Acidic soils and their management

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Soil acidity is the result of excessive accumulation of H⁺ ions over OH⁻ ions in the soil solution. In other words acidity means low percentage of base saturation. In acid soil regions (ASR) precipitation exceeds the evapo-transpiration and hence leaching is predominant causing loss of bases from the soil. When the process of weathering is drastic, the subsoil and in many cases, the whole profile becomes acidic.

Development of soil acidity :- Soils become acid due to the following reasons :

1. Losses or removal of base from soil :
   (a.)Leaching due to high rainfall : Due to heavy rainfall, soluble base salts are dissolve and remove along with the rain water and in the process exchange site become saturated with H⁺ ions. The precipitation takes the bases like Ca, Mg etc. downward from the surface of soil and due to which plant roots become unable to utilize such nutrients. In humid regions (with precipitation of 100 cm annually) soils are more susceptible to acidity.

   \[
   \text{CaCO}_3 + \text{H}_2\text{CO}_3 \leftrightarrow \text{Ca(HCO}_3\text{)}_2 \downarrow \quad \text{Leachable}
   \]

   (b.)Due to crop removal : Crops remove significant amount of bases from the soil.

2. Soil formed from the acid parent materials : Soils developed form acidic parent materials having granite, rhyolite, sandstone, gneiss etc. are acidic in nature. If soils are formed in insitu, than acid soils are form SiO₂ contain is less than soils will not be acidic.

3. Use of acid forming fertilizers :
   Ammonium sulphate and ammonium nitrate fertilizers produce acidity when added in the soil. Ammonium ions of these fertilizers replace calcium and magnesium from the exchange complex and the calcium sulphate so formed is lost due to leaching. In case the soils not having free lime, the acidity increases continuously by the use of acidic fertilizers. Residual acidity of different fertilizers produced acidity in the soils.

   \[
   \begin{align*}
   \text{(NH}_4\text{)}_2\text{SO}_4 & \leftrightarrow 2\text{NH}_4^+ + \text{SO}_4^{2-} \\
   \text{NH}_4\text{NO}_3 & \leftrightarrow \text{NH}_4^+ + \text{NO}_3^-
   \end{align*}
   \]
(a.) Equivalent acidity refers to the kilogram of pure $\text{CaCO}_3$ required to neutralize the acids produced in the soil from the quantity of fertilizer indicated.

(b.) Equivalent basicity refers to the kilogram of pure $\text{CaCO}_3$ equivalent to the alkalinity produced in the soil from the quantity of fertilizer indicated.

4. **Microbial activity**: Microbes have been found responsible for many processes like decomposition of organic residues and nitrification. Such microbial activities result in the formation of inorganic and organic acids in soils.

5. **Presence of alumino silicates**: Layered materials containing $\text{Al}_2\text{O}_3$ and $\text{SiO}_2$ produce the charges by isomorphous substitution of cations of lower valency like aluminium by silica and by dissociation of $\text{H}^+$ ions from $\text{OH}^-$ ions. At low pH values most of the aluminium is present in the soil as hexa hydrated ions ($\text{Al}^{+++}$)

$$
\begin{align*}
\text{Al}^{+++} + \text{H}_2\text{O} & \rightarrow \text{Al(OH)}^{++} + \text{H}^+ \\
\text{Al(OH)}^{++} + \text{H}_2\text{O} & \rightarrow \text{Al(OH)}^{+} + \text{H}^+ \\
\text{Al(OH)}^+ + \text{H}_2\text{O} & \rightarrow \text{Al(OH)}_3 + \text{H}^+
\end{align*}
$$

6. **Hydrous oxide**: The oxides of Fe and Al with colloidal dimensions e.g. gibbsite remain as coatings of soil colloidal particles and block the exchange sites and with the result CEC becomes less. These oxides further on hydrolysis, produce H+ ions.

7. **Contribution from environment**: $\text{H}_2\text{SO}_4$ and $\text{HNO}_3$ cause soil acidity. When the electric discharge on the atmosphere during rainy season, atmospheric nitrogen ($\text{N}$), sulphur (S) and oxygen (O) formed acidity in the soil. In industrial area coal is used as energy sources (sulphur dioxide) which produce $\text{SO}_2$ in the environment, this $\text{SO}_2$ react with water ($\text{H}_2\text{O}$) in the atmosphere and bring back to the surface as acid rains.

$$
\begin{align*}
\text{N}_2 + \text{O}_2 & \rightarrow 2\text{NO}_2 \\
2\text{NO}_2 + \text{H}_2\text{O} & \rightarrow 2\text{HNO}_3 \\
\text{S} + \text{O}_2 & \rightarrow \text{SO}_2 \\
\text{SO}_2 + \text{H}_2\text{O} & \rightarrow \text{H}_2\text{SO}_4
\end{align*}
$$

8. **Presence of sulphide**: It is an important source in the coastal regions, where sea water contribute sulphate sulphur. It contains about two gram sulphate sulphur per litre. In the inland areas coal and parent material may act as a source of sulphide.

$$
\text{Fe(OH)}_3 + \text{CaSO}_4 + 9\text{CH}_2\text{O} \rightarrow 4\text{FeS} + 4\text{Ca(HCO}_3)_2 \downarrow + \text{CO}_2 + 11\text{H}_2\text{O}
$$

In the above reaction organic matter ($\text{CH}_2\text{O}$) is used by micro-organisms as a source of energy, therefore, this material present in the reduced form.

$\text{FeS}$ and $\text{FeS}_2$ polymerize both are present under anaerobic conditions it gives neutral pH but under aerobic condition they oxidized by chemical and microbial processes.
4FeS₂ + 15O₂ + 2H₂O → 2Fe₃(SO₄)₃ + 2H₂SO₄

If CaCO₃ or MgCO₃ is present then it will be converted into gypsum or MgSO₄ otherwise H₂SO₄ there so pH is low may be 2 – 3. These compound further polymeric leaching to the formation of yellow stricked mineral like
Jarosite – [KFe₂(OH)₆(SO₄)₂]
Coquimbite – [Fe₂(SO₄)₃ * 9H₂O]

Further, ferric iron co-ordinates with H₂O molecule and behave as an acid i.e. acid sulphate soils.

**Classification of soil acidity :-** Based on the presence of H⁺ ions the acidity of soil is three types.

1. **Active acidity** – Hydrogen ions remain freely present in soil solution and produced limited acidity. Therefore, only about 25 g of CaCO₃ are sufficient to neutralize it in one hectare furrow slice of an average mineral soil having a pH of 6.0. If pH is 5.0 then CaCO₃ required may be approximately 250 g.

2. **Exchangeable acidity (reserve / potential)** – Hydrogen and aluminium ions held on soil colloids referred to as exchangeable or reserve acidity. Reserve acidity may be 1000, 50000, 100000 and still higher than the active acidity in case of sandy, clayey and organic soils, respectively.

In very acidic soil, exchangeable H⁺ and Al³⁺ ions are present in large quantities, but its quantity is quite less in moderately acidic soils.

3. **Residual acidity** – Residual acidity is that which remains in the soils after active and exchangeable acidity has been neutralized. Residual acidity is generally associated with Al³⁺ and H⁺ ions and with aluminium and hydrogen atoms that are found in non-exchangeable forms by organic matter and silicate clay. The residual acidity is commonly for greater than either active or exchangeable acidity.

**Forms of acidity in soil :-**

1. **Strong acidity** – This is due to presence of soluble Al and absorbed Al. Aluminium being trivalent preferably adsorbed as compared to H⁺ ions. This Al undergoes hydrolysis forming Al hydroxide. If pH is < 5.0, than Al may be present in the form of hexa hydrated Al ions and it may occupy more than 40% of exchange capacity.

   \[
   [\text{Al(H}_2\text{O)}_6]^{3+} + \text{H}_2\text{O} \rightarrow [\text{Al(H}_2\text{O)}_5(\text{OH})]^2+ + \text{H}^+ \\
   [(\text{Al(H}_2\text{O)}_3\text{OH})]^3+ + \text{H}_2\text{O} \rightarrow [\text{Al(H}_2\text{O)}_2(\text{OH})_2]^4+ + \text{H}^+ \\
   [\text{Al(H}_2\text{O)}_4(\text{OH})_2]^5+ + \text{H}_2\text{O} \rightarrow [\text{Al(H}_2\text{O)}_3(\text{OH})_3]^{6+} + \text{H}^+
   \]

   Due to this formation effective cation exchange capacity will decreases, but soil pH increases.
2. **Moderate acidity**: In this case per cent base saturation is higher than strong acidity. Aluminium present not as on Al ion but as hydroxy ions. This hydroxy ion move in between the crystal unit and are tightly adsorbed thereby presenting expansion and blocking the exchange site.

3. **Weak acidity**: It is due to the presence of hydrated Al$^{3+}$ ion and H$^+$ ions. pH of the weak acidity is 5.2.

4. **Very weak acidity (pH 5.2 – 6.5)**: This acidity is due to the presence of COOH group of organic origin and hydrogen group of hydroxy Al polymer in the interlayer position and due to carboxylic acid and basic Al sulphate.

5. **Very – Very weak acidity**: This acidity due to phenol group of organic acids, hydrogen group of hydroxy Al polymers. Bicarbonate of Ca and Mg.

6. **Extremely weak acidity**: Acidity is due to presence of alcoholic group of organic matter, salicylic acid, gyspic acid etc.

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Degree of acidity</th>
<th>Soil pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Extreme acidity</td>
<td>4.0 – 4.5</td>
</tr>
<tr>
<td>2</td>
<td>Very strong acidity</td>
<td>4.5 – 5.0</td>
</tr>
<tr>
<td>3</td>
<td>Strong acidity</td>
<td>5.0 – 5.5</td>
</tr>
<tr>
<td>4</td>
<td>Medium acidity</td>
<td>5.5 – 6.0</td>
</tr>
<tr>
<td>5</td>
<td>Slight acidity</td>
<td>6.0 – 6.5</td>
</tr>
</tbody>
</table>

**Effect of soil acidity on plants growth**:

Soil acidity influence plant growth by the production of organic acid which are produces due to decomposition of organic matter or due to root secretion. Effect of soil acidity may be separated into two group.

**Direct** –

1. Toxicity effects of H$^+$ ions are observed in root tissues.
2. Permeability of the plant membranes for cations is affected.
3. Balance between basic and acidic constituents through roots is disturbed.
4. Enzyme changes occur in plants due to pH changes.

**Indirect** –

1. Availability of some nutrients like phosphorous.
2. Higher availability of Al, Mn, Fe, Zn, Cu etc.
3. Adverse effects on the beneficial activities of micro-organism.
4. Increase of plant diseases.
5. Nutrients like Ca, K, Mo etc. become deficient.
Toxic effect of soil acidity:

1. **Cell elongation** – Due to the soil acidity reduces the cell elongation because it adversely affected the development of meristmatic tissues of root tip in which maximum water and nutrients are occurred.

2. **Aluminium toxicity** – The toxicity of Al is influence by nature and concentration of accompanying concentration. Example – When muriate of potash (salt of muriatic acid) is used in the acidic soils, Cl ion of KCl will aggregate the toxic effect of Al. Aluminium accumulate on the surface of plant root and affected the root permeability. Root permeability will be adversely effected than also accumulates in the cortex particularly nuclei and cell protoplasm (it is colloidal in nature). If it is accumulates than protoplasm colloidal character present and the result of this cell division or cell growth is checked and form binucleate cells.

3. **Mn toxicity** – Under acidic condition Mn also show behavior similar to Al and as concentration of solution increases as the pH is decreases. Example – Plant can tolerant upto 1 – 4 µg per ml of Mn, the plant will be suffered from Mn toxicity. Sometimes typical occur in the field condition no Mn toxicity observed but in a pot experiment Mn toxicity occur because of the steaming effect appear as a result of which are more Mn comes to the soil solution and at therefore plant can suffer from Mn toxicity. Tolerance of Mn toxicity varies from crop to crop, paddy can tolerant higher concentration of Mn.

4. **Specific effect of soil acidity** – It effects the root tissue resulted in restricted in root growth.

5. **Non-specific effect of soil acidity** – Under acidic condition the presence of more amount of Fe, Mn etc. on the exchange side.
   - **Nitrogen economy** : Plant absorbs most of their nitrogen in the form of NO3 whose availability depends on the activity of nitrifying bacteria. The organism responsible for nitrification is most active when the pH is between 6.5 – 7.5. Nitrogen is present in two per cent (2%) in inorganic form and 98% in organic form, respectively. Under acidic condition mineralization process will be low and nitrogen avoid reduced. Nitrogen fixing bacteria like Azotobactor also fails to function below pH 6.0. De-nitrification loss is more availability decreases.
   - **Phosphorous economy** : It availability is at its highest when the reaction is below 6.5 & 7.5. In strongly acidic condition (pH is 5.0 or less), Fe, Al and Mn are present in soluble state. These phosphates (Fe, Al and Mn) with water and form insoluble phosphates.

\[
\begin{align*}
\text{Al}^{3+} + \text{H}_2\text{PO}_4^- + 2\text{H}_2\text{O} & \rightleftharpoons 2\text{H}^+ + \text{Al(OH)}_2^+\text{H}_2\text{PO}_4^- \\
& \text{(Insoluble)}
\end{align*}
\]

The phosphate reacts with hydrated oxides of Fe & Al and form insoluble hydroxy phosphate of Fe & Al. This unavailability of phosphorous is called as P-fixation. The monovalent H$_2$PO$_4^-$ ions predominant in highly acidic solution (pH 4.0 – 5.0).
- Potassium economy: In acidic soil K is lost through leaching. The unavailability of K is due to the conversion of exchangeable to non-exchangeable K. It is not converted in any organic form in the plant and availability of K is decreases.
- Ca, Mg and S: In acidic soils the availability of Ca, Mg and S is decreases.
- Fe, Mn and Al: In acidic soil these elements creates toxic effect on plants.
- Mo: Its availability increases with increasing soil pH.

**Management of acid soils**

Management of the acid soils should be directed towards enhanced crop productivity either through addition of amendments to correct the soil abnormalities or by manipulating the agronomic practices depending upon the climatic and edaphic conditions.

**Soil amelioration**

Lime has been recognized as an effective soil ameliorant as it reduces Al, Fe and Mn toxicity and increases base saturation, P and Mo availability of acid soils. Liming also increases atmospheric N fixation as well as N mineralization in acid soils through enhanced microbial activity. However, economic feasibility of liming needs to be worked out before making any recommendation.

**Liming materials**

Commercial limestone and dolomite limestone are the most widely used amendments. Carbonates, oxides and hydroxides of calcium and magnesium are referred to as agricultural lime. Among, the naturally occurring lime sources calcitic and dolomitic are important carbonates.

The other liming sources are marl, oyster shells and several industrial wastes like steel mill slag, blast furnace slag, lime sludge from paper mills, pressmud from sugar mills, cement wastes, precipitated calcium carbonate, etc equally effective as ground limestone and are also cheaper. Considering the efficiency of limestone as 100%, efficiencies of basic slag and dolomite are 110 and 94 % respectively. Basic slag and pressmud are superior to calcium oxide or carbonates for amending the acid soils. Fly ash, a low- density amorphous ferro-alumino silicate, also improves pH and nutrient availability.

\[
2H^+ \text{[Clay]} + CaCO_3 \rightarrow Ca^{2+} \text{[Clay]} + H_2O + CO_2
\]

**Lime requirement** of an acid soil may be defined as the amount of liming material that must be added to raise the pH to prescribed value. Shoemaker et al. (1961) buffer method is used for the determination of lime requirement of an acid soil.
Lime requirement scale of an acid soil by buffer method (t ha\(^{-1}\)):

<table>
<thead>
<tr>
<th>Soil Buffer pH</th>
<th>Lime Requirement</th>
<th>Soil Buffer pH</th>
<th>Lime Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.7</td>
<td>3.95</td>
<td>5.7</td>
<td>18.77</td>
</tr>
<tr>
<td>6.6</td>
<td>5.43</td>
<td>5.6</td>
<td>20.25</td>
</tr>
<tr>
<td>6.5</td>
<td>6.92</td>
<td>5.5</td>
<td>21.24</td>
</tr>
<tr>
<td>6.4</td>
<td>8.40</td>
<td>5.4</td>
<td>23.47</td>
</tr>
<tr>
<td>6.3</td>
<td>9.88</td>
<td>5.3</td>
<td>24.95</td>
</tr>
<tr>
<td>6.2</td>
<td>11.12</td>
<td>5.2</td>
<td>27.17</td>
</tr>
<tr>
<td>6.1</td>
<td>12.84</td>
<td>5.1</td>
<td>28.90</td>
</tr>
<tr>
<td>6.0</td>
<td>14.37</td>
<td>5.0</td>
<td>30.63</td>
</tr>
<tr>
<td>5.9</td>
<td>15.81</td>
<td>4.9</td>
<td>32.60</td>
</tr>
<tr>
<td>5.8</td>
<td>17.30</td>
<td>4.8</td>
<td>34.58</td>
</tr>
</tbody>
</table>

**Crop choice**

Selection of crops tolerant to acidity is an effective tool to counter this soil problem and breeding of such varieties is of specific importance for attaining higher productivity, particularly in areas where liming is not an economic proposition. The crops can be grouped on the basis of their performance in different soil pH range.

<table>
<thead>
<tr>
<th>Relative tolerance of crops to soil acidity Crops</th>
<th>Optimum pH range</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cereals</strong></td>
<td></td>
</tr>
<tr>
<td>Maize, sorghum, wheat, barley</td>
<td>6.0-7.5</td>
</tr>
<tr>
<td>Millets</td>
<td>5.0-6.5</td>
</tr>
<tr>
<td>Rice</td>
<td>4.0-6.0</td>
</tr>
<tr>
<td>Oats</td>
<td>5.0-7.7</td>
</tr>
<tr>
<td><strong>Legumes</strong></td>
<td></td>
</tr>
<tr>
<td>Field beans, soybean, pea, lentil etc.</td>
<td>5.5-7.0</td>
</tr>
<tr>
<td>Groundnut</td>
<td>5.3-6.6</td>
</tr>
<tr>
<td><strong>Others</strong></td>
<td></td>
</tr>
<tr>
<td>Sugarcane</td>
<td>6.0-7.5</td>
</tr>
<tr>
<td>Cotton</td>
<td>5.0-6.5</td>
</tr>
</tbody>
</table>