Influence of soil pH on nutrient availability: A Review

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ABSTRACT

A conceptual analysis over the plant growth and soil conditions provide an insight towards the effect of chemical properties of soil on the nutrient status of soil. It has been observed that soil reactions play a pivotal role in determining the nutrient availability for the plants. Whenever acidity or basicity is induced in the soil solution, certain reactions come into play whereby certain cationic and anionic release, supply and exchange between plants and soils are involved.

Keywords: pH, acidity, basicity, nutrient, soil, etc.

Introduction:

Soil pH is a measurement for acidity and alkalinity of the soil solution. It can be defined as the negative logarithm of hydrogen ion concentration [H^+] or hydroxide ion concentration [OH^-], or simply, pH = -log [H^+]; pH= -log [OH^-] . By reference of acidic, neutral or alkaline nature, the pH value of soils can be provided on basis of a scale ranging from approximately 0 to 14. A pH value of 7 is neutral (pure water), values less than 7 refers to acidic and above 7 is alkaline. Being a logarithmic function, one unit of a pH scale is 10 times more alkaline (or 10 times more acidic) than the unit below it. As an example, if we consider a solution of pH value 4, it has a 10 times higher concentration of OH^- ions than a solution of pH 5 or a 100 times higher concentration than a pH 6 solution [McCauley et al., 2009]. The effect of both acid and base forming ions influences soil pH. Pronounced effect on acidity can be stimulated by acid-forming cations such as hydrogen (H^+), aluminium (Al^{3+}) and iron (both Fe^{2+}, Fe^{3+}); while basicity is influenced by base-forming cations like calcium ($Ca2^+$), potassium (K^+) and sodium (Na^{2+}). Soils having a basic pH range are primarily associated with the presence of basic cations along with carbonates and bicarbonates from the soil and irrigation water. Furthermore, limited leaching of base cations due to low precipitations can act as a factor for the relative raise of pH values higher than 7. Distinctively, the acidic conditions in soil are associated with areas of high precipitations and also with soils having parent materials of silicic origin. Increased precipitation causes higher rate of base cations leaching and hence the soil pH is lowered.

The major source for human nutrition is primarily derived from soil. A good, fertile and productive soil is a basic necessity to develop an ecosystem [Radulov et al., 2011]. In order to maintain a proper productivity aspect of the soil, it is rudimentary for soil to have a good physical and chemical property, organic matter content, proper aeration with an optimum pH and nutrient status [Cresser, 1993]. The chemical and physical nature of soil determines the potential of the soil for production capability of crops. The chemical nature of soil includes soil reactions (pH), nutrient constitution, ion exchange etc. The fact remains that soil reaction (pH) is not an indicator for growth attributes of plants; however, it provides a good indication of several plant growth factors, mostly for nutrient status of the soil. The availability of nutrients in soil highly associated with the pH of the soil. The uptake of ions such as Ca^{2+} and Mg^{2+} by plants increases along with pH while micronutrient availability increases with decrease in soil pH [Finck, 1976]. More specifically, pH impacts the chemical solubility and availability of essential plant nutrients along with organic matter decomposition [McCauley et al., 2009].

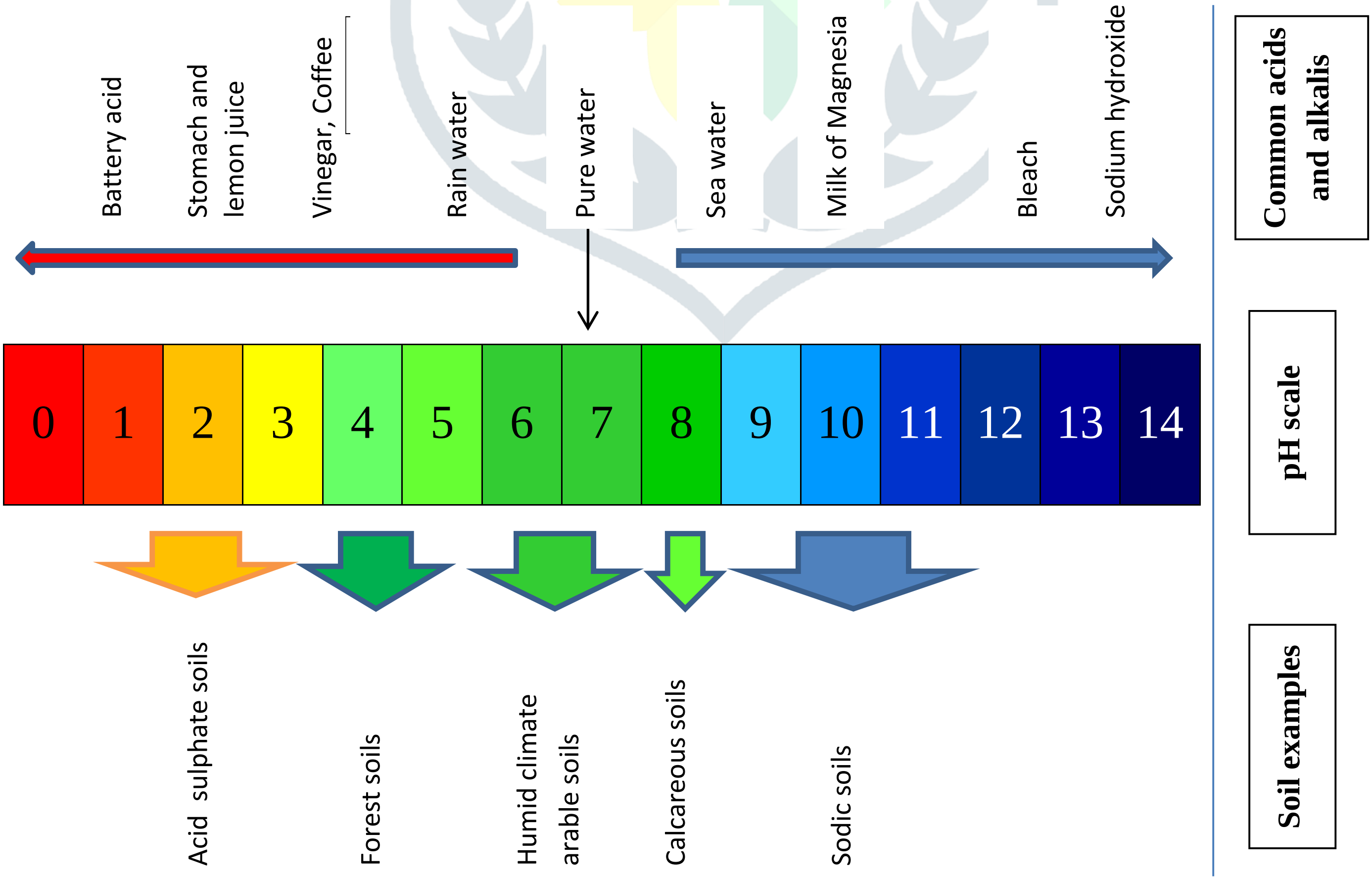

Fig 1: pH scale (Source: Nutrient Manager, 1996)

Availability of nutrients:

Ion exchange capacity:

The ion exchange capacity is directly impacted by soil pH. The ion exchange capacity is the ability of the soil to retain, release and supply plant nutrients in the form of positively charged ions. The chemical elements (or plant nutrients) in the soil occurs as cations (+ve charged ion) or anions (-ve charged ions). The essential plant nutrients such as H, Ca, Mg, Fe, Mn and Zn appear in soil as cations. Other ions available are Na, Ba, Hg, Cd,Cr, etc. but these ions are non- essential for plants.

Soils with high cation exchange capacity possess good buffering capacity; which in turn can resist changes in pH. Clay soils have a considerable high amount of CEC than silt or sandy soils. In an alkaline (or basic) medium, the concentration of H^+ ions is low; H^+ ions will compete less with the other cation for exchange sites and more base cations will remain on the particle exchange sites. Thus, the cations are least susceptible to leaching in alkaline conditions. This process occurs in reverse in the acidic medium as H^+ ions exchanges the base cations from the exchange sites. These nutrients are released in the soil solution which is either taken up by the plants or incur leaching losses [McCauley et al., 2009].

However, even though a proper CEC is desirable for crop growth, it does not directly regulate the crop yield factors. Advantages of having a high CEC are retention of cations from leaching losses and provision of essential nutrients from the roots of plants via exchange of H^+ ions. CEC become apparent from minerals and organic matter through the negative electrostatic charges. Organic matter inculcates low CEC which can be increased when they undergo decomposition and residues are converted to humus. This process takes a long time which may span from 5 years to a few centuries [Fernandez et al., 2009]. So, practices which can reduce erosion, leaching losses and maintain good organic matter content in soil is preferred for retention of CEC.

The CEC (in units of milliequivalent per 100 grams of soil) of some soil types are provided depending upon the clay and humus content.

1. Sandy soils: <4
2. Silt loam soils: 8-22

3. Clay soils: 18-30 [Fernandez et al., 2009]

Plant nutrient availability:

The availability of essential plant nutrients is highly correlated with the function of pH. Plant nutrients are broadly classified as macro-nutrients and micro-nutrients as per the requirement of the plant. Availability of these nutrients to the plants corresponds to differential pH conditions. The macronutrients such as nitrogen, calcium, potassium, magnesium and sulphur, with phosphorus as exception, are more readily available in a pH range of 6.5-8. The micronutrients however are available in slightly in a slight acidic pH of 5-7. These are the optimal range in which nutrients are available to plants in favourable quantity. Availability becomes less outside these pH ranges.

As the pH increases and approach 8, cations are bonded strongly to the soil and are not readily exchangeable. Due to this, the micronutrient availability, apart from molybdenum, decreases in alkaline conditions. Also, nutrient elements of Fe, Cu, Mn, Zn and Ni are tightly bound at alkaline pH and hence, they are more readily available in lower pH levels. This can induce toxicity symptoms to the plants in acid soils.

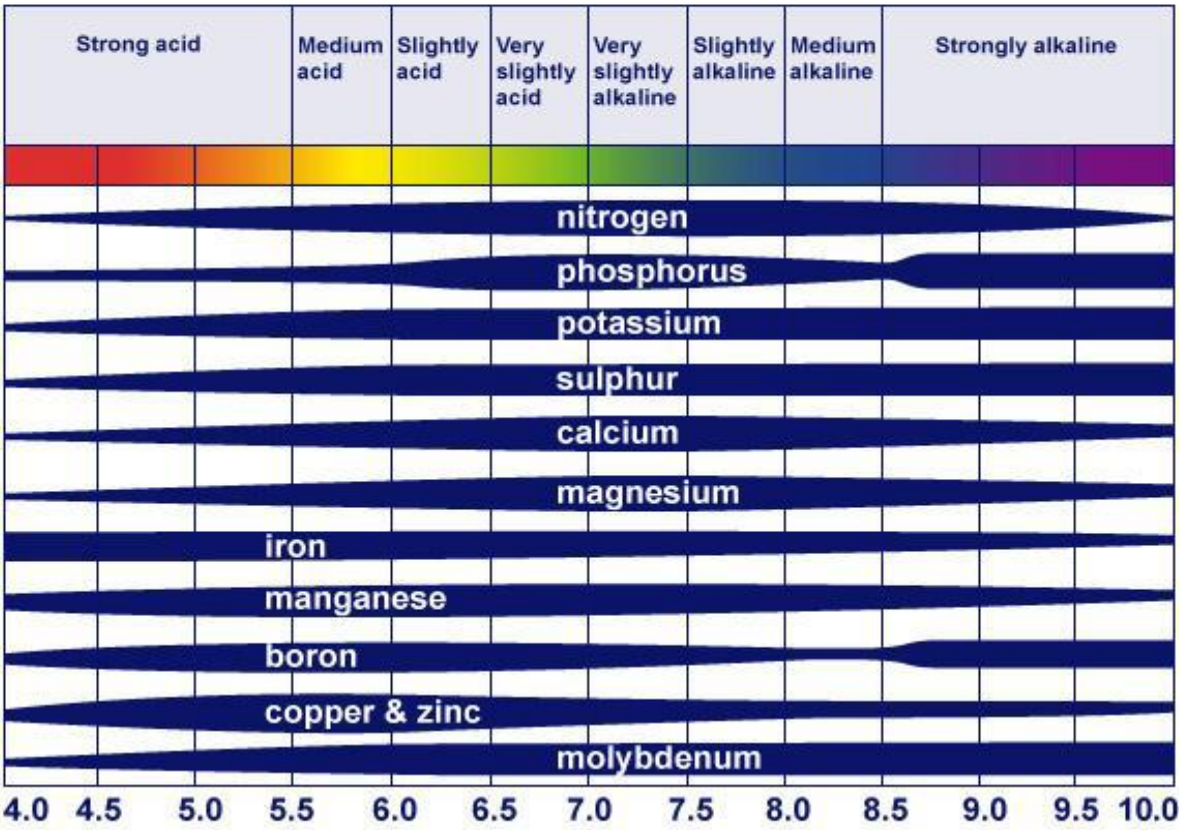

Fig 2: Nutrient availability based on soil pH (Source: Roques et al., 2013)

Plant growth and soil acidity:

The growth of plants can be affected greatly by different pH conditions. In acidic conditions, certain situation may arise such as metal toxicity. The active microbial population and its activity involved in immobilization/mineralization of N, P and S may be hampered. Calcium becomes deficient in acidic conditions and symbiotic N fixation can be greatly affected. Also, acid soils having low organic matter content has poor tilth.

Selection of crops is highly recommended for such type of conditions. Generally, crops having high tolerance to acidic or basic pH can be selected. For example, alfalfa crop can grow well in acidic medium of pH 6.2-7.5. Barley, corn, oats can tolerate pH as low as 5.5. Potatoes can grow favourably at an optimal pH condition of 5.0-5.5. At this pH, bacteria causing common scab disease of potatoes can also be controlled [Walworth, 1998]. However, in the extreme conditions of high acidity or alkalinity, certain reformations may be needed such that crops can grow under optimal conditions. Table 1 shows some crops and their favourable soil pH conditions.

Table 1: Optimum pH range for some common crops

Crop	Soil pH
Alfalfa	6.2-7.5
Barley	5.5-7.0
Corn	5.5-7.0
Pea	6.0-6.0
Potato	5.0-5.5

Source: Havlin et al., 1999

pH management in soils:

Acid soils:

A commonly followed method for increasing the pH of soil is through liming process or precisely the addition of liming materials such as $CaCO_3$, CaO or $Ca(OH)_2$. The rate of liming is accessed based upon the type of soils, tillage depth and quality of the limestone [Fernandez et al., 2009]. Dolomite is a cheap substitute for liming materials. The major function of the liming materials is the removal of acid forming cations like H^+ and Al^{3+}. Bicarbonates produced by the reaction between liming materials with carbon dioxide and water are able to perform this function. Certain criteria must be met by companies supplying liming materials to ensure effectiveness of the product. Effective Neutralising Value or ENV is one of such criteria which tests the effectiveness of the materials in neutralising acidity. The Calcium Carbonate Equivalent or CCE determines the purity of the chemicals in use. An increase in the CCE effectively increases the power of neutralization of the lime. The size of the liming materials is also one of the criteria. Fine sized lime will provide more effective management by reacting quickly in the soil; but the coarse lime will take a longer period to react completely and remains in the soil for a long time. Commercial lime is a mixture of different particle sized lime in order to provide a sudden hike in pH as well as regulating this increase for a longer period of time [Rehm et al., 2002].

Alkaline soils:

Acidification of alkaline soil can be achieved by sulphur amendments in the soil [Slaton et al., 2001]. Elemental sulphur upon oxidization by microbes produces sulphate (SO_4^{2-}) and H^+ ions, which causes lowering in pH. The addition of sulphates of iron and aluminium in the soil also seems to do the job as Fe^{3+} and Al^{3+} are acidic cations. The amendments are specific to particle size, oxidation rate of the chemicals as well as the original soil conditions like pH, buffering capacity, etc. Ammonium fertilizers and soil organic matter also acidifies the soil through the production of H^+ ions. The addition of gypsum ($CaSO_4.2H_20$) is also a commonly used practice.

Summary:

The soil pH provides a measure of soil acidity and alkalinity. An imperative effect on the soil nutrient status and availability of these nutrients can be observed at different pH levels. Some relevant factors impacting the soil pH are parent materials of the soil, the organic matter content and its decomposition, climatic factors and land use practices. Furthermore, ion exchange between soil solution and plants play an important role in the release of cations/anions which play pivotal role in maintaining soil pH. Management of soils for maintaining the alkalinity or acidity with the help of certain tools and chemicals should be considered for proper availability of essential nutrients to the plants.

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