physical condition beside balanced nutrient availability.

Green manuring

The green manuring of 'dhaincha' along with gypsum is useful in restoring physical condition and enriching the soil in nitrogen and organic matter. Mulching reduces the moisture evaporation from surface soil and prevents salinization. Suitable crop rotation including salt tolerant crops has also proved successful. The conjunctive use of surface and groundwater particularly in canal and lift irrigated region must be ensured as it helps to reduce the water table thereby operating as drainage to check the salinity of the land.

In alkali soil green manuring of dhaincha has been found to be beneficial along with gypsum in resorting physical condition and enriching the soil in nitrogen and organic matter.

Use of Solid waste /spent wash /molasses

Many industries (distilleries, thermal power plants, etc.) that end up with large volumes of non-hazardous solid

Fig 1. Use of spent wash @ 5 and 10 cm/ha are effective in reclamation (Source: Anonymous 2003)

waste mounds can now process their wastes much more efficiently and create lush green belts or even cash crops, depending on their geo-climatic conditions using this unique mycorrhizal-based technology.

Molasses are used to reclaim alkali soils @ 5 Mg ha^{-1} along with 2.5 to 5 Mg of press mud and 50 to 100kg of urea (Anonymous 2008). It provide source of energy for micro-organisms and on fermentation, produce organic acids which reduce alkalinity while press mud help in reducing exchangeable sodium. One time application (5-10 cm ha^{-1}) also helps to improve soil and crop production (Fig 1).

Management of alkali vertisols

These problematic soils occur in association with normal soils (Vertisols and associated soils) in a given landscape in Madhya Pradesh, Rajasthan, Gujarat, Maharashtra, Andhra Pradesh, Karnataka and Tamil Nadu. Swelling-shrink nature, low permeability and in absence of irrigation facility, the amelioration and economic utilization of these soils is difficult. The chemical amelioration in basically gypsum based viable technology for reclamation of these soils. Depending upon soil texture and initial ESP, 15 to 40 Mg ha^{-1} of gypsum is required to reclaim the upper 15 cm soil for raising crops. This also requires large amount of fresh water supplies for leaching of salts again a very high cost technology for poor farmers looking to the return.

Grasses for reclamation of sodic clay soils

Twenty four grasses collected from different sources were planted in the month of August 2002 at four different soil ESP (ESP viz., 25, 30, 35, 40 (± 2) to record their survival and growth parameters. The survival percent of different grasses decreased with the increasing level of soil ESP. The survival of Napier, Para, Sewan, Vetiver, Karnal, Rhoads, Marvel, Lemon/ Borthriochloa/ Deenanath was more than 50 per cent up to soil ESP 40 whereas other species failed to survive at this sodicity. Some grass species like, Anjan, Spear, Andropogen, Guinea (all three varieties) and Setaria grass could not survive at any level of soil ESP and were found very sensitive for planting in sodic clay soil. The performance (survival % >50) of different grass species at various soil ESP is as below.

Evaluating tree and fruit plantation for alkali black soils

The evaluation of sodicity tolerance of different tree species was done (Verma et al. 2006). It was observed that apart from the native check plant Prosopisjuliflora, Azadirachtaindica and Eucalyptus tereticornis were the tree species which revealed better survival and growth in alkali soils under rain fed situations. Aaonla (*Emblica officinalis*), Sapota, Ber (*Zizyphus jujuba*), Jamun and Drumsticks were found to be sodicity tolerant fruit plants.

Raised and sunken bed system

The black alkali soils are generally characterized by poor hydraulic conductivity, high bulk density, highly dispersible and have low potentials (Gupta & Verma 1983, 1984, 1985). The survival of crop in such soils are normally not feasible either due to water stress or temporary water logging, crop growth suffers heavily on both the accounts. The reclamation with the help of chemical amendments need ample of water for efficient chemical reactions and leaching process. These soils are normally found in low rainfall areas having poor irrigation facilities. After adopting all the recommended management practices and necessary techniques, the effective depth of reclamation remains a limiting factor. Under such abnormal situations no farmer can think about rehabilitation of such typical black alkali soils for crop production. Several workers have reported that these soils have almost negligible infiltration when soil ESP approaches to >35 due to dispersion of fine soil particles and clogging of micro-pores (Gupta and Verma 1985; Sharma and Verma 1998; Verma and Sharma 1998 b). Thus the soil can work, as impervious sheet and may prove good for storing of surface runoff during rains. Insitu and exsitu rainwater harvesting technique can provide sufficient tool for reclamation of such soils and a proper way for management of our natural resource. The water retained insitu will provide sufficient and justified amount of water for crop use and reclamation without damaging while exsitu stored water is to be used only under stress conditions to optimize crop production.

There are certain crops like paddy which is one of the tolerant and can be cultivated under submerge conditions (Michel 1978) at higher ESP levels. The other tolerant crops are sorghum, cotton and safflower but they require proper drainage (Gupta et al 1994 a & b) and can be planted in upland conditions. Some tree species (*Azardirechta indica*, *Accacia nilotica* and *Eucalyptus teriticornis*), Fruit trees (*Emblica oficinalis* and *Ziziphus mauritiana*) and certain grass species (*Brachiaria mutica*, *Dicanthium annulatum*, *Leptochloa fusca* and *Vetiveria zizanioides*) are also advisable for planting on raised beds for reclamation and rehabilitation of such soils. After certain period and partial reclamation the crop scenario could be modified as per the level of soil ESP and water conservation capacity of the soil.

The conceptual model was planned to reclaim the degraded black clay soil up to a greater depths through adaptation of raised and sunken bed system and enhance the crop production through rainwater management under rain fed cultivation in arid or semiarid region having sodic black clay soils. The suitability of the system was tested for different cropping pattern, system (viz. Double crop, Agro forestry and Agri-horticulture) and agro-climatic conditions (Madhya Pradesh, Haryana and Tamilnadu).

Selection of crops

Effective achievement on reclamation and crop production is possible through putting crops and varieties at proper lands configuration to meet out the objectives. The crop selection must be done by keeping in mind that maximum rainwater can be stored in field. The paddy crop will be most suitable crop at higher ESP and water storage whereas, the crops like cotton, sorghum and sunflower can be put on raised beds. To economize gypsum application agro-forestry, agri- horticulture and silvi-pastoral system can be recommended for some period.

Soil management & reclamation

The result from soil conservation point of view clearly indicates that adoption of raised and sunken bed system always helps in management by minimizing runoff, soil and nutrient loss as compared to any system in sodic clay soils (Table 2).

The five years results clearly indicate a sharp reduction in soil alkalinity. The soil alkalinity reduced to more than about 60% (soil ESP < 25) and up to a depth of 40 cm. The reduction in soil alkalinity was comparatively higher in sunken beds as compared to raised beds probably due to continuous submergence (>60 days) in sunken beds, which favor better chemical reaction. The safe disposal of stored water after first rain reduced the damage of crop due to dissolutions of salts and their accumulation at surface during summer. Monitoring the soil content of stored water throughout Kharif season also conferred this. The electrical conductivity of stored water after first rain was about 1.45 to 1.3 dSm^{-1} in two years respectively whereas after disposal it lowered down to level about 0.9 dSm^{-1}.

Water Management

Soil water balance was computed for estimation of crop water use with the help of inflow and outflow parameters. The main inflow sources were precipitation and profile moisture before the commencement of rains. The other inflow parameters like inflow seepage and upward flux was almost negligible due to very poor hydraulic conductivity. The main outflow sources were safe disposal of excess rainwater, change in soil moisture storage and downward seepage. The difference in inflow and outflow was considered as water available for plant growth. The measurement were carried out only for one bed of 15m width having 7.5m raised and 7.5m sunken bed considering that only a little change in data under various widths of raised and sunken bed as ratio of raised to sunken was constant. The root zone depth was considered 50m for all-purpose. The five years data showed a strong variation due to very erratic rainfall events and long dry spells during first three years (1994-96). The first year (1994) witnessed a very wet season (1040 mm rainfall) where as second year (1995) was relatively dry and total rainfall was lower (618 mm) than normal rainfall (730 mm) of the area and third year (1996) it was again normal (923.1 mm).

The effective rain water conserved were only 731,633.9 and 723.1 mm in 1994, 95 and 96 respectively and 390,70 and 200 mm was disposed off either for safety measures or due to lack of storage capacity under strong storms. The conserved water was just sufficient for raising paddy crop but it failed to provide sufficient moisture to the cotton crop on raised bed particularly in latter stage

Table 2. Losses under different land configurations in a sodic clay soil (Anonymous 2003)

Properties	System of land configuration			
	R & S	BBF	RF	Flat land
Runoff (%)	33.39	53.88	57.12	61.97
Sediment loss(t ha^{-1})	0.959	18.792	24.656	28.687
Nitrogen loss (kg ha^{-1})	1.048	19.489	22.639	27.067
Potassium loss (kg ha^{-1})	1.736	31.261	35.032	47.914

R & S - Raised & Sunken bed, BBF-Broad bed & furrow, RF- Ridge & Furrow system as crop start showing stress. One irrigation (100 mm) to paddy during stress was provided during 1997 while two irrigations to paddy (100 mm each) and one irrigation to cotton (50 mm) was provided during the year 1998 and it result in secured and optimum crop yield (cotton and paddy both) was received.

Crop Production

Rice

The rice grain yields for five consecutive years recorded from sunken beds (Table 3) revealed that the grain yield was comparatively higher during 1998 as compared to all the other years due to higher amount of available water either from insitu or exsitu storage. The mean paddy yield was 3885, 2511, 1524, 4760 and 5551 kg ha^{-1} during the five years 1994, 1995, 1996, 1997 and 1998 respectively. The number of irrigations supplied through storage tank during stress was one in 1997 and two in the year of 1998.In all the years' maximum paddy yield (3950, 2558, 1684, 4708 and 5612 kg ha^{-1}) were obtained in sunken beds of 7.5m width and was followed by 6m bed width. The bed width of 4.5m had the minimum yield in all the years as compared to others. It is therefore, evident from the study that paddy can survive in black alkali soils even under low rainfall but moisture stress in some parts of crop physiological period may result in low crop yield. The system becomes very vital if there is provision to supplement the crop with recycling of rainwater stored outside the field in storage tank during the stress or after cessation of monsoon for optimizing the crop yield.

Fig 2. Raised and sunken bed for cotton- paddy (a), and sunflower - paddy system (b) (source: AICRP, Indore)

Table 3. Water balance under raised and sunken bed system and crop availability (mm) (computed for 7.5m width system), (Source: Verma and Sharma 1998)

Factors	1994	1995	1996	1997	1998
A. Inflow parameters:					
i. Rains during the crop	1040.0	613.6	923.1	639.0	882.3
ii. Soil water before sowing	82.9	90.3	86.6	84.4	89.2
Total	1122.9	703.9	1011.7	824.4	971.5
B. Outflow parameters:					
i. Surface runoff	309.0	70.0	200.0	225.0	225.0
ii. Change in soil storage	200.0	192.0	196.0	198.0	220.5
Total	509.0	262.0	396.0	423.0	445.5
Water for the crop (A- B)	613.9	441.9	615.7	401.0	746,0
Water used by crop					
a. Cotton (July to October)	210.0	156.0	190.7	165.0	197.2
b. Paddy	1017.8	727.8	1040.7	637.0	1294.5
Total Available water					
a. Cotton	410.0	318.0	386.7	363.0	397.7
b. Paddy	1227.8	919.8	1236.7	835.0	1495.0

Table 4. Rice and seed cotton yield (kg ha^{-1}) from raised and sunken bed system under different width and years (Source: Verma and Sharma 1998)

Treatments (beds width in m)			Rice		
1994	1995	1996	1997	1998	
4.5	3897	2493	1429	4663	5520
6.0	3990	2483	1460	4918	5520
7.5	4112	2558	1684	4708	5612
Cotton					
4.5	240	430	250	365	465
6.0	360	463	329	571	610
7.5	419	490	435	508	600

Table 5. Effects of raised beds on grain yield of sunflower during different years. (source: Verma & Sharma 1998)

Sunken beds width (cm)		Grain yield (q ha^{-1})		
	1995	1996	1998	Mean
Check (normal)	7.0	6.0	7.9	7.0
135	8.1	6.3	9.3	7.9
270	8.5	7.4	10.2	8.7
405	9.2	6.5	10.8	8.87
CD at P=0.05	1.2	0.2	-	-

Table 6. Investments and returns from sodic black clay soil in raised & sunken bed system under rain fed conditions (in absence of water storage tank)(Source: Verma and Sharma 1998)

Management factor	First year	Second year	Third year	Total
Cost of gypsum @ 10 tons /ha	14,000	-	-	14,000
Cultivation and mixing of gypsum	450	-	-	450
Bed preparations by tractor for 10 hrs	1,500	-	-	1,500
Finishing of beds by manual labours	450	250	250	950
Cost of cultivation- Paddy				
Nurssery & Fertilizers	1,200	1,200	1,200	3,600
Weeding & interculture	700	700	700	2,100
Cost of cultivation- Cotton				
Seeds & Fertilizers	1150	1150	1150	3450
Weeding & interculture	1,750	1,750	1,750	5,250
Total investments per hectare	21,200	5,050	5,050	31,300
Yield of paddy	2.0 ton	2.0 ton	2.0 ton	6.0 ton
Yield of cotton	0.3 ton	0.3 ton	0.3 ton	0.9 ton
Cost of paddy @ Rs 6,000/ton	12,000	12,000	12,000	36,000
Cost of cotton@ Rs 25,000/ton	7,500	7,500	7,500	22,500
Total returns per hectare	19,500	19,500	19,500	58,500
Net return per hectare	(-) 1,700	14,450	14,450	27,200

Cotton

The highest seed cotton yield (Table 4) was recorded on raised beds having width of 6.0m and was followed by 7.5m in all the years and the lowest was with 4.5m bed width. The crop was provided irrigation during the year 1998 during a long dry spell. The crop yield was in general not affected by the amount of rainfall but mostly by distribution pattern that is why the cotton yield was more during 1995 as compared to 1994 and 1996. The assured irrigation during last two years was the reason for higher cotton yield.

Sunflower

A similar experiment was carried out in an alkali soil (pH-9.1, ESP-18.5) amended with gypsum @ 50% GR during 1995-99 at tiruchirapalli (Tamilnadu). The results of the experiment indicated improvement in yield of sunflower with raised beds of varying width. The overall result (Table 5) showed that 405/30 cm had been giving a good performance in term of soil moisture conservation, nutrient uptake and thereby seed yield of sunflower.

This system was also applied to other crops at Indore during various years like sunflower- paddy (Fig 2), sorghum-paddy, agro-forestry (Acacia/ Neem- paddy) and agri- horticulture (Aonala / Ber- paddy) and silvi-pastoral system (Acacia/ Neem- Para/ Marvel/ Karnal) and its effectiveness in water conservation, reclamation and crop production was almost similar.

Economic aspects of the system

Success and viability of any system in agriculture depends

Table 7. Changes in Physico-chemical characteristics of soil due to grasses at 180 days intervals (Anonymous 2003 and 2008)

Name of grass	pH	ECe (dSm^{-1})	ESP	Bulk density (Mgm^{-3})	Infiltration rate ($cm\ h^{-1}$)
			After 360 days		
Marvel	8.6	1.62	37.46	1.27	0.07
Para	8.7	1.68	38.42	1.30	0.13
Vetiver	8.5	1.82	40.25	1.53	0.12
Karnal	8.7	1.29	39.40	1.42	0.09
Napier	8.8	1.67	42.25	1.46	0.14
Control	8.6	1.79	42.50	1.39	0.09
			After 720 days		
Marvel	8.43	1.58	38.20	1.01	0.18
Para	8.62	1.63	37.76	1.08	0.27
Vetiver	8.32	1.73	36.52	1.07	0.31
Karnal	8.51	1.31	32.45	0.94	0.12
Napier	8.63	1.58	37.42	1.06	0.10
Control	8.64	1.77	39.85	0.99	0.26
			After1080 days		
Marvel	8.2	1.76	30.20	1.05	0.20
Para	8.3	1.79	25.50	1.11	0.26
Vetiver	8.6	1.75	36.22	1.02	0.32
Karnal	8.4	1.42	31.80	1.16	0.24
Napier	8.5	1.84	37.20	1.06	0.12
Control	8.3	1.94	38.22	1.10	0.14
			After1260 days		
Marvel	8.3	1.66	29.80	1.08	0.18
Para	8.4	1.72	25.20	1.14	0.22
Vetiver	8.4	1.65	34.32	1.12	0.26
Karnal	8.4	1.46	31.20	1.14	0.20
Napier	8.3	1.72	36.20	1.08	0.16
Control	8.3	1.78	37.22	1.10	0.12

on economics calculated on the basis of input required and output gained from the crop in the form of grain and straw. The cost benefit was computed on the basis of investment and retune of first three years. The economics give in Table 5 is for adverse conditions where soil ESP is more than 60 and input cost will reduce as there is soil of low ESP and vis a vis the benefit will increase. The computation indicated that there was loss during first year due to high investment on gypsum as black sodic soils have high cation exchange capacity (CEC) hence gypsum requirement is very high. This investment can be spilited over all the three years but looking to its availability and feasibility of application, practically it will not be possible to farmers to apply gypsum in split doses and this may also.

Increase the cost of investment. The use of gypsum is always recommended for reclamation of such soils and here only additional investment is about two thousand rupees for bed preparation but it gives an effective approach to reclamation in absence of irrigation sources. However, the system will be economically sound in coming years and if we take care for three years then there is benefit starts from second year and will continue for long time (Table 6).

The five years (1994- 1998) experimental results at Indore under case study confirmed that raised and sunken bed land configuration along with introduction of small storage tank can serve the purpose of reclamation of degraded land with satisfactory crop production under un-irrigated conditions in the areas having modest rainfalls. The raised and sunken bed system helps in increasing depth of reclamation. However, the present design can be used at any place and for any crop pattern with only certain modifications after considering the rainfall, crop requirement, and soil and weather conditions of the locality.

Reclamations and Conservations through Grasses

The grasses work principally in two ways; (a) improvement in infiltration, and (b) release of carbon dioxide during decomposition. In calcareous soils the CO_2 brings in, additionally, the soluble calcium for exchange reaction to replace sodium in the soil exchange complex. However, only few studies have been conducted on the duration of cultivation of grasses. Instead of growing simple grasses with only fodder value, some grasses having medicinal value like vetiveria may provide substantial income to the poor farmers along with reclamation.

The grasses grow well even without application of amendments and their growth in turn improves the physico-chemical condition of light textured alkali soils. Ashok Kumar and Abrol (1986) indicated that after growing Karnal grass for two to three year's satisfactory yields of rice and wheat could also be achieved.

Changes in soil properties

The experimental soil belongs to order Vertisols (Haplusterts - Sodic phase) and reveal high CEC (40 c mol kg^{-1}) and ESP (40.0 2.0) with low ECe (0.9 to 1.4 dSm^{-1}) and moderate pH (8.2-8.4) with some minor spatial variability. The soil is clay in texture (clay 54.6%, silt 34.4% and sand 11.0%) with almost negligible steady state infiltration rate (terminal rate). The bulk density of plough layer soil (0-15 cm) is in the range of 1.40 to 1.45 (Mgm^{-3}).

The $CaCO_3$ content of the soil is in between 7.0 to 10.0 %. Changes in physico-chemical conditions of soil after every years and total time (three years and six months) of planting different grasses are presented in Table 7. The significant changes were observed in soil ESP and associated properties after 42 months of grass planting.

Table 8. Sodium removal (kg ha^{-1}) by different grasses through cuttings during the different years (Source: AICRP, Indore)

Name of grass	Years				Total
	2001-02	2002-03	2003-04	2004-05	
Marvel	4.96	24.96	28.56	18.43	76.91
Para	24.45	70.82	104.72	87.13	287.12
Vetiver	2.07	24.68	39.79	35.47	102.01
Karnal	25.77	71.99	47.01	75.07	219.84
Napier	3.46	82.45	39.77	10.97	136.65

Sodium uptake

The uptake of sodium by Karnal grass was highest followed by Para grass (Table 8) at every stage of cutting vice. The total uptake of Na was higher by Para grass due to higher yield potential followed by Karnal grass.

The quantitative removal of sodium by different grasses through their forage production at different stages during study period for all the four years indicates that the removal of sodium from soil through its uptake was higher in Para (287.12 kg ha^{-1}) and Karnal (219.84 kg ha^{-1}) grasses as compared to others.

The quantitative removal of sodium by all grasses was higher in second year as compared to first year. Napier grass removed very high quantity (82.45 kg) of sodium during second year and it highest among all the grasses. The other grasses i.e. Vetiver and Marvel took very less amount of sodium from soil.

The quantitative removal of sodium by all grasses was highest in third year as compared to other years. Para grass removed very high quantity (104.72 kg) of sodium during third year and it highest among all the grasses. The other grasses i.e. Vetiver and Napier took almost same amount of sodium from soil.

Reclamation through afforestation

The data on physico-chemical properties of plough layer soil (0-15 cm) collected before tree plantation and after seven and fourteen years are reported in Table 9. Tree plantation in general caused a remarkable reduction in soil pH, EC and ESP whereas; soil organic carbon, available nitrogen and phosphorus content had increasing pattern with progress in time. The soil infiltration rate also improved remarkably due to tree plantation. This gradual favorable improvement in physico-chemical properties may be attributed to an increased biological activity in barren soil as a result of cultivation, growing of grasses, root penetration, litter fall and nitrogen fixation. The maximum changes occurred in the plots where *Prosopis juliflora, Azadirachta indica* and *Eucalyptus tereticornis*

Table 9. Changes in physicochemical-properties of a saline-alkali black clay soil after seven (1997) and fourteen (2004) years of plantation (Source: AICRP, Indore)

Particulars	pHs	ECe (dSm^{-1})	ESP	Org.C (%)	Av.N (kg ha^{-1})	Av.(P_2O_5) (Kg ha^{-1})	H. C. (cm hr^{-1})
Initial (1990)	8.8	4.00	35.0	0.35	185	3.4	Negligible
				1997			
Cassia siamea	8.1	1.42	15.6	0.50	235	8.0	0.25
Acacia nilotica 1994	8.3	2.00	25.0	0.49	200	5.6	Negligible
Albizia lebback	8.5	1.40	20.0	0.57	215	5.6	0.25
Hardwickea binnata 1993	8.3	2.10	22.0	0.63	238	3.2	Negligible
Casuarina equisetifolia	8.5	1.54	17.0	0.52	204	6.5	Negligible
Prosopis juliflora	8.5	1.29	10.2	0.71	263	8.0	0.25
Azadirachta indica	8.5	1.30	14.0	0.62	235	9.6	0.50
Acacia catechu 1993	8.4	1.43	19.0	0.51	200	3.2	0.25
Eucalyptus tereticornis	8.2	1.24	20.2	0.67	240	16.8	0.85
				2004			
Cassia siamea	8.2	1.29	15.0	0.69	263	16.8	0.28
Acacia nilotica 1994	8.3	1.52	22.4	0.65	250	13.6	0.21
Albizia lebback	8.0	0.95	18.8	0.56	235	14.0	0.16
Hardwickea binnata 1993	8.0	0.96	21.0	0.56	235	13.6	0.18
Casuarina equisetifolia	8.1	0.75	16.6	0.56	235	9.6	0.18
Prosopis juliflora	8.1	0.81	8.4	0.82	284	19.2	0.66
Azadirachta indica	8.3	0.62	12.6	0.69	263	23.2	0.49
Acacia catechu 1993	8.3	0.62	18.4	0.50	200	13.2	0.16
Eucalyptus tereticornis	8.3	0.94	19.2	0.65	250	18.0	0.38

were planted in comparison to all other tree species.

Recent technological approaches of reclamations

Microbial Reclamation

It is important to find out alternative options in place of amendments like gypsum, pyrites etc. for reclaiming sodic soils as both their availability and cost can be a bottleneck. Microorganisms are able to survive in extreme soil physical and chemical environments. It is a fact that the potential of using microbes for a multitude of activities is heavily underutilized. Paikray and Singh (2012) have developed a consortium of microorganisms (fungi and bacteria) along with molasses and farm yard manner that is able to reclaim sodic soil up to deeper layers through removed of excess sodium and its leaching. Removal of sodium, the primary cause of sodicity, improves the soil aggregation and its water holding capacity. The acidic produced during the microbial decomposition leads to lowering of pH along with the exchangeable sodium percentage of the soil.

Biotechnological Approaches

Biotechnological tools and their applications have been developing at a very fast pace and in today's scientific world, gene flow has no barriers. Genes identified for a specific traitsin a specific species can be easily incorporated into another species with the tools available with the scientists. Powerful new molecular tools for manipulating genetic resources are becoming available, but the potential of these technologies are yet to be fully utilized to introduce new genes for tolerance into current cultivars. Increased salt tolerance requires new genetic sources of this tolerance, and more efficient techniques for identifying salt tolerant germplasm. For salt tolerant candidate genes have been listed for ion transport, osmo-protection, and making plants grow more quickly in saline soil.

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Heavy metals : Causes of soil pollution and its remediation

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Abstract

Heavy metals are among the most important sorts of contaminants in the environment. The agricultural activities involve addition of fertilizers, pesticides and amendments to soil for increasing productivity. The use of water for irrigation and industrial effluents pollute the soil with solid wastes, heavy metals and several other organic and inorganic substances. Heavy metals are the integrated components of the biosphere and thus occur naturally in soils and plants. Contamination of soils by heavy metals is of widespread occurrence as a result of human agricultural and industrial activities. The most common heavy metal contaminants are Cd, Cr, Cu, Hg, Pb, and Zn. Metals are natural components in soil. Some of these metals are micronutrients necessary for plant growth, such as Zn, Cu, Mn, Ni, and Co, while others have unknown biological functions, such as Cd and Pb. Currently, phytoremediation has been found as an effective and affordable technological solution used to extract or remove inactive metals and metal pollutants from contaminated soil and water. This technology is environmental friendly and potentially cost effective. Some recommended plants which are commonly used in phytoremediation and their capability to reduce the contaminant are also reported.

Keywords: Heavy Metals, Pollution and Remediation.

Soil not only acts as a source of nutrients for plant growth but also acts as a sink for the contaminants added to soil through the waste generated from human and industrial activities. Heavy metals are conventionally defined as elements with metallic properties and an atomic number >20 (Lasat 2000; Gaur and Adholeya 2004). Metal pollution has harmful effect on biological systems and does not undergo biodegradation. Toxic heavy metals such as Pb, Co, Cd can be differentiated from other pollutants, since they cannot be biodegraded but can be accumulated in living organisms, thus causing various diseases and disorders even in relatively lower concentrations (Pehlivan et al. 2009). Heavy metals, with soil residence times of thousands of years, pose numerous health dangers to higher organisms. They are also known to have effect on plant growth, ground cover and have a negative impact on soil microflora (Roy et al. 2005).

The productive soils are regularly being dumped with chemical and industrial materials. This has deteriorated the soil, which has resulted in decline in soil productivity at several parts of the country. When a trace of toxic element from soil or rock enters into the environment, follows normal biogeochemical cycles, being governed by air, water and gravity until it reachs to a geochemical sink. Soil is a universal sink for many substances particularly the metals that accumulate in soil and move under the process of leaching, plant uptake and erosion. Organisms, which temporary form sink and on decay the element is released into the soil. Soils may become contaminated by the accumulation of heavy metals and metalloids through emissions from the rapidly expanding industrial areas, mine tailings, disposal of high metal wastes, leaded gasoline and paints, land application of fertilizers, animal manures, sewage sludge, pesticides, waste water irrigation, coal combustion residues, spillage of petrochemicals, and atmospheric deposition. Heavy metals constitute an ill-defined group of inorganic chemical hazards, and those most commonly found at contaminated sites are lead (Pb), chromium (Cr), arsenic (As), zinc (Zn), cadmium (Cd), copper (Cu), mercury (Hg), and nickel (Ni) (Khan et al. 2008 and Zhang et al. 2010).

Fertilizers and micronutrients are the manufactured products containing certified amounts of plant nutrients to facilitate crop growth when applied on cultivated lands. In addition to the active ingredients, however, fertilizers and micronutrients may contain trace elements such as cadmium and lead that are potentially harmful to consumers of the harvested products. When the phosphatic fertilizers and micronutrients are applied to the soil, the amounts applied invariably exceeded the amounts taken up by plants. In addition, parts of plant biomass would be reincorporated into the soil after the crop harvests, thus recycling part of the nutrients and contaminants. Therefore, active ingredients of phosphatic fertilizers, along with micronutrient ingredients namely phosphorus, zinc, iron, and manganese are expected to accumulate in soil receiving routine applications. The phosphorus contents of the cultivated soils would invariably increase in proportion with the amount of the fertilizers used. Fe and Mn are abundant in soils and increases in their concentrations could not easily be distinguished from the already high background levels. However, zinc contents of the soil would be sensitive to the inputs and may be used as an indicator of micronutrient inputs. The content of lead and cadmium which are present in soil are either geogenic or added through applications of phosphate fertilizer. The cadmium content of phosphatic fertilizer in Indonesia is 35-255 g mt^{-1} (Alloway 1995). While single super phosphate used in India, contains Cd in the range of 2-200 mg kg^{-1} (Foy et al. 1978).

Sources of heavy metals in soil

The sources of various heavy metals are listed in Table 1. The presence of any metal may vary from site to site, depending upon the source of individual pollutant. Excessive uptake of metals by plants may produce toxicity in human nutrition, and cause acute and chronic diseases. For instance, Cd and Zn can lead to acute gastrointestinal and respiratory damages and acute heart, brain and kidney damages. High concentrations of heavy metals in soil can negatively affect crop growth, as these metals interfere with metabolic functions in plants, including physiological and biochemical processes, inhibition of photosynthesis, and respiration and degeneration of main cell organelles, even leading to death of plants (Garbisu and Alkorta 2001; Schmidt 2003; Schwartz et al. 2003). Soil contamination with heavy metals may also cause changes in the composition of soil microbial community, adversely affecting soil characteristics (Giller et al. 1998; Kozdrój and van Elsas 2001; Kurek and Bollag 2004).

Anthropogenic source of heavy metals

The heavy metals in any soil depend initially on the nature of parent materials. Flanagan (1969) reported that the concentration of heavy matels was higher in basaltic rocks and comparatively low in granite rocks and Vine and Tourlets (1970) reported the heavy metal composition in coal ash.

Fertilizers and soil amendments

To grow and complete the life cycle, plants must acquire not only macronutrients (N, P, K, S, Ca, and Mg), but also essential micronutrients. Some soils are deficient in the heavy metals (such as Co, Cu, Fe, Mn, Mo, Ni and Zn) that are essential for healthy plant growth (Lasat 2000), and crops may be supplied with these as an addition to the soil or as a foliar spray. Large quantities of fertilizers are regularly added to soils in intensive farming systems to provide adequate N, P, and K for crop growth. The compounds used to supply these elements contain trace amounts of heavy metals (eg. Cd and Pb) as impurities, which, after continued fertilizer, application may significantly increase their content in the soil (Jones and Jarvis, 1981). Metals, such as Cd and Pb, have no known physiological activity. The heavy metals concentrations

Table 1. Different sources of heavy metals

Heavy metals		Sources References
Cadmium	Geogenic sources, anthropogenic activities, metal smelting and refining, fossil fuel burning, application of phosphate fertilizers, sewage sludge.	Nriagu and Pacyna 1988; Alloway 1995; Kabata-Pendias 2001
Chromium	Electroplating industry, sludge, solid waste, tanneries.	Knox et al. 1999
Lead	Mining and smelting of metalliferous ores, burning of leaded gasoline, municipal sewage, industrial wastes enriched in Pb, paints.	Gisbert et al. 2003
Nickel	Volcanic eruptions, land fill, forest fire, bubble bursting and gas exchange in ocean, weathering of soils and geological materials.	Knox et al. 1999

in some common fertilizers and soil amendments are presented in Table 2.

Pesticides

Several common pesticides used fairly or extensively in agriculture and horticulture in the past contained substantial concentrations of metals. For examples copper-containing fungicidal sprays such as Bordeaux mixture (copper sulphate) and copper oxychloride (Jones and Jarvis 1981). Lead arsenate was used in fruit orchards for many years to control some parasitic insects. Compared with fertilizers, the use of such materials has been more localized, being restricted to particular sites or crops (McLaughlin et al. 2000).

Biosolids and Manures

The application of numerous biosolids (eg, livestock manures, composts, and municipal sewage sludge) to land inadvertently leads to the accumulation of heavy metals such as As, Cd, Cr, Cu, Pb, Hg, Ni, Se, Mo, Zn, Tl, Sb, and so forth, in the soil (Basta et al. 2005). Certain animal wastes such as poultry, cattle, and pig manures produced in agriculture are commonly applied to crops and pastures either as solids or slurries (Sumner 2000). The manures produced from animals on such diets contain high concentrations of As, Cu, and Zn and, if repeatedly applied to restricted areas of land, can cause considerable buildup of these metals in the soil in the long run. Biosolids (sewage sludge) are primarily organic solid products, produced by wastewater treatment processes that can be beneficially recycled (USEPA 1994). Land application of biosolids materials is a common practice in many countries that allow the reuse of biosolids produced by urban populations (Weggler et al. 2004). The term sewage sludge is used in many references because of its wide recognition and its regulatory definition. However, the term biosolids is becoming more common as a replacement for sewage sludge because it is thought to reflect more accurately the beneficial characteristics inherent to sewage sludge (Silveira et al. 2003). Heavy metals most commonly found in biosolids are Pb, Ni, Cd, Cr, Cu, and Zn, and the metal concentrations are governed by the nature and the intensity of the industrial activity, as well as the type of process employed during the biosolids treatment (Mattigod and Page 1983). Under certain conditions, metals added to soils in applications of biosolids can be leached downwards through the soil profile and can have the potential to contaminate groundwater (McLaren et al. 2005).

Table 2. Heavy metal contents in common fertilizers and soil amendments

Fertilizers	Heavy Metals (mg kg^{-1})										
	Zn	Cu	Fe	Mn	B	Mo	Pb	Cr	Cd	As	Ni
Urea (1)	4.0	0.6	36	0.5	1.0	5.3	4.0	6.0	1.0		
Single Super Phosphate (1)	165	15.5	4050	8900	133	335	487	88	187	-	-
Potassium Chloride (1)	10.0	3.12	110	3.5	16.3	26	-	-	-	-	-
Diammonium Phosphate (1)	112	7.2	11275	307	396	75.3	195	81	109	-	-
Dairy manure (mean) (2)	-	18	-	-	-	-	7.5	-	0.7	6.8	9.6
Poultry manure (3)	330-456	48-78	-	-	-	-	6.0-8.4	<1.0-7.7	0.20-0.30	-	7.1-9.0

Source: (1) Behera 2007 (2) Raven and Loeppert 1997 & (3) Wolfgang and Dohler 1995

Toxicity of Heavy Metals

Lead

The visual non specific symptoms of Pb toxicity are rapid inhibition of root growth, stunted growth of the plant and chlorosis (Burton et al. 1984). Pb phytotoxicity leads to inhibition of enzyme activities, disturbed mineral nutrition and water imbalance. These disorders upset normal physiological activities of the plant. At high concentration Pb eventually may cause to cell death (Ernst 1998; Seregin and Ivanov 2001). Pb toxicity inhibits germination of seeds and retards growth of seedlings. Pb decreases germination percent, germination index, root/shoot length, tolerance index and dry ness of roots and shoots (Mishra and Choudheri 1998). High concentrations of Pb (1 mM) caused 14 to 30% decreased germination in rice seeds and reduced the seedling growth by more than 13 to 45% (Verma and Dubey 2003).

Cadmium

Cadmium is a toxic and carcinogenic metal, nearly ubiquitous in the environment, which is hazardous to human and ecosystems in excessive amounts. Inputs are mainly from atmospheric depositions, application of bio-solids, use of phosphates fertilizer, and effluents from cadmium using and recycling industries. Cd induced reduction in the number of flowers and in vitro pollen germination, it stimulated tube growth, decreased number of ovules/pistil (ovules were morphologically normal and receptive), inhibited number of pods, seeds, seed weight/ plant and 100 seed weight. Cd treatment increased protein content in physiologically matured seed. Significant yield reduction was obtained only in Alfisol and Ultisol amended with higher rate of Cd- enriched sewage sludge/ city compost. The amount of cadmium in leachates remained more or less similar to the original values. The applied Cd remained in the top 10 cm soil (87-96%) and resulted in lower recovery of heavy metals (Cd 8.3%) in the leachates (Gupta et al. 2007).

Table 3. Maximum allowable limits of heavy metal in irrigation water, soils and vegetables

Heavy metals	Maximum permissible level in irrigation water ($\mu g\ ml^{-1}$)	Maximum permissible level in soils ($\mu g\ g^{-1}$)	Maximum perimissible level in vegetables ($\mu g\ g^{-1}$)
Cadmium (Cd)	0.01	3	0.10
Lead (Pb)	0.065	100	0.30
Nickel (Ni)	1.40	50	67
Chromium (Cr)	0.55	100	-
Zinc (Zn)	0.20	300	100
Copper (Cu)	0.017	100	73
Iron (Fe)	0.50	50000	425
Manganese (Mn)	0.20	2000	500
Cobalt (Co)	0.05	50	50
Arsenic (As)	0.10	20	-

Table 4. Values of maximum allowable limits for heavy metals in different countries (mg kg^{-1})

Element	Austria	Canada	Poland	Japan	Great Britain	Germany
Cd	5	8	3	-	3	2
Co	50	25	50	50	-	-
Cr	100	75	100	-	50	200
Cu	100	100	100	125	100	50
Ni	100	100	100	100	50	100
Pb	100	200	100	400	100	500
Zn	300	400	300	250	300	300

(Source: Rattan et al. 2002)

Chromium

Toxicity of Cr to plants depends on its valence state, Cr (VI) which is highly toxic and mobile whereas Cr (III) is less toxic. Toxic effects of Cr on plant growth and development include alterations in the germination process as well as in the growth of roots, stems and leaves, which may affect total dry matter production and yield. Cr also causes deleterious effects of plant physiological processes such as photosynthesis, water relation and minerals nutrition. In plans, high levels of Cr supply can inhibit seed germination and subsequent seedling growth. Peralta et al. (2001) found that 40 ppm of Cr (VI) reduced the ability of seeds of lucerne (*Medicago sativa*) to germinate by 23%.

Nickel

The phytotoxic effects of Ni have been known for a long time (Tinker 1986). Apart from a decrease in growth the symptoms of Ni toxicity include chlorosis, stunted root growth and sometimes brown interval necrosis and symptoms specific to the plant species. The concentrations of Ni associated with Ni toxicity vary widely. For example, Patternson (1971) reported toxicity symptoms in spring wheat at 8 mg kg^{-1} but no yield loss in oats at 90 mg kg^{-1}.

Permissible limits of heavy metals in water and soil :

The maximum allowable limits of heavy metals in soils and vegetables have been established by standard regulatory bodies such as World Health Organization (WHO), Food and Agricultural Organization (FAO) and Ewers U, Standard Guidelines in Europe as shown in Table 3 and maximum allowable limits of heavy metals in different contries in Table 4 (Behera 2007).

Standard of Compost Manure Solid Waste

Maximum allowable limit of heavy metals and other standards for compost manure solid waste by Central Pollution Control Board (CPCB), (Management and Handling) Rules 2000, MEF (Behera 2007) are given in Table 5.

Remediation of heavy metals from contaminated soils

For heavy metal-contaminated soils, the physical and chemical form of the heavy metal contaminant in soil strongly influences the selection of the appropriate remediation treatment approach. The contamination in the soil should be characterized to establish the type, amount, and distribution of heavy metals in the soil. Once the site is characterized, the desired level of each metal in soil must be determined. This is done by comparison of observed heavy metal concentrations with soil quality standards for a particular regulatory domain, or by performance of a site-specific risk assessment. Remediation goals for heavy metals may be set as total metal concentration or as leachable metal in soil, or as some combination of these. Several technologies exist for the remediation of metal contaminated soil (Wuana and Okieimen 2011). The following methods are used for the remediation of heavy metals from contaminated soils.

Phytoremediation

During recent years the concept of using plants to remediate heavy metal contaminated sites (called phytoremediation) has received greater attention (Vassil et al. 1998, Jarvis and Leung 2002). Phytoremediation may involve either phytostabilization or phytoextraction. Phytoextraction involves the use of plants to remove the contaminant from contaminated soils. The concept of using plants to accumulate metal for subsequent processing is both technically and economically attractive. The generic term "phytoremediation" consists of the Greek prefix phyton (plant), attached to the Latin root remedium (to correct or to remedy) (Erakhrumen and Agbontalor 2007; USEPA 2000).

Generally, phytoremediation is an emerging technology using selected plants to clean up the contaminated environment from hazardous contaminant to improve the environment quality. For organics, it

Table 5. Heavy metals, C/N and pH standards for compost manure solid waste

Parameters	Maximum acceptable concentration (mg kg^{-1})
Arsenic	10
Cadmium	5
Chromium	50
Copper	300
Lead	100
Mercury	0.15
Nickel	50
Zinc	1000
C/N ratio	20-40
pH	5.5-8.5

involves phytostabilization, rhizodegradation, rhizofiltration, phytodegradation, and phytovolatilization. These mechanisms related to organic contaminant property are not able to be absorbed into the plant tissue. For inorganics, mechanisms which can be involved are phytostabilization, rhizofiltration, phytoaccumulation and phytovolatilization.

Areas of phytoremediation

Phytoextraction

Is the uptake/absorption and translocation of contaminants by plant roots into the above ground portions of the plants (shoots) that can be harvested and burned gaining energy and recycling the metal from the ash. The extraction of metal from polluted soils into harvestable plant tissues (Phytoextraction). Very few plant species such as Sutera fodina, Dicoma niccolifera and Leptospermum Scoparium have been reported to accumulate Cr to high concentrations in their tissues.

Phytostabilisation

Is the use of certain plant species to immobilize the contaminants in the soil and groundwater through absorption and accumulation in plant tissues, adsorption onto roots, or precipitation within the root zone preventing their migration in soil, as well as their movement by erosion and deflation.

Rhizofiltration

Another promising clean-up technology appears to be rhizofiltration, which involves use of plant roots to remove contaminants such as heavy metals from contaminated water (Dushenkov et al. 1995). Rhizofiltration is the adsorption or precipitation onto plant roots or absorption into and sequesterization in the roots of contaminants that are in solution surrounding the root zone by constructed wetland for cleaning up communal wastewater. A high level of Pb deposition is seen in corn root tips as revealed by histochemical and electron microscopy studies. Malkowski et al. (2002) also showed that corn plants treated with 10-3 M Pb accumulated 138, 430 mg of Pb per kg of dry weight in root tips compared to 26,833 mg in the root basal part. Since the first 8 mm of the apical root accounts for approximately 50% of the Pb accumulated by the entire root system (Malkowski et al. 2002), it appears that the plant with a more branched root system will take up more Pb and other heavy metals compared to plants with longer and less branched root systems. Generally aquatic plants are growing in contaminated water. Examples- *Scirpus lecusteris, Phragmites karka* and *Bacopa monnieri*.

Phytovolatilization

Is the uptake and transpiration of a contaminant by a plant, with release of the contaminant or a modified form of the contaminant to the atmosphere from the plant. Phytovolatilization occurs as growing trees and other plants take up water along with the contaminants. Some of these contaminants can pass through the plants to the leaves and volatilize into the atmosphere at comparatively low concentrations.

Phytodegradation

Use of plants and associated micro-organisms to degrade organic pollutants. In phytoremediation, the root zone is of special interest. The contaminants can be absorbed by the root to be subsequently stored or metabolised by the plant. Degradation of contaminants in the soil by plant enzymes exuded from the roots is another phytoremediation mechanism (Merkl et al. 2005). For

Table 6. Bioaccumulation coefficients of various *Brassica* spp. at maturity stage

Species	Heavy metals (mg kg^{-1})			
	Zn	Cu	Ni	Pb
B. juncea	6.83	3.08	3.21	12.86
B. compestris	12.48	2.59	13.61	2.56
B. carinata	11.89	1.94	12.30	17.72
B. napus	9.87	1.14	8.98	9.37
B. nigra	6.56	2.04	8.66	7.94

(Source: Bhadrawaj et al. 2004)

many contaminants, passive uptake via micropores in the root cell walls may be a major route into the root, where degradation can take place (Hinchman et al. 1998).

Hyper accumulation

A plant is classified as hyper accumulator when it takes heavy metals against their concentration gradient between the soil solution and cell cytoplasm, and thus acquiring capacity of accumulating a very high metal concentration in tissues without much difficulty in carrying out growth and metabolic functions. Some important heavy metal hyper accumulators are given below. Bioaccumulation coefficient is a useful indicator of hyper accumulating efficiency of plant (Table 6).

Chelation

Results from chelation experiments indicate that Pb concentration in the shoot can be increased dramatically when the soil Pb concentration is increased by adding a synthetic chelate to the contaminated soil. The synthetic chelate EDTA forms a soluble complex with many metals, including Pb (Kroschwitz 1995) and can solubilize Pb from soil particles (Vassil et al. 1998). Application of EDTA to Pb-contaminated soils has been shown to induce the uptake of Pb by plants causing Pb to accumulate more than 1% (w/w) of the shoot dry biomass (Huang and Cunningham 1996, Huang et al, 1997). Large Pb particles cannot easily cross the casparian strip due to their size and charge characteristics but once they form a complex with chelators such as EDTA, their solubility increases, the particle size decreases and they become partially 'invisible' to those processes that would normally prevent their unrestricted movement such as precipitation with phosphates and carbonates, or binding to the cell wall through mechanisms such as cation exchange (Jarvis and Leung 2002). It is important to point out that the addition of chelates to the soil has to be done in a carefully controlled manner so as not to mobilize Pb into ground water or otherwise promote its off-site migration (Huang and Cunningham 1996). Nutrient culture studies revealed a marked enhancement in uptake and translocation of chelated 51Cr in P. verlgaris. Cr chelated by DTPA was most effectively translocated followed by 51Cr-EDTA and 51Cr-EDDHA (Alhalye et al. 1995).

Soil scraping

Replacement of uppermost contaminated soil (0-15 cm depth) from cultivated field has been possible. The maximum amount of lead was absorbed / adsorbed by soil in clay - humus complexes. By scraping of contaminated soil highest quality of heavy metals can be removed from the soil and become suitable from growing the crops. One to two times further cleaning by phytoremediation or rhizofiltration leads to remove the traces amount of heavy metals from soil and then crop produce becomes edible for animal consumption.

Conclusion

The environmental pollution through heavy metal ions is the current world growing problem. It is increasing due to increase in urbanization and industrialization. Soil is the final sink for most of the pollutants. The discharge of heavy metal ions as a byproduct of various human activities are ccompanied with large scale water and soil pollutions. The most common heavy metal contaminants are Cd, Cr, Cu, Hg, Pb, and Zn. Metals are natural components in soil. Some of these metals are micronutrients necessary for plant growth, such as Zn, Cu, Mn, Ni, and Co, while others have unknown biological function, such as Cd and Pb. Currently, phytoremediation is an effective and affordable technological solution used to extract or remove inactive metals and metal pollutants from contaminated soil and water. This technology is environmental friendly and potentially cost effective.

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Role of molybdenum and biofertilizers in enhancing BNF and productivity of chickpea

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Abstract

Molybdenum plays a very vital role in nitrogen nutrition in legumes through its involvement in BNF because it is an essential component of bacterial nitrogenase. Molybdenum deficiency causes reduction in the number and size of flowers and many of them fail to mature leading to lower seed yield. Considering the significant role of molybdenum in BNF and its reduced availability at the site of N fixation in root nodules, it is considered as the limiting factor in enhancing chickpea/ legumes yield in MP. The present study is a review of work done on molybdenum nutrition in chickpea at several locations in M.P. and at other locations within india. Field experiments conducted in a medium black soil at Sehore,M.P. indicates that the application of molybdenum as ammonium molybdate (AM) either as soil application (1.0 kg AM ha^{-1}) or through seed treatment (1.0 g AM kg^{-1} seed) in combination with *Rhizobium* + PSB + RDF significantly increased number and dry weight of nodules, branches/plant, plant height, flowers and pods/plant, N and P uptake, chlorophyll content in leaves, protein content in seed and finally the grain yield by 39.9 and 32.4% respectively over RDF alone (1253 kg ha^{-1}).Both soil as well as seed application treatments were statistically on par. Multilocational trials conducted at Sehore, Indore, Gwalior and Ujjain also resulted significant enhancement in nodule dry weight, N uptake and on an average 26.7% higher seed yield due to Mo supplementation with seed in chickpea. Similarly experiments conducted at Kota and Sriganganagar in Rajasthan and at Junagarh in Gujarat also showed significantly higher chickpea seed yield and better net return due to the treatment of molybdenum @1g ammonium molybdate kg^{-1} seed over RDF. In farmers fields also yield enhancement of 20 to 27% under 15 FLD'S, 17.5%-46.8% under OFT (at Sehore, Guna, Shajapur, Sagar) and 11.6 to 35.8% under other demonstrations (Sehore, Bhopal, Rajgarh, Dewas, Indore and Gwalior) recorded by the use of molybdenum @1gAM kg^{-1} seed and as such proved very effective technology for enhancing chickpea productivity. Department of Farmers Welfare and Agriculture Devlopement, M.P. has also adopted this technology in chickpea under NFSM,A3P programme. In cluster demonstrations conducted under NFSM in 13 districts of M.P., the beneficiary and also the state experience indicated an yield enhancement to the tune of 20% by the use of ammonium molybdate in chickpea.

Keywords: Molybdenum, Chickpea, BNF, Crude protein, Chlorophyll content, N uptake.

Chickpea (*Cicer arietinum* L.) is one of the important annual grain legumes of the world which is used extensively as the primary source of protein for human beings as well as nitrogen for many cropping systems and is widely grown in all Indian states. India is the largest producer of chickpea amounting to 75% of the world production. Madhya Pradesh, Uttar Pradesh, Rajasthan, Maharashtra, Gujarat, Andhra Pradesh and Karnataka are the major chickpea producing States sharing over 95% area (Anonymous 2011 - 2012a). Chickpea is grown in India in an area of 9.93 million ha with a production of 9.53 million tonnes and productivity of 960 kg ha^{-1}. Madhya Pradesh is the leading state in country in terms of chickpea acreage with 3.16 million hectares and also in terms of production with 3.30 million tones with productivity of 1044 ha^{-1} (Anonymous 2014-15a). Madhya Pradesh contributes nearly 31.8% and 34.6% in terms of area and production of chickpea to the nation. Last 5 years (2009-10 to 2013-14) average productivity data of India and M.P. showed enhancement in the chickpea productivity to 922 kg ha^{-1} and 1039 kg ha^{-1} as against 821 and 905 kg ha^{-1} respectively from the preceding last five years (2004-05 to 2008-09). However, looking to the availability of potential and good yielding varieties (20-25 q ha^{-1}) of chickpea, the average productivity of this crop in the state and also at national lavel is still low which needs to be enhanced compulsorily in order to meet the protein demand of the dominating vegetarian population of nation. In Madhya Pradesh, major cultivation of chickpea is done under rain fed conditions with less/imbalance use of fertilizers, limited seed inoculation (10% approximately) with *Rhizobium* and phosphorus solubilising bacterial cultures (Sharma and Gupta 2005) and also crop suffered due to attack of insects, and its susceptibility to wilt and sometimes due to hailstorm and frost.. Further, due to intensive cultivation of soybean and chickpea in Vertisols of M.P some of the micronutrients deficiencies are also observed which might also be affecting the productivity of chickpea which needs proper attention if the productivity is to be enhanced further.

Mineral nutrient deficiencies are a major constraint limiting legume nitrogen fixation and yield. Nodule rhizobia can fix nitrogen effectively only if the plant is adequately supplied with all the mineral elements essential for active growth (Russel 1977). In this context elements like P, Mo, Fe, Zn and Co can play an important role (SubbaRao 1977). Molybdenum is a trace element found in the soil and is required for growth of most biological organisms including plants (Agarwala et al. 1978). Nodule formation requires more molybdenum than does the host plant, and in some symbioses nitrogen fixation may be specifically limited by low availability of Ca, Co, Cu and Fe (Graham et al. 1988).

Gupta et al. (1991) and Hale et al. (2001) stated that the molybdenum is a component of some bacterial nitrogenase and, therefore, is especially important for plants that live in symbiosis with nitrogen-fixing bacteria. It was also reported that molybdenum is also essential for nitrate reductase and nitrogenase enzyme activity (Westermann 2005) and *Rhizobium* bacteria fixing nitrogen needs molybdenum during the fixation process (Vieira et al. 1998). Molybdenum is a component of nitrate reductase, nitrogenase, xanthine oxidase/dehydrogenase and sulphite oxidase. Biological nitrogen fixation (BNF) is catalysed by the Mo- containing enzyme nitrogenase essentially comprising of Mo-Fe-S protein and a Fe-S cluster protein which directly transfers electrons to N_2. Because of its involvement in BNF, Mo requirement of nodulation legumes is particularly high. Further nitrate is reduced by nitrate reductase (NR) enzyme in cytoplasm by transfer of electrons from Mo to NO_3. Molybdenum is also involved in protein biosynthesis through its effect on ribonuclease and alanine aminotransferase activity and it also affects the formation and viability of pollens and development of anthers. In legumes, Mo serves an additional function: to help root nodule bacteria to fix atmospheric N (Campo et al. 2000). Mo deficiency symptoms are often similar to N deficiency. In legumes, the nitrogen-fixing ability of soil microorganisms is severely hampered by Mo deficiency, rendering them N-deficient. Deficiency of molybdenum cause poor assimilation of atmospheric nitrogen fixation in chickpea.

Molybdenum is reported to be found deficient in 18% of the analyzed (227) soil samples of M.P. (Tandon 1995). In another report it is mentioned that out of 32867 soil samples of M.P analysed for various micronutrients, 18% showed Mo deficiency (Anonymous 2011). Still there is an urgent need for exploring and analyzing large number of soil samples for Mo status and also for reviewing for the critical limit. Gaur et al. (2010) stated that chickpea meets 80% of its nitrogen (N) requirement from symbiotic nitrogen fixation and can fix up to 140 kg N ha^{-1} from air. The availability of molybdenum is often low in high clay soils (Vertisols of Madhya Pradesh and Gujarat in India) and laterites, but it is high in saline and alkaline soils. Molybdenum deficiency causes reduction in the number and size of flowers and many of them fail to mature leading to lower seed yield.

Gupta et al. (2006) in a study conducted in black soils of experimental field of RAK College of Agriculture, Sehore, MP found that these soils have shown molybdenum below the critical limit (0.016 mg kg^{-1}) extracted through Lakanen and Ervio (1971) extractant. With the background of significant role of Molybdenum in BNF and nitrogen assimilation and its likely reduced availability in soils with high clay content at the site of N fixation in root nodules. In this article, a review of research work has been done on molybdenum application in chickpea in MP and also at other locations recently during last ten years have been compiled.

Symbiotic Traits

Number and dry weight of nodule at 45 DAS recorded significant increase in the entire Mo and Fe fortified treatments over RDF. Furthermore, nodule number and its dry weight under RDF + *Rhizobium* + PSB + 0.5 and 1.0 kg AM ha^{-1} as soil application, RDF + *Rhizobium* + PSB + 0.5 and 1.0 g AM kg^{-1} seed as seed treatment, and RDF + *Rhizobium* + PSB + 1.0 g $FeSO_4$ kg^{-1} seed as seed treatment + 0.5 and 1.0 g AM were significantly higher over both RDF alone (with 15 nodules & 26 mg nodules dry weight $plant^{-1}$) and RDF + *Rhizobium* + PSB (21 nodules & 40 mg nodules dry weight $plant^{-1}$).

Significant increase in nodule number and its dry weight in treatments receiving AM either as soil application or as seed inoculation in combination with *Rhizobium* + PSB + RDF or with $FeSO_4$ as seed inoculation along with *Rhizobium* + PSB + RDF might be due to better root and shoot growth together with increased activity of *Rhizobium* + PSB in the rhizosphere as the molybdenum is an essential constituent of nitrogenase which is essential for BNF and favorable activity of *Rhizobium* bacteriod. The results are in agreement with those reported by Deo and Kothari (2002).

Plant attributes

Dry weight per plant recorded at 45 DAS (Table 1) was also significantly higher with all the treatment combinations over control. Moreover, AM + ferrous sulphate or AM in combination with *Rhizobium* + PSB + RDF recorded significantly higher total plant dry weight over that in both RDF (1.98 plant^{-1}) and RDF + *Rhizobium* + PSB (2.18 g plant^{-1}). This might be due to increased plant growth following Mo supplementation in soil as well as seed treatments.

Yield attributes

Significantly higher pods plant^{-1} were recorded under all the treatments than in RDF (Table 1). Moreover, the treatments viz., 0.5 and 1.0 kg ha^{-1} AM as soil application + *Rhizobium* + PSB + RDF, 0.5 and 1.0 g AM kg^{-1} seed as seed treatment with *Rhizobium* + PSB + RDF and 0.5 and 1.0 g AM + 1.0 g $FeSO_4$ kg^{-1} seed as seed treatment with *Rhizobium* + PSB + RDF produced significantly higher pods plant^{-1} over that in RDF + *Rhizobium* + PSB inoculation. Here both soil and seed application of molybdenum in presence of *Rhizobium* + PSB + RDF was equally effective. Enhanced BNF and nitrogen metabolism coupled with better P utilization resulted in favorable effect on pods plant^{-1} in all the treatments receiving molybdenum (Ali and Mishra 2001). These findings were in agreement with Shil et al. (2007) for calcareous soils.

N and P Uptake

Nitrogen and Phosphorous uptake by plants significantly increased with AM application (Table 2) and the maximum uptake (77.8 kg N and 5.15 kg P ha^{-1}) was analyzed under 1.0 kg AM ha^{-1} as soil application + *Rhizobium* + PSB + RDF. Increase in N and P uptake by plants following supplementation of AM and $FeSO_4$ might be attributed to enhanced BNF following better nodulation and N assimilation due to higher nitrogenase and nitrate reductase activities with use of Mo and Fe (Shil et al. 2007).

Chlorophyll content in leaves

Highest chlorophyll content (6.03mg g^{-1} fresh leaves) was observed with 1.0 kg AM ha^{-1} as soil application + *Rhizobium* + PSB + RDF. Increase in chlorophyll content

Table 1. Effect of bio fertilizers and micronutrients on symbiotic traits and yield attributes of Chickpea (Pooled mean of 2007-08 and 2008-09)

Treatments	Nodule plant^{-1} at 45 DAS	Nodule dry weight mg plant^{-1}at 45 DAS	Total plant dry weight g plant^{-1} at 45 DAS	No of pods plant^{-1}
T_1. Control (RDF)	15	26	1.98	22.8
T_2. RDF + *Rhizobium*(Rh) + PSB	21	40	2.18	25.3
T_3. RDF + 0.5 kg AM ha^{-1}in soil + (Rh) + PSB	26	54	2.44	29.8
T_4. RDF + 1.0 kg AM ha^{-1}in soil + (Rh) + PSB	27	54	2.56	31.1
T_5. RDF + 0.5 g AM/ kg^{-1} seed + (Rh) + PSB	28	56	2.39	28.3
T_6 RDF + 1.0g AM kg^{-1} seed + (Rh) + PSB	27	61	2.47	30.2
T_7. RDF + 0.5 g AM + 1.0g $FeSO_4$ kg^{-1} seed + (Rh) + PSB	27	60	2.37	28.8
T_8. RDF + 1.0 g AM + 1.0g $FeSO_4$ kg^{-1} seed + (Rh) + PSB	30	65	2.47	30.3
CD at 5%	3.1	4.5	0.10	1.45
CV (%)	15.2	11.5	4.8	6.3

AM =Ammonium molybdate
Source:Gupta and Gangwar (2012)

due to Mo as soil application or seed treatment with or without $FeSO_4$ might be due enhanced BNF and assimilation of complementary nutrients caused by favorable effect on nitrogenase and nitrate reductase activities. Kanter 2003 also reported similar increase in chlorophyll content in leaves due to *Rhizobium* inoculation in chickpea.

Protein content in chickpea grain

Protein content also significantly increased in all the AM treatments over RDF (Table 2). The highest protein content (22.73%) was analyzed under 1.0 kg AM as soil application + *Rhizobium* + PSB + RDF. Increase in protein content in seed with Mo and Mo + Fe along with *Rhizobium* + PSB might be attributed to favorable effect of these nutrients on nitrogenase and nitrate reductase activities resulting in increased BNF and N assimilation. The findings are in agreement with Deo and Kothari (2002).

Seed yield

Seed yield in chickpea increased significantly in all the treatments over control (Table 3). The treatment *Rhizobium*

Table 2. Effect of bio fertilizers and micronutrients on nutrient uptake, chlorophyll and protein content of chickpea (Pooled mean of 2007-08 and 2008-09)

Treatments	N uptake (kg ha^{-1})	P uptake (kg ha^{-1})	Chlorophyll content (mg g^{-1}) of leaves	Protein content (%)
T_1. Control (RDF)	51.8	3.12	3.54	20.41
T_2. RDF + Rhizobium(Rh) + PSB	58.0	3.63	4.00	20.74
T_3. RDF + 0.5 kg AM ha^{-1}in soil + (Rh) + PSB	71.5	4.61	5.81	22.10
T_4. RDF + 1.0 kg AM ha^{-1}in soil + (Rh) + PSB	77.8	5.15	6.03	22.73
T_5. RDF + 0.5 g AM/ kg^{-1} seed + (Rh) + PSB	66.0	4.15	4.78	21.85
T_6 RDF + 1.0g AM kg^{-1} seed + (Rh) + PSB	72.5	4.51	5.52	22.40
T_7. RDF + 0.5 g AM + 1.0g $FeSO_4$ kg^{-1} seed + (Rh) + PSB	68.0	4.46	5.01	21.99
T_8. RDF + 1.0 g AM + 1.0g $FeSO_4$ kg^{-1} seed + (Rh) + PSB	73.7	3.83	5.57	22.29
CD at 5%	2.50	0.23	0.27	0.35
CV (%)	5.70	7.20	6.3	11.7

AM =Ammonium molybdate , Source:Gupta and Gangwar (2012)

Table 3. Effect of bio fertilizers and micronutrients on seed yield and economics of chickpea

Treatments	Mean grain yield (kg ha^{-1})	% increase in yield	Economic viability	
			Additional cost over control (Rs)	Additional net return over control (Rs)
T_1. Control (RDF)	1253	-	-	-
T_2. RDF + *Rhizobium*(Rh) + PSB	1386	10.6	50	2344
T_3. RDF + 0.5 kg AM ha^{-1}in soil + (Rh) + PSB	1640	30.9	1050	5946
T_4. RDF + 1.0 kg AM ha^{-1}in soil + (Rh) + PSB	1753	39.9	2050	6950
T_5. RDF + 0.5 g AM/ kg^{-1} seed + (Rh) + PSB	1534	22.4	130	4928
T_6 RDF + 1.0g AM kg^{-1} seed + (Rh) + PSB	1659	32.4	210	7098
T_7. RDF + 0.5 g AM + 1.0g $FeSO_4$ kg^{-1} seed + (Rh) + PSB	1582	26.3	146	5776
T_8. RDF + 1.0 g AM + 1.0g $FeSO_4$ kg^{-1} seed + (Rh) + PSB	1684	34.4	226	7532
CD at 5%	114	-		
CV (%)	9.8			

Cost of inputs:AM =Ammonium molybdate Commercial Grade Rs 2000 kg^{-1}, Rhizobium &PSB inoculants Rs 50 ha^{-1}, $FeSO_4$ Rs.200 kg^{-1},Chickpea (Gram) grain Rs 1800 q^{-1}

+ PSB + RDF + 0.5 and 1.0 kg AM as soil application, *Rhizobium* + PSB + RDF + 0.5 and 1.0 g AM kg^{-1} seed as seed treatment, and *Rhizobium* + PSB + RDF + 1.0 g $FeSO_4$ kg^{-1} seed as seed treatment + 0.5 and 1.0 g AM significantly increased seed yield of chickpea over both RDF and RDF + *Rhizobium* + PSB. Increase in seed yield due to Mo application along with *Rhizobium* + PSB + RDF might be due to enhanced nodulation and BNF, N and other complementary elements assimilation as a consequence of favorable effect of Mo and Mo-Fe on nitrogenase activity in nodules and nitrate reductase activity in plant system. The result of this investigation also corroborated the findings of Deo and Kothari (2002), Ahlawat et al. (2007), Shil et al. (2007) and Valenciano et al. (2010).

Economics

A maximum net return of Rs. 7532 ha^{-1} was occrued under 1.0 g AM + 1.0g $FeSO_4$ kg^{-1} seed as seed treatment with *Rhizobium* + PSB + RDF and was followed by the treatment 1.0 g AM kg^{-1} seed as seed treatment with *Rhizobium* + PSB + RDF (Rs 7098 ha^{-1}).

Evaluation of Molybdenum application in chickpea at other locations in Madhya Pradesh

In order to verify the results obtained at Sehore centre by the application of molybdenum multilocational testing trials at four different locations in MP viz; Sehore, Indore, Gwalior and Ujjain centers were conducted during 2009-10. Results obtained at all the locations showed significant enhancement in the nodule dry weight $plant^{-1}$, N uptake and seed yield of chickpea by the use of molybdenum either as soil application or supplementation with seed.

Evaluation of molybdenum application in chickpea in research trials at other locations in India

Shivran (2014) in a three year study on chickpea in Kota soils of Rajasthan reported significant enhancement in

Table 4. Effect of microbial (*Rhizobium* + PSB) inoculation and supplementation of micronutrients either in soil or with seed on chickpea in MP (2009-10)

Treatments	Mean of all four centers (Sehore,Indore,Gwalior,Ujjain)			Percent increase
	Nodule dry wt. (mg $plant^{-1}$)	N* Uptake (kg ha^{-1})	Grain Yield (kg ha^{-1})	
Control (RDF)	41	81.3	1870	
RDF + *Rhizobium*(Rh) + PSB	60	94.9	2045	9.3
RDF + 0.5 kg AM ha^{-1} in soil + (Rh) + PSB	69	111.7	2279	21.9
RDF + 1.0 kg AM ha^{-1} in soil + (Rh) + PSB	77	114.9	2359	26.2
RDF + 1.0g AM kg^{-1} seed + (Rh) + PSB	73	115.3	2370	26.7
RDF + 2.0g AM kg^{-1} seed + (Rh) + PSB	130	116	2331	24.7

*Mean of three centres; RDF= Recommended dose of fertilizer; PSB= Phosphate solubilizing bacteria; AM= ammonium molybdate

Table 5. Effect of Molybdenum supplementation with seed inoculation on chickpea yield at Kota and Sriganganagar in Rajasthan

Treatments	Pooled seed yield of chickpea (kg ha^{-1})	
	Kota pooled mean	Junagarh pooled mean
RDF	1531	1538
RDF + Rhizobium + PSB	1634	1805
RDF + 1gAmmo.Molybdate kg^{-1} seed + Rhizo. + PSB	1817	1880
RDF + 2gAmmo.Molybdate/ kg^{-1} seed + Rhizo. + PSB	1549	1833
CD at 5 %	126	214

pods plant^{-1} and seed yield due to the application of 1g ammonium molybdate kg^{-1} seed along with *Rhizobium* + PSB + RDF over the recommended dose of fertilizer.Net return was also higher under this treatment.

Coating of soybean and chickpea seed with ammonium molybdate @1.0 g kg^{-1} seed significantly increased the yield (21.8 per cent) over control in a Vertisol of Jabalpur (Anonymous 2013-14a).

Front Line Demonstrations

In order to validate the results and to disseminate this technology, front line demonstrations were conducted under AICRP on Chickpea by Sehore, MP centre during 2011-12 to 2014-15. The data (Table 6) on molybdenum application in chickpea @ 1g ammonium molybdate kg^{-1} seed alongwith *Rhizobium* + PSB indicates yield enhancement ranging from 20.1 to 27% over no

Table 6. Effect of use of molybdenum supplementation with seed inoculation (Ammonium molybdate(@1g kg^{-1} seed) under FLD in Madhya Pradesh

Year	No. of demonstration	Grain yield (kg ha^{-1}) 100 kg DAP + with Rhizo. + PSB inoculation	Grain yield (kg ha^{-1}) 100 kg DAP + Molybdenum seed treatment with Rhizo. + PSB inoculation	% increase in grain yield
2011-12	05	850	1084	27.0
2013-14	05	930	1160	24.7
2014-15	05	1066	1280	20.1

Table 7. Demonstrations under Tribal Sub plan on Technological Modules in Rajgarh District of M.P. (Improved variety + Mo application in Chickpea) 2012-13

Village and District of Demonstration	No of Demo.	Farmers practice	Average yield (kg ha^{-1}) 100kgDAP + Molybdenum @ 1g AM kg^{-1} seed	Average yield increase (kg ha^{-1})	Average yield increase (%)
Padia and Sondita (Lodwar area Block&District Rajgarh)	27	1162	1603	441	38.0
Keelkheda (Block Biora -Dist Rajgarh	16	1124	1536	412	36.7
Kondiapura-Mundla,Badba,Molpura - Rajgarh	07	1211	1624	413	34.1
Total Demonstrations	50	1166	1588	422	36.2

Am= Ammonium Molybdate

Table 8. Mo Demonstrations (@1g Ammo.molybdate kg^{-1} seed with *Rhizobium* + PSB inoculation) in Chickpea rabi 2013-14

Name of District	No of Demonstrations	Mean Yield control (q ha^{-1})	Mean yield with Molybdenum (q ha^{-1})	% Increase
Sehore	9	13.34	16.22	21.6
Bhopal	6	16.79	20.68	23.2
Rajgarh	9	14.10	18.80	35.8
Indore	12	15.00	18.61	24.1
Dewas	13	14.68	18.44	25.6
Gwalior	05	23.75	26.50	11.6

molybdenum (*Rhizobium* + PSB only) in 15 trials. (Anonymous 2011-12b, Anonymous 2013-14b and Anonymous 2014-15b).

In other 50 demonstrations conducted under tribal sub plan in Rajgarh district of M.P. during 2012-13 with the use of 100DAP ha^{-1} + Ammonium molybdate @1g kg^{-1} seed resulted on an average 1588 kg ha^{-1}chickpea yield over the farmers practice yield of 1166 kg ha^{-1} which indicates an yield improvement of 36.2% by improved practices as against farmers practice (Table 7).

On Farm Testing by KVK'S

Large number of demonstrations trials (54) at farmers field in chickpea crop on the application of molybdenum during 2013-14 at Sehore, Bhopal, Rajgarh, Dewas ,Indore and Gwalior districts during rabi 2013-14 indicate that the use of molybdenum (@1g Ammo. Molybdate kg^{-1} seed with *Rhizobium* + PSB inoculation) produces yield increase to the tune of 11.6 to 35.8% (average increase of 23.6%) over no molybdenum application (Anonymous 2014). State experience indicated an yield enhancement to the tune of 20% by the use of ammonium molybdate in Bengal garm (Anonymous 2012).

Impact assessment

For assessing the impact of technology five years mean of productivity of chickpea in Madhya Pradesh before the recommendation (2004-05 to 2008-09) and after the recommendation of molybdenum technology (2009-10 to 2013-14) were calculated and are shown in Table 9. The data indicate that the average productivity of chickpea in M.P. increased from average 905 kg ha^{-1} (2004-05 to 2008-09) to 1039 kg ha^{-1} (2009-10 to 2013-14). This shows 14.8% increase in the productivity of chickpea during these 5 years over the preceding 5 years.

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Table 9. Change in productivity of chickpea in M.P. on 5 years mean basis

5 years preceding to Molybdenum recommendation	Chickpea productivity before Molybdenum recommendation (kg ha^{-1})	5 years after the Molybdenum recommendation	Chickpea Productivity after the Molybdenum recommendation (kg ha^{-1})
2004-05	928	2009-10	1071
2005-06	926	2010-11	865
2006-07	980	2011-12	1081
2007-08	711	2012-13	1135
2008-09	981	2013-14	1044
5 years average yield (kg ha^{-1})	905		1039

Data Source: Project Coordinators Report on chickpea (2014-15a) AICRP on Chickpea, -IIPR ,Kanpur

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Potential uses of saline soils in agriculture

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Abstract

Soil salinization/ alkalinization is one of the most serious land degradation problems affecting approximately 10 % of the total land surface of the globe. Out of an estimated area of 173.64 million ha of total degraded area approximately 6.73 million ha is affected by salinity/ sodicity. Agricultural production is drastically reduced in most salt affected soils which are either lying barren or produce very poor crop yield owing to their in hospitable properties. Soil salinity and waterlogging are issues that need to be considered in much broader perspective. The study showed that pearl millet-wheat; pearl millet-barley; pearl millet- mustard; sorghum (fodder)- wheat and sorghum (fodder)- mustard cropping sequences are more remunerative in saline soils. In India the problematic areas with high water table cover 2.6 million ha while 3.4 million ha suffer from surface water stagnation. The prime requirement for successful crop production in waterlogged saline soils is that of reversing the flux of water to enhance salt leaching. To achieve this provision of natural (surface) or artificial (subsurface-vertical/horizontal) drainage is essential according to the prevailing situation. Saline/ waterlogged saline lands can be put to alternate land use system such as for growing salt tolerant trees, grasses and other halophytic plants.

Keywords: Salinity, Sodicity, Reclamation, Leaching, Drainage and alternate land use

The problem related to the salinity/alkalinity occurs in varying intensities in more than 120 countries. The soils more prominently witness in the arid and semi arid areas, though many areas in the humid climate are also affected due to in grace of sea water. Out of an estimated area of 173.64 million ha of total degraded area approximately 6.73 million ha is affected by salinity sodicity (Mandal et al. 2010). These problem soils are spread widely in the country covering arid and semiarid areas of Indo-Gangetic plains, arid areas of Rajasthan and Gujarat, black soil region and coastal areas. About one third of the salt affected soils occur in Rajasthan, Gujarat and other black soil region.

Causes of accumulation of salts in soils

Capillary rise from subsoil salt beds or from shallow brackish ground water. Indiscriminate use of irrigation waters of different qualities. Weathering of rocks and salts brought down from the upstream to the plains by rivers and subsequent deposition along with alluvial materials. Ingress of sea water along the coasts. Salt laden sand blown by sea winds.Lack of natural leaching due to topographic situation, especially in arid and semi arid regions.

Reclamation and management of saline soils

Leaching of salts

The amount of crop yield reduction depends on crop growth, the salt content of soil, climatic condition etc. If the concentration of salts in the root zone is very high, crop growth may be entirely prevented. To improve crop growth in such soils the excess salts must be removed from the root zone. The term reclamation of saline soils refers to the methods used to remove soluble salts from root zone. The methods include:

Scraping

Removing the salts that have accumulated on the surface of the soils by mechanical means has had only a limited success although this method might temporarily improve crop growth the ultimate disposal of salt still poses a major problem.

Flushing

Washing away the surface accumulated salts by flushing water over the surface is some time use to desalinize soils having surface salt crust.

Leaching

This is by far the most effective procedure for removing the salts from the root zone of soils. Leaching is most often accomplished by ponding fresh water on the soil surface and allowing it to infiltrate. Leaching is effective when the salty drainage water is discharged through sub surface drains that carry the leached salts out of the area under reclamation. Leaching may reduce salinity levels in the absence of artificial drains when there is sufficient natural drainage, i.e. the ponded water drains without raising the water table. In some parts of India, leaching is the best accomplished during the summer months because this is the time when the water level is deepest and the soil is dry. This is the only time when large quantities of fresh water can be diverted for the reclamation.

Amount of water for leaching

It is important to have reliable estimate of the quantity of water required to accomplish salt leaching. The initial salt content of soil, desired levels of soil salinity after leaching, depth to which reclamation is desired and soil characteristics are the major factor that determine the amount of water needed for reclamation. A thumb rule is that a unit depth of water will remove nearly 80 % of salts from a unit soil depth.

The extent of leaching required is governed largely by the initial soil salinity and its nature, salt tolerance of the crops to be grown and the depth of the water table. Regarding the depth of the soil to be reclaimed, it has been a general thinking that the salts from the entire depth of the root zone should be removed when attempting reclamative leaching. Some of the recent studies on behavior of crops in relation spatial and temporal change in salinity (Minhas and Gupta 1992 and 93) show that bringing down the salinity of surface 45-60 cm of soil below the threshold limits. Moreover, as most saline soils occur in areas with deficiency of high quality waters, the efforts during leaching must aim at improving the efficiency of salt removed which is defined in terms of quantity of soluble salts leached per unit volume of water applied. The amount of water required for leaching of salts to predetermined level can be obtained from breakthrough or leaching curves

Table 1. Extent and distribution of salt affected soils in india (Mandal et al. 2010)

State	Area of salt affected soils (ha)			
	Saline	Sodic	Coastal saline	Total
Andhra Pradesh	0	196609	77598	274207
A & Nicobar Islands	0	0	70000	70000
Bihar	47301	105852	0	153153
Gujarat	1218255	541430	462315	2222000
Haryana	49157	183399	0	232556
J & K	0	17500	0	17500
Karnataka	1307	148136	586	150029
Kerala	0	0	20000	20000
Maharashtra	177093	422670	6996	606759
M.P.	0	139720	0	139720
Orissa	0	0	147138	147138
Punjab	0	151717	0	151717
Rajasthan	195571	179371	0	374942
Tamil Nadu	0	354784	13231	368015
U.P.	21989	1346971	0	1368960
W.B.	0	0	441272	441272
Total	1710673	3788159	1239136	6737968

which essentially relate (Cf-Ci)/(Co-Ci) with the number of pore volume or depth of water displaced from a given soil depth. Here, Co is the initial salt concentration Cf is the final salt concentration after leaching and Ci is the leaching water salinity or the salinity of the surface few centimeters after equilibrium with the leaching water. The traditional method of leaching saline soils was involved ponding water on the field for long periods of time where leaching usually progressed under nearly saturated conditions. Thus it was opined earlier as a thumb rule (Reeve et al. 1955) that salts from soils could be removed by leaching with a depth of water equivalent to the depth of soil to be reclaimed. But later controlled studies with soil columns and field leaching trials have shown the leaching efficiency to depend upon the soil - water volume that need to be displaced and the efficiency of displacement of this water. Thus, the depth of water required and the time needed for reclamation has been observed to vary with

- Soil properties; soil texture, soil structure, soil pore geometry, cracking phenomenon, clay mineralogy and physico-chemical behaviour of clays.
- Initial salt content and chemical composition of soluble salts.
- Salt content and the chemical composition of water used for leaching.
- Leaching techniques and scope of planting a salt tolerant crop during reclamation.

Soil Type

Several studies where the disturbed soils where repacked in columns (Ghuman et al. 1975, Singh et al. 1979) have shown a surface slug of chloride to be displaced to deeper depth and the spread of solute to be greater in coarse textured soils of lower retentively than in the fine textured soils when the amount of water applied was kept the same. In field soils large variations in water conducting pores and aggregate sizes of clay soils especially when cracked further contributes towards decreasing leaching efficiency in addition to greater volume of solution to be displaced. Thus higher water requirements of heavier soils for attaining particular leaching were evident from different field trials (Beyce 1972; Oster et al. 1972 and Verma and Gupta 1989) and these have been summarized in Table 2.

Water application method

It appears that leaching efficiency should increase when leaching takes place at water contents below saturation. Such a situation under field conditions may prevail during intermittent water application, low intensity rainfall or use of sprinklers. Observed that intermittent sprinkling of water (0.03 mm applied in 30 sec after every 0.5 hr and plot covered to avoid evaporation) required 26.2 cm water to reduce salinity to the same level as with 75 cm of continuous ponding (infiltration rate 2 mm hr^{-1}). Miller et al. (1965) monitored leaching of surface applied chloride as KCl for three methods of water applications, viz. continuous ponding intermittent 5 cm and 15 cm splits, when the suction 30 cm soil depth equaled 150 m bar and observed that continuous ponding spreads the salts more uniformly through the soil profile and promotes higher surface concentration whereas the salt move out as a slug with more pronounced peaks and smaller surface concentration with intermittent ponding. Chloride distribution profiles were comparable after 90 and 60 cm water had entered the soil with continuous and intermittent ponding, respectfully. Oster et al. (1972) during reclamation of Holtville silty clay loam confirmed that the intermittent ponding was more efficient than continuous flooding or sprinkling and half as much water was required for same reduction in salinity.

Minhas and Khosla (1987) observed the occurrence of dense layer at the surface of barren saline soils of water-logged areas which reduces the pore size variations and induces unsaturated flow in lower layers negating the benefits to be achieved with intermittent leaching. These studies thus imply that not much benefit is expected in terms of water requirements for leaching of most saline soils of alluvial plains of India, which are usually lighter textured(loamy sand- silty loam) band where high evaporative demands prevail except during winter. The other disadvantages of intermittent ponding are that it involves more costs on labour and supervision as well as special equipment when sprinklers are used.

Monsoon induced salt leaching

One of the fortunate situations with the continental monsoon climate of India is the concentration of rains in a short span of 2 - 3 months (July - September). Thus, water penetrating in to soils during this period usually exceeds the evapo-transpiration demands of crops and this induces leaching of salts, accumulating in the surface of soil layers with the upward movement from shallow and saline water-table or with saline irrigation to winter crops. Thus, integration of the expected leaching with monsoon rains into reclamative leaching programmes is also of utmost importance for reducing drainage volumes. Besides the amount and frequency of rains during monsoon season, salt leaching is also governed by soil texture, as is obvious from the following hyperbolic relations developed by Minhas and Gupta (1992) from a number of experiments conducted over different rain fall and soil conditions.

Characteristics and Extent of waterlogged saline soils

Saline soils are usually formed as a result of the salt stored in the soil profile and or groundwater being mobilized by extra water provided by human activities such as irrigation. The extra water raises the water table or increases pressures of confined aquifers to create an upward movement to the water table. When the water table comes closer to soil surface, water is evaporated, leaving salts behind and causing land salinization. In India the problematic areas with high water table cover 2.6 million ha while 3.4 million ha suffer from surface water stagnation. The characteristic features of some of the typical saline pedons are included in table 3. Wide range of options are available for control of salinity and water logging in canal command areas but technical, economic, social and political considerations are the major factors which influence their large scale implementation as most of the options involve community actions.

Table 2. Water requirements for salt leaching in different soils as affected by method of water application

Source	Soil Texture	Water application method	Dw/Ds for 80 % salt removal (cm cm^{-1})
Reeve et al. (1955)	Silty clay loam	Continuous	1.5
Deilman (1963)	Loam-silt loam	Continuous	0.4
	Clay loam silt loam	Continuous	1.15
	Silt loam	-	0.9
Talsma (1967)	Loam	-	0.7
Beyce (1972)	Peat	Continuous	2.58
		Intermittent	4.43-4.17
		-do-(sprinkler)	2.25
Oster et al. (1972)	Silty clay loam	Continuous	1.2
		Intermittent	0.5
		Sprinkling	0.8
Laffelaar and Sharma (1977)	Sandy loam	Continuous	0.3(1.5 PV)
		Intermitten	0.68(1.5 PV)
Khosla et al. (1979)	Sandy loam	Continuous	0.4
Dahiya et al. (1981)	Sandy loam	Continuous	0.3
		Intermittent	0.15
Sharma and Khosla (1984)	Silt loam (sodic water irrigated)	Continuous	0.9
Prichard et al. (1985)	Saline organic	Continuous	2.25
		Intermittent	2.25
Chawla (1985)	Loamy sand - Sandy loam	Continuous	0.4
		-do-saline water	0.6
Minhas and Khosla (1986)	Silt loam (after equating infiltration and redistribution periods)	Continuous	0.89
		Intermittent	0.91
		-do-(no evaporation)	0.71
Minhas and Khosla (1987)	Loamy sand over Sandy loam	Continuous	0.40
		2 splits	0.64
Rao et al. (1987)	Silt loam	Continuous	0.60
Verma and Gupta (1989)		Continuous	0.60
		Intermittent	0.60

Source: Minhas (1998)

Reclamation of waterlogged saline soils

Provision for Drainage

The prime requirement for successful crop production in saline soils is that of reversing the flux of water to enhance salt leaching. To achieve this and to maintain water table depth deep enough to provide adequate root development and aeration, the provision of natural or artificial drainage is considered essential. The major drainage techniques being pursued in India include both the surface and subsurface (vertical, horizontal) drainage. These are summarized below:

Surface Drainage

For removing excessive surface water, land shaping is done in such a way that water flows over the field surface to furrows or ditches and ultimately into the waterways. In shallow water table areas, surface drains are created deep enough to intercept ground water, which will then enter the main drain. The rate of groundwater flow into the drain depends on soil permeability and depth of water table. The deeper a drain, the greater is the width of adjacent land affected by the drawn down of the groundwater. The use of surface drains to control water table suffers from the disadvantages of loss of land, hindrance to farming operations, heavy maintenance costs

Table 3. Some characteristics of salt affected soils pedons

Depth (cm)	pH_2	ECe (dSm^{-1})	$CaCO_3$ (%)	O.C. (%)	Clay (%)	ESP
Aquic Natrustalf (Karnal, Haryana)						
0-10	10.6	22.3	5.1	0.14	12.5	96.0
10-48	10.2	6.3	8.9	0.10	18.9	91.0
48-76	9.8	4.2	9.4	0.07	22.7	88.0
79-104	9.5	2.3	12.6	0.05	21.2	85.0
104-163	9.6	1.3	13.8	0.04	31.8	69.0
Typic Natrustalf (Akbarpur, Kanpur, UP)						
0-20	10.0	60.5	4.6	0.30	27.4	75.0
20-64	9.9	4.7	4.8	0.28	37.0	74.0
64-97	9.3	0.9	1.2	0.21	38.6	33.0
97-121	8.5	0.6	5.6	0.17	33.2	18.0
121-180	8.4	0.4	10.0	0.16	25.6	10.0
Typic Heplustert (Barwaha, Khargone, MP)						
0-20	8.5	8.9	7.5	0.63	42.8	58.0
20-44	8.5	8.9	11.5	0.43	53.4	74.0
44-84	8.6	5.9	14.5	0.43	44.2	74.0
84-106	8.6	4.8	19.0	0.24	39.6	63.0
106-145	8.6	2.3	19.0	0.12	37.5	63.0
145-166	8.5	1.6	20.0	0.06	35.0	45.0
Typic Ustochrept (Sampla, Haryana)						
0-19	6.8	65.2	0.9	-	16.5	3.0
19-38	7.2	6.9	0.4	-	17.2	3.0
38.79	7.3	4.2	1.8	-	18.2	4.0
79-119	7.4	3.4	3.8	-	16.5	3.0
119-147	7.4	4.0	2.0	-	17.2	3.0
Typic Natrargid (Banaskantha, Gujarat)						
0-10	8.0	68.9	3.7	0.32	15.8	45.0
10-23	8.2	44.3	6.5	0.30	21.9	41.0
23-46	8.5	32.8	5.6	0.30	22.1	43.0
46-71	8.2	29.5	13.0	0.25	23.3	63.0
71-87	8.1	25.5	22.3	0.21	17.2	52.0
87-112	8.0	20.2	23.3	0.21	17.6	57.0
112-140	8.1	30.1	36.4	0.15	22.5	43.0
140-170	7.6	32.7	27.9	0.12	16.1	62.0

in terms of weed control and overland instability of banks. However, properly designed surface drains can provide adequate drainage in agricultural farms to reduce ponding problems during monsoon and check rise in water table. A 3-tier system of optimum rainwater management was suggested (Gupta and Narayana 1972, Narayana 1979. The main features of this system are:

- Part of the rainfall should be collected in the cropland till such time and in an amount that will not be harmful to the crops e.g. the experiments showed that excess rainwater up to 15 cm could be stored in bunded rice field.
- After storage in the cropland, the excess water from the catchment should be collected in the dugout ponds located in the lower regions of the catchment. The stored water can be utilized for irrigation during the dry spells.
- The remaining excess water is then led into the regional drainage system.

Sub-surface Drainage

Two manmade systems of sub-surface drainage, viz., vertical and horizontal are in vogue. Vertical drainage is mainly achieved by pumping out ground water through the tube wells and the horizontal drainage involves engineering structures laid parallel to the ground surface. In other words, these structures work like tube wells laid horizontally. Both types of drainage systems aim at lowering the water table in response to recharge caused by rainfall, irrigation, leaching water etc.

Vertical drainage

The success of vertical drainage system is associated with the presence of favorable unconfined aquifers within 50 cm depth below the ground surface and with the quality of groundwater. The vertical drainage has not been feasible in saline areas due to their poor aquifer yields and saline ground waters. The water tables are rising at alarming rates leading to secondary salinization. For such areas, a multiple well point system has been devised to lower water table by skimming fresh water floating over saline water (Shakya et al. 1995). The system consist of a number of well points are ranged in a line, interconnected to each other through a horizontal pipe line buried at 70 to 100 cm below the ground level which is pumped by a centrally located sump. Similarly, Singh et al. (1994) have tried installation of open wells placed at 150-300 m grid for skimming of good quality water.

Horizontal drainage

Horizontal subsurface drainage is the technique of controlling the water table and salinization by installation of horizontal drains at a certain depth (about 1-5 to 2-5 m) below the surface. The pattern of drains allows the land to drain in to the collectors that carry the water away from the land. The drains are installed at an appropriate depth and are spaced at intervals designed to ensure that the water table in the intervening space does not rise above a given depth. Drainage design parameters are related mainly to the hydraulic conductivity of the soil and drainage criterion, which specifies the required discharge and the hydraulic head. Many useful practical recommendations have emerged from recent installations at different locations in the country (Rao et al. 1990; 1994; Rao and Gupta, 1998). These recommendations are summarized as follows:

- The depth of lateral drains can vary between 1-5-2.0 m depending upon the soil type, nature of crops to be grown and the outlet conditions. Initial and operational costs will escalate with deeper drains, in addition to the trench caving problems during the laying process.
- The lateral drain spacing of 50-75 m in alluvial soils and 12-24 m in black soils has been observed to be sufficient to facilitate growing of crops within 2-3 years on lands that have been fallow for considerable time due to salinity problems.
- For many years, tile and concrete pipes have been predominantly use for subsurface drainage. Corrugated plastic drain pipes with small perforations have now become available. The corrugated form makes these pipes more resistant to deformation. They are manufactured in diameters ranging from 50 to 200 mm, and are delivered in coils of different lengths. These have proved to be successful that they are gradually replacing the tile and concrete drain pipes. Corrugated plastic pipes are made of polyvinyl chloride (PVC), polyethylene (PE) and polypropylene (PP). Preference for one of these materials should be based on economic grounds (Kumbhare and Rao, 1994).
- Envelope materials were originally intended to protect the drain pipes against soil particle invasion, but they must also facilitate water inflow by creating a more permeable environment surrounding the pipe. The materials such as sand fine gravel are still widely used. Nowadays synthetic envelope

materials are replacing granular materials. They can easily be wrapped around the drain pipes and do not decay once the drain pipes are installed (Rao et al. 1994; Rao and Gupta, 1998). After the introduction of corrugated plastic drain pipes, techniques have been developed to pre-wrap these pipes with an envelope material in the factory.

- When a seep is fed by a distinct water source as is common in black soil areas, the use of interceptor drains can cut off this excess ground water before it reaches the low lying problem area. Interceptor drains are usually a single tube or open drain placed between the water source and the problem area. Accurate location of the source of excess groundwater and proper placement of the drain are critical to the success of this form of drainage. These drains have been observed to be quite effective for control of salinity in black soils those are usually underlain with bedrocks and sandwiched in between by a highly permeable murrum layer (AICRP-Saline Waters 1998).

Crop management

Tolerance to salinity varies a great deal, almost 10 fold, amongst the crop plants and their genotypes. The inter and intra-generic variations in salt tolerance of plants can be exploited for selecting crops or varieties that produce satisfactorily under a given root-zone salinity. However, the cultivation of high water requiring crops like sugarcane and rice should be avoided as these aggravate the salinity problems. Mass (1986) and Minhas and Gupta (1992) have compiled the salt tolerance limits of important agricultural crops of the different agro-ecological zones of India, which provides a basis for selection of appropriate crops to be grown in rotation. The most common crops for saline areas in alluvial tracts are usually wheat, mustard and barley during rabi and cotton, sorghum (fodder) and pearl millet during kharif. Singh and Sharma (1991) reported that pearl millet- wheat; pearl millet-barley; pearl millet- mustard; sorghum (fodder)- wheat and sorghum (fodder)- mustard cropping sequences were more remunerative in saline soils. Cotton based cropping systems were not of much benefit since the yields of the following rabi crops were low. In the water scarce areas, mustard can replace wheat since the water requirement of the former are lower.

During the initial stages, the interacting zone of roots is limited to surface few inches where most salt concentrate due to the evaporation of water from soils. Hence, germination and early seedling establishment are the most critical stages for most crops in saline soils (Minhas and Gupta 1992). The other critical periods for crops are during the transition to reproductive development, i.e. flowering, Otherwise tolerance to salinity increases with an advancement of age of crops. Under non-steady state conditions such as existing during monsoon climate, wheat responses to initially variable salinity profiles superimposed by various patterns of salinization have been reported by Minhas and Gupta (1993). Although the total salt with which wheat roots interacted during growth period was kept constant, three fold variations in its yields were observed. Independent estimates of response to salinity that existed down to rooting depth at different stages of wheat showed ECe50 (ECe for 50% yield reduction) to increase from 9.1 until crown rooting to 13.2 dSm^{-1} at dough stage. It was thus implied that salt tolerance at critical stages of crop plants changes in response to salinity and modes of salinization. Initial distribution of salinity needs to be considered for effective description of crop responses to salinity.

Soil salinity and waterlogging are issues that need to be considered in much broader perspective. It is stated that all the salt affected soils cannot be economically reclaimed for crop production. Such lands can be put to alternate land use system such as for growing salt tolerant trees, grasses and other halophytic plants. The trees based land use system, because of their higher evapo-transpiration demands, can also contribute toward minimization of secondary salinization through reduction in underground water table. More efforts should be directed towards biodiversity and further exploitation of environmentally and economically useful plants e.g. halophytes with aromatic and medicinal value. In other words bio-saline agriculture should be promoted on salt affected soils.

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Efficient land use planning for medium rainfall regions of central India

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Abstract

In spite of considerable development in irrigation systems in country, rainfed ecosystems are still the spinal cord of the Indian agricultural production system and account more than 60 per cent spreading across the country. Based on the amount of rainfall, the entire country has been grouped in to low (< 750 mm), medium (750-1150 mm) and assured or high (>1150 mm) rainfall regions. Among these regions, the medium rainfall region covers maximum (42 %) area which is spread over eight (out of 21) diverse agro-ecological regions of the country. The agro-ecological regions of India covering medium rainfall zone have highly variable potentials and constraints for agricultural production which need to be addressed with suggestive land use planning to make agricultural system sustainable. With this in view an overview on potential land use planning for medium rainfall region of India has been presented in this paper. Some case studies regarding land use management alongwith future strategies have also been included.

Keywords: Agro-ecological regions, medium rainfall zones, potentials, constraints and land use planning, Indo-Gangetic Plains and Vertisols.

Increasing food production on sustainable basis demands a systematic appraisal of soil and climatic resources of the country to recast / develop an effective alternate land use plan. Since the soil and climatic conditions largely determine the cropping pattern and productivity in that region, the reliable information on agro-ecological regions will help in developing a region/site specific technology including crops/cultivars and effective transfer of agro-technology. According to FAO (1983) a land unit in terms of major climate and length of growing period which is climatically suitable for a certain range of crops and cultivars is referred as an agro-climatic zone.

India was earlier divided in to 24 agro-climatic zones (Krishnan and Singh 1972) using Thornthwait Indices. Later on, the Planning Commission divided the country in to 15 broad agro-climatic zones based on physiography and climate (Khanna 1989) giving the emphasis on development of resources and their fullest utilization in a sustainable manner. Considering the recommendations of Advisory Committee on Agro-ecological Zoning, Chaired by Prof J.S. Kanwar, ex. DDG, ICRISAT, the National Bureau of Soil Survey & Land Use Planning, Nagpur brought out a map of 21 Agro-ecological Regions of India in the form of a Bulletin (Sehgal et al. 1992) wherein efforts were made to delineate regions as uniform as possible introspect of physiographic, climate, length of growing period and soil for macro level land use planning.

Rainfall regions of India

The country has a diverse landscape and a climate varying from highest rainfall in Mawsynram near Cherrapunji (Meghalaya) to the driest parts of western Rajasthan and from a hot and humid southern peninsula to the snow bound Himalayan Mountains. Broadly, the climate of India is of the tropical monsoon type. It is affected by two seasonal winds: the southwest monsoon and the northeast monsoon. The distribution of rainfall is very uneven in terms of time and space. About 72 per cent of the area receives an annual rainfall of not more than 1150 mm (Table 1). Here, our emphasis is on medium rainfall area with special reference to Central India. This area of the country can be divided in to three zones viz. south of 22^0N, between 22^0N and 29^0N, and north of 29^0N (FAO 1983).

Table 1. Area distribution according to annual precipitation

Category	Rainfall (mm)	Area (%)
Dry	0-750	30
Medium	750-1150	42
Assured	1150-2000	20
	> 2000	8

Source: FAO (2005)

South of 22^0N Zone

Being in rainshadow during south-west and north-east monsoon, this zone receives most of the rainfall between June and October. It is warm in winter and hot during remaining period. Daily range of temperature is moderate to large but less during monsoon. Relative humidity is moderate to high in the south-west monsoon period but low at other times.

22^0N to 29^0N Zone

Receiving all the rains during the south-west monsoon period between June to October, it is cool in winter and very hot in summer. The daily range of temperature is large except in the Monsoon period. Relative humidity is low but increases during the monsoon.

North of 29^0N Zone

In this zone, an effectice amount of rainfall is received from December to May, though a large part of the annual raifall occurs during the south-west monsoon period. It is very cold in winter and very hot during summer. Daily range of temperature is large. Relative humidity is moderate but increases during the monsoon period.

Agro-ecological regions of India

The systematic appraisal of agro-ecological regions encompassing relatively homogenous regions in terms of soil, climate, physiography and length of growing period (LGP) is helpful in appropriate land use planing. Accordingly the 21 agro-ecological regions of the country are given below (Sehgal et al. 1992):

1. Western Himalayas (cold arid)
2. Western plains, Kachchh and part of Kathiawar peninsula (hot arid)
3. Deccan plateau (hot arid)
4. Northern plains and Central highlands including Aravallis (hot semi-arid)
5. Central (Malwa) Highlands, Gujarat plains and Kathiawar peninsula (hot semi-arid)
6. Deccan plateau (hot Semi-arid)
7. Deccan plateau (Telangana) and Eastern Ghats (hot semi-arid)
8. Eastern Ghats (T N Uplands) and Deccan Plateau (hot semi-arid)
9. Northern plains (Hot sub-humid-dry)
10. Central highlands (Malwa and Bundelkhand), (hot sub-humid-dry)
11. Deccan plateau and Central Highlands (Bundelkhand), (hot sub-humid)
12. Eastern plateau (Chhattisgarh) (Hot sub-humid)
13. Eastern plateau (Chhota Nagpur) and Eastern Ghats (hot sub-humid)
14. Eastern plains (hot sub-humid-moist)
15. Western Himalayas (Warm sub-humid to humid with inclusion of perhumid)
16. Assam and Bengal Plains (hot sub-humid to humid with inclusion of perhumid)
17. Eastern Himalayas (warm perhumid)
18. North-eastern Hills (Purvachal), (warm perhumid)
19. Eastern Coastal plains (hot sub-humid to Semi-arid)
20. Western Ghats and Coastal plains (Hot humid-perhumid)
21. Islands of Andaman-Nicobar and Lakshadweep (hot humid to perhumid)

Agro-ecological regions of medium rainfall (750-1150 mm) zone of India

Out of 21 diverse agro-ecological regions, the medium rainfall zone is spread over eight major agro-ecological regions (Fig 1) which are briefly described below:

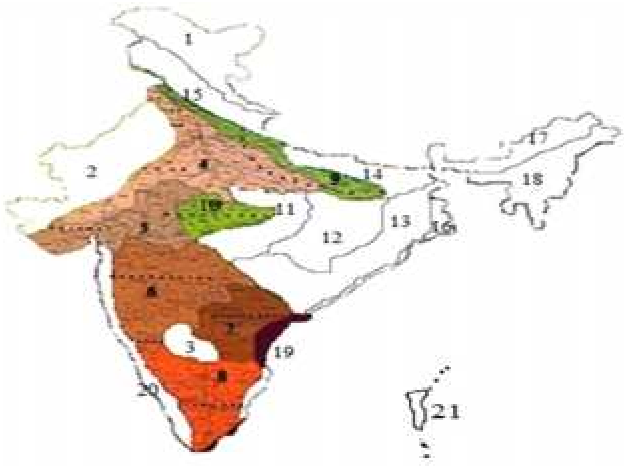

Fig 1. Agro-ecological regions of India in medium rainfall zone

Northern Plains and Central Highlands

The ecoregion covers the Northern Punjab plains, Ganga-Yamuna Doab and Rajasthan uplands. It covers an area of 32.2 m ha, representing 9.78 per cent of the total geographical area of the country. This is further divided into four eco-subregions viz. (i) North Punjab plains, Ganga-Yamuna Doab and Rajasthan Upland, hot, dry semi-arid; (ii) North Gujarat plains (inclusive of Aravalli range and East Rajasthan uplands), hot dry semi-arid; (iii) Ganga Yamuna Doab, Rohilkhand and Avadah Plain, hot moist semi-arid and (iv) Madhya Bharat Pathar and Bundelkhand Uplands, hot moist semi-arid.

Distribution

- Uttar Pradesh: Meerut, Muzzafarnagar, Ghaziabad, Bulandshahr, Aligarh, Mathura, Etah, Agra, Mainpuri, Ferozabad, S. Muradabad, Budaun, S. Sahajahanpur, Farrukhabad, Hardoi, Jaunpur, Raibarali, Pratapgarh, Unnao, Allahabad, Fatehpur, W. Varanasi, Etawah, Kanpur, Jhansi, Hamirpur, Lalitpur, and Banda
- Madhya Pradesh: Bhind, Shivpuri, Gwalior, Morena, Datia, N. Guna and Sagar
- Punjab: Amritsar, Kapurthala, Sangrur, W. Ludhiana and Chandigarh, Patiala, Northern Firozpur and Faridkot.
- Gujarat: Sambarkantha, E.Mehesana, Ahmadabad, E.Surendranagar, Northern Bhavnagar and Rajkot.
- Haryana: Kuruksgetra, Karnal, Kaithal, Jind, Panipat, Rohtak, Faridabad, Gurgaon and Rewari
- Delhi
- Rajasthan: Jaipur, Alwar, Sawai-Madhopur, Bharatpur, Dhaulpur, Dausa, Tonk, Ajmer, Udaipur, Bhilwara, Dungarpur, Rajsamand, W. Chittaurgarh and N. Bundi.

Agro-climate

The climate of this region has been characterized by hot and dry summer and cool winter. The annual precipitation ranges from 500 to 1000 mm with an increasing trend from west to east. It covers 35-42 per cent of the mean annual potential evapotranspiration (PET) demand (1400 -1900 mm). Annual water deficits of 700-1000 mm. The LGP ranges between 90 and 150 days. The soil moisture regime is typic-ustic and the soil temperature regime is hyperthermic. The parts of Bundelkhand region comprising the districts of Banda, Hamirpur, Jhansi, Jalaun (Orai) and Datia are subjected to occasional and acute droughtiness.

Soils

Soils are moderately to gently sloping, coarse to fine loamy, great group of Ustochrepts and Natrustalfs, grading through gently to very gently sloping great groups of Ustochrepts and Ustipsamments to nearly level Ustifluvents. Soils of the region are dominantly represented by Kanjili series classified as Ustochrepts and occasionally by Chomu and Zarifa Viran and Ghabdan series. Chomu soils are sandy (Ustipsamments), the Zarifa-Viran soils are fine loamy and highly sodic (Natrustalfs) and the Ghabdan soils are fine loamy, highly sodic (Salic Natrustalfs).

Land use

Almost 65 per cent of the region is under irrigated and remaining part is under traditional rainfed agriculture. In northern plain, the droughty climate is overcome by introducing tube well irrigation and the area is intensively cultivated for both kharif and rabi crops, such as rice, millets, maize, pulses, berseem, wheat, mustard and sugarcane. In some parts of central highlands, like Bundelkhand, less than 25 per cent of the net cropped area is under irrigation, while the rest is under rainfed agriculture. Predominant kharif crops grown under rainfed agriculture are jowar, pigeonpea and soybean, while rabi crops such as gram, lentil and wheat are grown on residual moisture with one or two protective irrigations at critical stages of crop growth. In Chambal catchment, the cropping pattern has undergone drastic change replacing millets by wheat, mustard and sugarcane after the introduction of irrigation. The natural vegetation comprises tropical dry deciduous and thorn forests.

Potentials and Constraints

The region has pockets of good ground water as well as aquifer zones of good quality water having yielding ability more than 5 litres / second, thus with a systematic survey, these viable pockets can be used for expanding irrigated agriculture. The area has high potential for diversification in favour of horticultural and oilseed crops including sunflower. Also, the region is known for its livestock wealth like primarily dairy and to some extent poultry farming.

The constrants of the region are: coarser soil texture, poor soil fertility along the river and flood plains and low plant available water capacity; over exploitation of ground water, resulting in lowering of groundwater table in some areas; inter dry spell periods lead to occasional crop failure; imperfect drainage conditions at some places lead to spread of surface and subsurface soil salinity and sodicity causing limitation to optimum root growth and oxygen availability in low lying situation under irrigated farming; parts of the ecoregion have pockets of alkaline ground water and deficiencies of N, P and Zn.

Central (Malwa) Highlands, Gujarat Plains and Kathiawar Peninsula

The ecoregion covers the Central highlands (Malwa), Gujarat plains and Kathiawar peninsula, Western parts of Madhya Pradesh, south-eastern parts of Rajasthan and Gujarat States. It is spread over an area of 17.6 m ha, representing 5.4 per cent of the total geographical area of the country. This agro-ecoregion is further divided into following three eco-subregions viz., (i) Central Kathiawar Peninsula, hot dry semi-arid; (ii) Madhya Bharat plateau, Western Malwa plateau, eastern Gujarat plains, Vindhyan and Satpura Range and Narmada Valley, hot moist semi-arid; and (iii) Coastal Kathiawar Peninsula, hot moist semi-arid.

Distribution

- Gujarat- S. Rajkot, Amreli, Junagadh, Bhavnagar, parts of Ahmadabad, Godhra, Bharuch, Vadodara, Kheda, Northern and Central parts C.Surat.
- Madhya Pradesh: Jhabua, Ratlam, Mandsaur, Ujjain, Indore, Dewas, Khandawa, Khargone, Dhar, parts of Rajgarh and Shajapur.
- Rajasthan: S. Bundi, Kota, Banswara, Chittaurgarh, Jhalawar and Baran.
- Union Territory: Daman and Diu.

Agro-climate

The climate of the region is characterized by hot and wet summer and dry winter. The annual precipitation in the region ranges from 500 to 1000 mm. It covers 40 to 50 per cent of the annual PET demand (1600 - 2000 mm) resulting in gross annual water deficit of 800 to 1200 mm. The LGP ranges from 90 to 150 days in a year. The dominant soil moisture regime in the area is typic-ustic. The soil temperature regime is hyperthermic and Iso-hyperthermic (in coastal area of Kathiawar peninsula). The region is drought prone as the frequent inter drought spells lead to crop failures.

Soils

Dominant soils, representing the region are gently to very gently sloping deep, loamy to clayey Ustochrepts and nearly level to very gently sloping deep black soils (Chromusterts). The Kathiawar peninsula and the coastal areas are represented by Salorthids. The dominant soils of the Malwa plateau are represted by Sarol and Kamliakheri series. These are clayey, slightly alkaline and calcareous having swell-shrink properties.

Land Use

Dry land farming is the common practice in the region. The kharif crops usually cultivated in the area are sorghum, pearl millet, pigeon pea, groundnut, soybean, maize and pulses. The common rabi crops are sorghum, safflower, sunflower and gram. Wheat is grown under irrigated conditions. The natural vegetation comprises dry deciduous forest.

Potentials and Constraints

Region have great potential for introduction of multiple cropping in rows like inter-cropping, mixed cropping, relay cropping under rainfed agriculture; and also possesses vast areas having ground water aquifer zones with good quality and high yielding ability.

Major constraints of the region are: intermittent dry spell during the crop season and erratic rainfall leading to occasional crop failure; narrow range of workable moisture; imperfect drainage limiting optimum root ramification and oxygen availability in low-lying areas; salinity and alkalinity hazards under irrigated agriculture; severe salinity and seasonal inundation by sea water in the Kathiawar coast; extreme stickiness in rainy season and wide cracks in dry season pose severe limitation to intercultural operation and tillage practice in black soils; limitation of topography and tribal agriculture results in low productivity caused by low fertility and low investments; phosphorus, zinc and sulphur deficiencies pose nutrients imbalance and poor quality of ground water induces alkalinity in some parts of the region.

Deccan Plateau

The agro-ecoregion with hot, semi-arid climate covers the Deccan plateau, comprising most of the central and western parts of Maharashtra, northern parts of karnataka and western parts of Andhra Pradesh. It covers an area of 31.0 m ha, representing 9.5 per cent of the total geographical area of the country. It is further sub divided into four eco-sub regions viz., (i) S-W Maharashtra and N. Karnataka Plateau, hot dry semi-arid; (ii) C-W Maharashtra Plateau and N. Karnataka plateau and N-W Telangana plateau, hot moist semi-arid; (iii) E. Maharashtra plateau, hot moist semi-arid and (iv) N. Sahyadris and W. Karnataka Plateau, hot dry subhumid.

Distribution (States and Districts)

- Maharashtra: Ahmadnagar, Bid, Solapur, Sangli, Satara, Pune, Osmanabad, Latur, Nasik, Dhule, Aurangabad, Jalna, Nanded, Parbhani, E & W Jalgaon , Buldhana, Akola, Amravati, Yavatmal, E. Kolhapur.
- Karnataka: N. Bijapur, N-E Raichur, Bidar, Gulbarga, Belgaum and Dharwar.
- Andhra Pradesh: Nizamabad and Adilabad.

Agro-climate

The climate is characterized by hot and humid summer and mild and dry winter. The mean annual precipitation, ranging between 600 and 1200 mm, covers about 40 per cent of annual PET demand (1600 - 1800 mm) having gross annual deficit of 800 to 1000 mm of water. The LGP ranges from 90 to 150 days. A part of the region, covering districts of Ahmadnagar, Bid, Solapur, Sangli (eastern parts), Satara (eastern parts), Osmanabad and Latur in Maharashtra state, and Bidar, Gulbarga, Bijapur and Dharwar in Karnataka State, constitutes drought-prone areas. Severe drought spells repeat once in three years. The area is classified as Ustic soil moisture and Iso-hyperthermic soil temperature regimes.

Soils

Soils of the area are represented by moderately to gently sloping Ustorthents and Ustropepts, grading to level to very gently sloping Chromusterts/Pellusterts in valleys. These are classified as Pargaon, Sawargaon and Barsi series. The Pargaon soils are shallow, loamy skeletal and highly calcareous in nature. The Sawargaon and Barsi soils, however, are clayey, calcareous and moderately alkaline showing marked swell-shrink properties.

Land Use

The traditional practice is rainfed agriculture. The sorghum, pigeon pea and pearl millet are major kharif season crops. The drought-prone districts of the region, interestingly, have bimodal rainfall distribution. Therefore, crops are grown during September / October on stored residual soil moisture since there is a significantly long dry period during the first phase of rains. The post-rainy season crops grown on residual soil moisture are mainly sorghum, safflower and sunflower. Cotton and groundnut are grown under irrigated conditions. The natural vegetation in the region comprises tropical, dry deciduous and thorn forests.

Potentials and Constraints

The region has a great potential of ground water along vast bank of Bhima river (a main river of that flows through Maharashtra, Karnataka, and Andhra Pradesh). As the eastern bank is saline, the western side can be utilized for irrigated agriculture. Amravati and Jalegaon parts of the region have good aquifer zones with yielding ability of more than 5 litre/second could profitably be exploited for irrigation. Introducing watershed-based management and efficient water harvesting techniques, crop production is possible through multiple cropping systems under rainfed agriculture. Also a good possibility exists for growing dry land horticultural plantation crops like Vineyards, Chicku, Pomegranate and Zizyphus. Opportunities are there to grow vegetables like onion, birnjal etc. on shallow to moderately deep gravelly soils in winter season under supplementary irrigation. Potential for oilseed based cropping system also exists.

The constraints of the region are prolonged dry spells leading to frequent crop failure; high runoff during stormy cloud bursts in rainy season results in heavy soil loss; deficiencies of N, P, Zn and B lead to nutrient imbalance; shallow soils limit optimum root development and conducive to rapid droughtiness of plant environment resulting in crop failure; some parts of the region have rocky non aquiferous terrains so have remote chances for development of ground water; and subsoil sodicity coupled with very slow subsoil permeability affects the root rhizosphere.

Deccan (Telangana) Plateau and Eastern Ghats

The agro eco-region with hot, semi-arid climate and supporting red and black soils covers the parts of the Ghats of Andhra Pradesh. It occupies an area of 16.5 m ha, representing 5.2 per cent of the total geographical area of the country. It is subdivided into three ecological-subregion viz., (i) S. Telangana plateau and E. Ghats, hot dry semi-arid; (ii) N. Telangana Plateau, hot moist semi-arid; and (iii) Eastern Ghats, hot, moist semi-arid / dry sub-humid.

Distribution

- Andhra Pradesh: Cuddapah, Kurnool, Karimnagar, Warangal, Rangareddy, Mahabubnagar, Nalgonda, Khamman, Sangareddy, Hyderabad, Northern parts of West Godawari and Krishna, non coastal parts of Guntur, Prakasam and Nellore.

Agro-climate

The climate is characterized by hot and moist summer and mild and dry winter. The mean annual rainfall, ranges from 700 to 1100 mm and covers about 40 per cent of annual PET demand, resulting in gross deficit of 700-800 mm of water. The LGP ranges from 90 to 150 days. The area, covering the districts of Nalgonda, Mahbubnagar, Kurnool, Prakasam, Nellore and Cuddapah, is recognized as drought-prone. The soil moisture regime is Ustic and soil temperature regime is Iso-hyperthermic.

Soils

Soils in the region are of moderately to gently sloping Ustorthents and Rhodustalfs (red soils), grading through gently to very gently sloping Ustropepts, to nearly level Chromusterts / Pellusterts (black cotton soils). The black cotton soils are represented by Kasireddipalli series. These are clayey, calcareous and strongly alkaline in reaction showing remarkably swell and shrink phenomena on wetting and drying. The red soil represented by Patancheru series (Rhodustalfs), are non-calcareous and neutral in reaction.

Land Use

Rainfed agriculture is the traditional practice. The major Kharif crops grown in the area are sorghum, cotton, pigeon pea, rice, groundnut and castor. The crops grown on stored/residual soil moisture during post-rainy season are sorghum, sunflower, safflower and some oilseeds. At places rice is cultivated under irrigation in rabi season. The natural vegetation comprises tropical, dry deciduous and thorn forests.

Potentials and Constraints

The region has huge potential of screening of drought resistant, high yielding short duration genotypes of groundnut, sorghum, paddy etc. and improvement in farming system to enhance the productivity of the region many folds. Black soils of the region have high productivity potential and desirable results can be achieved under watershed-based management crop programmes. The region has potential for dryland horticultural crops like Zizyphus, Falsa and Amla to fetch high returns from shallow soils.

The region experiences constraints due to high runoff during rainy season in irrigated agriculture, non-judicious use of irrigation water and imperfect drainage conditions results in high groundwater table leading to subsoil salinity and sodicity, especially in the black soil areas; deficiencies of N, P and Zn in soils result in nutrient imbalance; and standing crops frequently experience drought and severe cyclonic outburst damages.

Eastern Ghats, Tamil Nadu Uplands and Deccan (Karnataka) Plateau

The agro-ecoregion with hot, semi-arid climate and red loamy soils covers E. Ghats, S. parts of Deccan plateau, Tamil Nadu uplands, and western parts of Karnataka. It has an area of 19.1 m ha, representing 5.8 per cent of the total geographical area of the country. It is divided into (i) Tamil Nadu uplands, hot dry semi-arid; (ii) C. Karnataka Plateau, hot moist semi-arid; and (iii) Tamil Nadu uplands and plains, hot moist semi-arid.

Distribution

- Tamil Nadu: Coimbatore, Madurai, Thirunelveli, Dindigal, Virudnagar, Tuticorin, Nagercoli (non coastal parts), N & S Arcot, Dharampuri, Periyar, Salem, Tiruchirapalli, Pudukottai, Sivaganga, Chengalpattu, non-coastal parts of Ramnathpuram and Tanjabur.
- Karnataka: Hassan, Tumkur, Bangalore, Mysore, Mandya, Kolar, Chickmangalur, E. Shimoga, and C &S. Chitradurga.
- Andhra Pradesh: Chittoor.

Agro-climate

Climate of this region is characterized by hot and dry summer and mild winter with annual rainfall of 550 to 1000 mm. The western parts of the region falling in Karnataka receive about 70 per cent of the rainfall during June to September. The eastern parts receive rains during October to December. The area experiences the annual water deficit of 400 to 700 mm. The LGP ranges from 90 to 150 days. The soil moisture regime is Ustic and soil temperature regime is Iso-hyperthermic.

Soils

Major soils of the area are of moderate to gently sloping Ustorthents and Ustropepts, grading to gently to very gently sloping Rhodustalfs and Plinthustalfs. These are represented by Tyamagondalu and Palathurai series. Both series are low in cation exchange capacity.

Land Use

Rainfed agriculture is the traditional practice in the region. Where millets, pulses, and groundnut are cultivated in kharif and sorghum and safflower in rabi season. Rice is cultivated under irrigation. At places sugarcane and cotton are also grown under irrigated conditions. The natural vegetation comprises tropical, dry deciduous and thorn forests.

Potentials and Constraints

The region has great potential for mulberry plantation in watershed-based management practices; and some parts has good aquifer zones with yielding ability up to 5 litre/ second which can potentially be utilized for expanding irrigated areas. The key constraints associated with this region are non aquiferous rocky terrain; low to medium available water content (AWC); severe droughtiness during the crop period; high runoff resulting severe soil erosion; deficiencies of N, P and Zn.

Northern Plains

This agro-ecoregion with hot, subhumid (dry) climate and alluvium-derived soils covers a part of the northern Indo-Gangetic plain, including piedmont plains of the western Himalayas. It occupies an area of 12.1 m ha, representing 3.7 per cent of the total geographical area of the country. The ecological region is divided into: (i) Punjab and Rohilkhand Plains, hot dry-subhumid, and (ii) Rohilkhand, Avadh and S. Bihar plains, hot dry-subhumid eco-subregions.

Distribution

- Punjab: S. Gurdaspur and Hoshiarpur, Rupnagar, Jalandhar, Ludhiana and N. Patiala.
- U.T. of Chandigarh
- Haryana: Ambala
- Uttarakhand: Udhamsingh Nagar.
- Uttar Pradesh: Rampur, Bareilly, Pilibhit, Kheri, Sitapur, North Lucknow, Barabanki, Faizabad, Sultanpur, Azamgarh, Ballia, S. Mau, Gazhipur, N. Sahajahanpur and E. Varanasi.
- Bihar: Bhojpur (Ara), Rohtas (Sasaram), Jahanabad, Patna, Nawada, Bihar-Sariff (Nalanda), Aurangabad, and Gaya

Agro-climate

The agro-climate of the region is characterized by hot summer and cool winter. It receives an annual rainfall of 700 to 1200 mm; 70 per cent of which is received during July to September. The rainfall covers about 70 per cent of the annual PET demand of 1400 to 1800 mm. The region has LGP of 150 to 180 days. It experiences dry period from February to June with mean annual temperature of more than 22°C and experiences Ustic soil moisture and Hyperthermic soil temperature regime. The areas adjacent to foot-hills are relatively cooler.

Soils

Soils of the region are generally deep, loamy and developed on alluvium. The dominant soil capes, representing the northern plain, constitute gently to very gently sloping Ustochrepts, Haplustalfs and Eutrochrepts and gently to moderately sloping Ustifluvents. The soils series of also Basiaram (Eutrochrepts), Shajadapur (Ustochrepts), Gurudaspur (Haplustalfs) and Itwa (Ochraqualfs) that dominate the area and are nearly level. Itwa soils are sodic in their subsurface, whereas others are neutral in reaction.

Land Use

Traditionally the rainfed and irrigated agriculture is common. Crops grown are rice, maize, barley, pigeon pea and jute in kharif season, and wheat, mustard and lentil in rabi season. Sugarcane and cotton are grown at places under irrigated conditions. The natural vegetation comprises tropical dry deciduous forests.

Potentials and Constraints

The region has immense potential of contributing in national food basket through adaption of suitable crop/ variety and supplemental irrigation during dry spell period in rabi as the soils of this region are highly productive with ideal soil-air-water relationship; some parts of the region have aquifer with good quality water for creating additional irrigation potential. The major constraints in this region are non judicious use of irrigation water leading to water logging and salinity hazards; ground water quality in some part is alkaline.

Central Highlands (Malwa, Bundelkhand and Eastern Satpura Range)

The agro-ecoregion with hot, subhumid climate and red and black soils covers part of Malwa plateau and Bundelkhand uplands including Baghelkhand plateau, Narmada valley, Vindhyan scarp lands and northern fringe of Maharashtra plateau, encompassing some districts of Madhya Pradesh. It covers an area of 22.3 m ha representing 5.8 per cent of the total geographic area of the country. It is subdivided into four subregions viz. (i) Malwa Plateau, Vindhyan Scarp land and Narmada Valley, hot dry subhumid; (ii) Satpura and E Maharashtra Plateau, hot dry subhumid; (iii) Vindhyan Scarp land and Bundelkhand plateau, hot dry subhumid and (iv) Satpura range and Wainganga valley, hot moist subhumid.

Distribution

- Madhya Pradesh: Guna, Rajgarh, Raisen, Sagar, Bhopal, Sehore, Shajapur, Hoshangabad, Jabalpur, Narsinghpur, South and Central Vidisha and Damoh, East Dewas, Betul, Tikamgarh, Chhatarpur, Panna, Satna, Rewa, Sidhi, Sahadol, Chhindwara, Seoni, Mandla and Balaghat.
- Maharashtra: Wardha, Nagpur, N Chandrapur and Bhandara.

Agro-climate

The climate of the region is characterized by hot summer and mild winter. The mean annual rainfall ranges between 1000 and 1500 mm covering about 80 per cent of the mean annual PET (1300-1600 mm). The region remains fairly dry during the post-rainy period with water 500-700 mm deficit.

Dry period occurs from February to May suggesting Typic Ustic soil moisture regime. The mean annual soil temperature of more than 22°C thus qualifies the area for Hyperthermic soil temperature regime. The LGP ranges from 150-180 days. The districts of Balaghat, Seoni, Mandla, Bhandara and Chhindwara are relatively more humid showing the LGP ranging from 180 to 210 days in a year thus area qualifying for Udic Ustic soil moisture regime.

Soils

Soils are largely medium. The deep black soils are interspersed with patches of red soils. Soils representing the region are typified by moderately to gently sloping Ustorthents, gently to very gently sloping Ustochrepts and Haplustalfs, and very gently sloping to nearly level Chromusterts. The dominant soil series of region are Marha, Kheri and Linga (Chromusterts) occurring in association with the moderately deep soils of Kamliakheri series (Ustochrepts). These are calcareous, slightly alkaline, montmorillonitic and have high swell-shrink potential. The red soils generally occur on ridges and on pediment surfaces. These are shallow to moderately deep, clayey, neutral to slightly acidic in nature and are represented by Dumra series (Udic Haplustalfs) in Bundelkhand region.

Land use

Rainfed agriculture is the common practice. Rice, sorghum, pigeonpea and soybean are common kharif crops. Gram, wheat and vegetables are common rabi season crops. Kharif cropping is totally rainfed, whereas rabi cropping is partly irrigated at critical stages of growth. However, rich farmers grow rice, wheat and gram and, at places, cotton using irrigation facilities. The natural vegetation comprises tropical moist deciduous forest.

Potentials and Constraints

Soils of the area are highly productive under watershed-based management practices, surplus rainfall; aquifer zones with good quality of water with high discharge potentials for expanding irrigated areas; and scope for higher production with the introduction of agro-forestry system. However, the major constraints associated with the region are cracking clayey soils with narrow workability, poor drainage, high runoff and soil losses; risk of inundation of the cropped areas during rainy season and acute droughtiness due to prolonged dry spells in kharif season lead to crop failure; rockiness hamper the exploitation of good quality ground water aquifers; poor water holding in shallow and sandy red soils; tribal agricultural practices limits the productivity potential; and deficiencies of N, P and Zn are observed.

Eastern Coastal Plains

The agro-ecoregion comprises the south-eastern coastal plain, extending from Kanyakumari to Gangetic Delta. The region covers an area of 8.5 m ha, representing 2.6 per cent of the total geographical area of the country. It is divided into four eco-subregions but only two (i) S Tamil Nadu Plains (Coastal), hot dry semi-arid and (ii) Andhra plains, hot dry subhumid fall in medium rainfall region.

Distribution

- Tamil Nadu: Coastal Ramnathapuram, Kanyakumari, Tirunelveli.
- Andhra Pradesh: Coastal Nellore, Prakasam, Guntur, Krishna and W Godawari.

Agro-climate

The eastern Coast extending from Kanyakumari to Gangetic delta experiences wide range of climatic conditions. Coastal parts between Kanyakumari and south of Thanjavur (Tamil Nadu) and between north of Madras and west Godavari (Andhra Pradesh) receive the rainfall of 900-1100 mm, of which about 80 per cent is received in October to December. The PET in this area varies between 1700 to 1800 mm. The annual deficit of water is 800 to 1000 mm. The LGP ranges from 90 to 150 days. The area represents a subhumid (moist) climatic type and the soil temperature regime is Iso-hyperthermic.

Soils

Soils of Haplaquents, Halaquepts, Ustifluvents and Pellusterts occur on level to very gently sloping topography and Ustropepts. Motto (Haplaquepts) and Kalathur (Pellusterts) series are slight to moderately sodic. Both are clayey in nature but have marked differences in their cation exchange capacity, suggesting differences in clay mineralogy. The Kalathur soils have high swell-shrink potential.

Land Use

Both rainfed and irrigated agriculture are practiced in the region. The lead crop cultivated in the area, both in kharif and rabi season is rice. Coconut is a dominant plantation crop of the region. In some parts, pulses, such as black gram and lentil, and oilseed crops, such as sunflower and groundnut are cultivated after rice (on residual moisture).

Potentials and Constraints

The region has immense potential for cultivation of rice, banana and groundnut; and the part of this region is most suitable for paddy-pisciculture system which may fetch potential economic return. Whereas, high runoff during rainy season leading to severe soil loss; crop management in swampy soil; salinity and alkalinity; and poor drainage are the major constraints in the region.

Case Study 1. Land use management for sustaining natural resources and production under agro-ecological regions - 4 and 9

Agricultural systems in Indo-Gangetic plains (IGP), which covers a major part of agro-ecological region 4 and 9, is gifted with productive soils and irrigation support which facilitated the intensive cropping systems. But after inception of green revolution an injudicious mining of ground water and nutrients for higher production of water loving crop rotations (rice-wheat) successively resulted in constant water table depletion and most of the tube wells turn into dry or ineffective (Kalra et al. 2003). At the same time problems of soil organic matter diminution and soil / water salinity emerged as barrier for crop production. Despite these prominent problems farmers are continuously following the same production systems due to its economics. In light of these problems conservation tillage technology has been introduced in this region aimed at conserving natural resources (water, fuel, and soil organic carbon), minimization of cultivation cost and as mitigation options for climate change impacts on agricultural systems. Accelerated adoption of zero-tillage by the farmers tells the success of this technology (Fig 2). Successful adoption of zero-tillage opened a venue for introduction of other conservation tillage practices with alteration in tillage machines for resource conservation and diversification of cropping system in the region (CIMMYT-India/RWC 2006). These technologies are able to capture location specific problems to facilitate alternate land use plan and higher production (Fig. 3).

Case study 2. Land use management for enhancing productivity of crops in Vertisols

Vertisols are considered as one of the most productive soils but due to swell-shrink properties, these soils are recognized as problematic due to difficulty in their management. It is estimated that out of 76.4 M ha coverage under Vertisols in India, approximately 16.7 M ha (23.0 %) is in Madhya Pradesh (Tomar et al. 1996a). Vertisols in Madhya Pradesh are vulnerable to erosion and high runoff losses and cropped only during post rainy season on profile stored moisture and remains fallow or poorly utilized during rainy season (Painuli et al. 2002). Despite of its detrimental effects, rainy season fallowing in Vertisols has been widely prevalent because of water stagnation and slow infiltrability causing crop failure (Table 2).

Table 2. Basic infiltration rate (BIR) of some Vertisols of different regions of MP

Regions	BIR (mm/hr)
Central Narmada Valley	3.5-4.0
Kymore plateau & Satpura hills	2.0-3.5
Nimar valley	1.5-4.0
Vindhyan plateau	7.0
Malwa Plateau	5.0

(Source: Painuli et al. 2002)

To overcome these problems field studies were conducted successively for sixteen years at JNKVV, Jabalpur on Raised-Sunken Bed Technology (RSBT). In this technology 6-9 m wide and 30-35 cm high raised bed along with sunken bed of 6 m width and normally 15 m were long were used to grow the contrast water requiring crops simultaneously either as sole or intercrops.

This technology provides an adequate drainage during heavy rains, favorable moisture regimes during dry

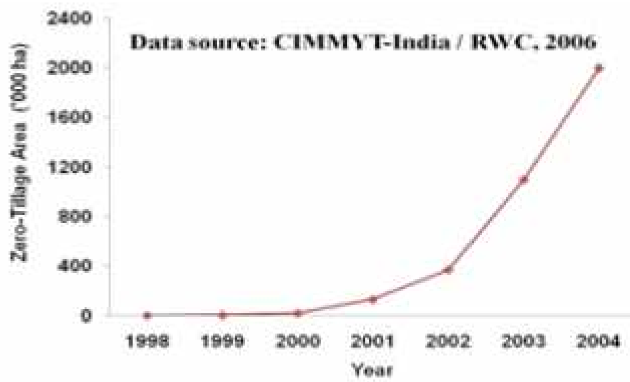

Fig 2. Adoption of zero-tillage in IGP

Fig 3. Technologies for improving crop productivity of under-utilized land in parts of agro-ecoregion-4

spell in kharif season to upland crops like soybean, sufficient pounding of water for paddy and channelizes the excess runoff water safely to farm pound for recycling to provide supplemental irrigation to rainy and post rainy season crops. It has also been demonstrated successfully at the farmer's fields (Tomar et al. 1996a and Painuli et al. 2002).

Yield performance of various crops (soybean, blackgram, paddy, pigeonpea and sesamum) as sole or intercrop during kharif season was evaluated under improved land use pattern (RSBT) and compared with that at farmers practice (Painuli, et al. 2002). Average seed yields of soybean and paddy (16 years), blackgram (7 years), pigeonpea (4 years), sesamum (3 years) and intercropping of soybean or blackgram (two rows) with pigeonpea (one row) under RSBT and farmers practice along with average rainfall are presented in Table 3.

Soybean was grown in rainy season in the raised beds of 6.0, 9.0, 12.0 and 15.0 m width and 0.30 to 0.35 m in height, whereas, rice was grown in the sunken beds of 6.0 m width running in parallel to the raised beds. In post-rainy season, chickpea, linseed and safflower were grown in raised beds and wheat in sunken beds (Tomar et al. 1996b). Maximum average seed yield of soybean was recorded in 6.0 m wide raised bed followed by 9.0 m raised bed and minimum in flat plots. The land configurations were also useful during prolonged dry-spell thereby, minimizing any adverse effect of soil moisture stress at flowering and seed development stages of rainy season crops. Post-rainy season crops were successfully grown with sufficiently high yields. Soybean-safflower and soybean-chickpea cropping sequences proved to be most economic than the other sequences. Economic viability analysis of raised-sunken bed (RSB) system indicated that the net return was Rs. 13363 ha^{-1} yr^{-1}, as against Rs. 1003 ha^{-1} yr^{-1} from soybean grown under farmers' practice.

Case Study 3. Experiences in Watershed Development Programme in Central India (Indore)

Integrated watershed management is considered as an effective unit for overall development of agriculture for obvious regions as it is the most rational approach in preventing deterioration of ecosystem, restoration of degraded lands, efficient water harvesting and improving the overall productivity in rainfed areas. During 1975-1984, under Indo-UK project at College of Agriculture, Indore, the Operational Research on Dryland Farming in black cotton soils (Vertisols) involved multidisciplinary integrated approach (Verma 1982). Under this project, the dryland technology, evolved through research to make the most efficient use of soil and water resources for improving overall socio-economic condition of the farming community including crop and livestock management of selected villages was demonstrated on farmers' fields to improve the productivity per unit land and livestock. The project area (2712 ha) covered three villages Jamburdi, Hapsi, Rainjlai and Nainod covering eastern part of two sub-catchments of Gambhir River. Before the inception of the project, mono-cropping pattern predominantly in Rabi season was practiced by most of the farmers of the

Table 3. Effect of land use pattern on yield of some kharif crops in a Vertisols (Tomar et al. 1996a)

Land use pattern	Seed yield (kg ha^{-1})						
	Soybean	Blackgram	Paddy	Pigeonpea	Sesamum	Soybean+ Pigeonpea	Blackgram+ Pigeonpea
RSBT	2282	1071	2980	2093	364	1750+1595	680+1776
Flat bed (FP)	957	429	995	148	109	826+138	192+110
Fold Increase over FP	2.4	2.5	3.0	14.1	3.3	2.1 +11.6	3.5 +16.1
Rainfall (mm)	1130.0	1111.7	1130.0	1321.3	951.0	1252.3	1321.3

study area. Farmers used to keep most of their cultivated area (50-90%) fallow during Kharif. To replace the fallow by Kharif crops, preparation of crop plans for individual farmer on the basis of catchments and land use was done Due to improvement in land and water resources, they started growing more crops in the Kharif as well as Rabi season and also started adopting a regular crop rotation.

The success of Indo-UK project, prompted ICAR to start ORP on dryland agriculture at 8 locations in the country including Indore during 1986. The Indore centre was given additional responsibility to develop model watershed by the Government of Madhya Pradesh in the year 1987. In watershed areas, the increased recharge due to runoff control measures resulted in enough rise in water level in open well that facilitated in improving productivity of kharif as well as of rabi crops (Tomar 2012).

Case Study 4. Land use management for accelerating soybean production in MP

Madhya Pradesh boasts of being a leader in soybean production in the country, with the crop accounting for more than half the area under cultivation (Ghatwai 2012). It, however, has a poor record of productivity, the average yield being lower than the national average. Millions of marginal and small soybean farmers across the state take home much less than what they can. It has been found that the low yield is frightening because the potential of the varieties grown is much more. Productivity of soybean under the demonstrations at farmers' field exceeded to 1.7-2.0 t ha^{-1} reflecting a sizeable gap of 0.6-0.9 t ha^{-1} when compared to that of actually experienced (1.1 t ha^{-1}) by farmers.

In the direction of suggesting alternate land use plans for enhancing the soybean productivity a significant efforts have been made at JNKVV, Jabalpur to optimize the drainage, tillage, and sowing method. The results indicated that the conventional tillage with broad bed, furrow and open drainage channel gave the highest yield (3.13 t/ha) and the conventional tillage with raised broad bed and furrow was statistically at par to it (Table 4). These two systems were best among the rest of the tillage systems indicating that proper land use management is helpful towards decreasing the yield gaps.

Future strategies

To make the effective land use plan for sustainable agricultural production in the present scenario the following components need to be considered critically:

Climate change

There is increasing concern that the Earth's climate is changing because of increasing concentration of greenhouse gases in the atmosphere. Land use and land cover are linked to climate in complex ways and are critical for mitigating global warming and climate change. Forests

Table 4. Optimization of drainage and tillage for soybean yield maximization
(Source: Anonymous 2013)

Treatment	Grain yield (q/ha)
Pre-monsoon sowing	
No till + flat bed	19.32b
No till + open drainage channel	23.39bc
No till + open drainage channel + sub-Soiler	25.56c
Conventional tillage + flat bed	25.96c
Conventional tillage + raised broad bed + furrow	26.95cd
Conventional tillage + raised broad bed + furrow + open drainage channel	31.37d
Post-monsoon sowing	
No till + flat bed	11.55a
No till + open drainage channel	10.02a
No till+ open drainage channel +sub-soiler (Previous monsoon)	13.58a
SEm ±	1.37
CD (P=0.05)	4.10

and soils have a large influence on atmospheric levels of carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4), three of the most important greenhouse gases (GHGs). Deforestation and agricultural practices are jointly responsible for about 30 percent of global GHGs emissions (Pathak et al. 2003 and IPCC 2007). The adoption of sustainable land use practices is a valid, and in many cases cost effective, mitigation strategy that often comes in tandem with significant adaptation, livelihood and biodiversity benefits.

Land use change, however can play a significant role in climate change mitigation and adaptation to reduce the damage due to climate change. Options such as use of biochar, practices of conservation agriculture, incorporation of crop residue, carbon sequestration, can help a lot in mitigating the deletarious effect of climate change and can be incorporated in improved land use plan (Lal et al. 1998, Rai et al. 2003, Jat et al. 2005 and Fang et al. 2008).

Soil and water management

Agriculture has now a definable role in change in ecology and climate throughout the world (Tomar and O'Toole 1980). For efficient land utilization the diversion of harvested water to the crop land is critical for maximizing the net hydrological gain, especially in areas with poor ground water storage or areas experiencing high inter-annual variability in runoff (Oweis et al. 2002). India harbors 17% of global population in only 2.3% land mass supported by 4% of fresh water resources. There is no denying the fact that the net cultivable area in the country of around 140 M ha is remaining constant or even squeezing from the pressures of urbanization, industrialization, infrastructure development and to house the ever increasing populace. Then loss of productive soil is another concern. Around 6000 to 12000 million tonnes of top soil is washed away every year taking away with it nearly 5.6 to 8.4 million tonnes of nutrients due to water erosion responsible for soil and water management practices. Emphasis on application of major nutrients has triggered widespread deficiencies of secondary and micronutrients like sulphur (41%), zinc (49%) and boron (33%) with other micronutrients, e.g. iron, copper manganese, molybdenum deficiencies are on the rise (Singh 2009). The water scenario is equally grisly. Per capita availability of water has radically reduced from over 5000 m^3 in the 50's to a meager 1656 m^3 in 2007 and is conjectured to be less than the internationally prescribed level (1700 m^3) to 1140 m^3 by 2050.

Organic farming systems

Recent reports have investigated the potential of organic agriculture to reduce greenhouse gas emissions (Burger et al. 2008 and Loschenberger et al. 2008). Organic systems of production increase soil organic matter levels through the use of composted animal manures and cover crops. Organic cropping systems also eliminate the GHGs emission from the production and transportation of synthetic fertilizers. In addition, higher organic matter content and more biomass in soils make organic fields less prone to soil erosion (Reganold et al. 1987 and Siegrist et al. 1998).

Crop diversification

Diversification of crop and livestock varieties, including the replacement of plant types, cultivars, hybrids, and animal breeds with new varieties intended for higher drought or heat tolerance, have been advocated as having the potential to increase productivity in the face of temperature and moisture stresses. Crop scheduling based on rainfall pattern determined cropping intensity drought and flood avoidance. Bunding, puddling, soil amendment, and subsurface barriers helped reduce water requirements for lowland rice. Ridge-furrow cultivation systems can save dryland crops from excess water damage and rain harvesting and runoff recycling can minimize the risk of drought (Hundal and Tomar 1985).

Adjusting cropping season

Adjustment of planting dates to minimize the effect of temperature increase-induced spikelet sterility can be used to reduce yield instability by avoiding the flowering period to coincide with the hottest period. Cropping systems may have to change to include growing suitable cultivars for increasing crop intensities or planting different types of crops. Farmers will have to adapt to changing hydrological regimes by changing crops. At the same time more attention should be given to spatial variability than temporal variability across the fields due to microclimatic difference in soil type, topography and irrigation status (Byerlee 1992). For example with the availability of short duration rice varieties in rice-fallow areas, practices such as rice- chickpea/ lentil/ linseed adoption of conservation agriculture technology gaining momentum.

Conclusion

It can be concluded that for developing the site-specific land use options from view point of identification of land-crop suitability plan, generation of area and site-specific agro-technologies, detection of area specific constraints in agricultural production, recognition of farm clusters for zoning and strategic planning, preparation of watershed development plans needs to be emphasized in addition to generation of farm level databases at 1:10,000 scale. Such studies will go a long way in developing best land use plans at village level.

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