Soil pH
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One important property of the soil solution is its reaction, which can be either acid, neutral, or alkaline. Some soil solutions possess a preponderance of hydrogen over hydroxyl ions and is therefore acid. Some show the reverse and are alkaline, while others which have an equal concentration of hydrogen and hydroxyl ions, are neutral.

The soil solution reaction does have significance in relation to plant nutrient availability. The following brief explains some direct and indirect effects of soil pH that may influence nutrient absorption and plant growth.

The exact relationship in any particular case is evaluated in terms of hydrogen ion concentration, which is usually expressed in terms of pH. The pH value of a solution is the logarithm of the reciprocal of the hydrogen ion concentration. It may be stated in the following expression:

\[ \text{pH} = \log_{10} \frac{1}{[\text{H}^+]} \]

For example, pH=6, the hydrogen ion concentration is \(10^{-6}\) equivalent per liter and the hydroxyl ion concentration is \(10^{-14}/10^{-6} = 10^{-8}\) equivalent per liter. It is understood, however, that the distribution of the hydrogen and hydroxyl ions in the soil solution is not homogeneous. Hydrogen ions are adsorbed by soils to a much greater degree than are the hydroxyl ions. Consequently, the hydrogen ions are seen as: (a) being especially concentrated at or near the colloidal interfaces, and (b) becoming less numerous as the outer portions of the water films are approached. Since hydroxyl ions vary in number inversely with hydrogen ions, this causes a higher pH in the outer moisture zones. This situation affects nutritional aspects concerning both microorganisms and high plants.

The soil pH influences absorption and plant growth in two ways: (a) through the direct effect of the hydrogen ion, or (b) indirectly through its influence on nutrient availability and the presence of toxic ions. Most plants are able to tolerate a wide range in the concentration of hydrogen ions so long as a proper balance of the other elements is maintained, even though at extreme pH values the hydrogen ion can be toxic. However, the availability of several of the essential nutrients is drastically affected by soil pH, as is the solubility of certain elements that are toxic to plant growth.

Several of the essential elements tend to become less available as the pH is raised from 5.0 to 7.5 or higher. This includes iron, manganese, and zinc. Molybdenum availability is affected in the opposite way, being higher at the higher pH levels. Phosphorus is never readily soluble in the soil, but it seems to be held with least tenacity in the pH range centering around 6.5.

At pH values below 5.0, aluminum, iron, and manganese are soluble in sufficient quantities to be toxic to the growth of some plants. At very high pH values, the bicarbonate ion is sometimes present in sufficient quantities to interfere with the normal uptake of other ions and makes it detrimental for optimum growth.

Since microorganisms and higher plants respond so markedly to their chemical environment,
the importance of soil reaction and the factors associated with it have been recognized for a long time. Soil acidity is common in regions where precipitation is high enough to leach significant amounts of exchangeable bases from the surface layers of soils.

Alkalinity occurs when there is a high degree of base saturation. The presence of salts, especially calcium, magnesium, and sodium carbonates, gives a preponderance of hydroxyl ions making the soil alkali. Alkaline soils are characteristic of most arid and semiarid regions.

**Source of Hydrogen Ions (Acidity)**

Two adsorbed ions are largely responsible for soil acidity - hydrogen and aluminum. They differ in their relationship to the source and nature of the charge to which each of these ions is attracted. Two types of negative charges exist on soil colloids (a) permanent, and (b) pH dependent. The first is associated primarily with silicate clays and its electrostatic forces. The charge sites are located mostly on internal surfaces. Cations are exchangeable at all pH levels at the permanent charge sites. The second type of charge is not permanent but is related directly to soil pH. The charge is low in very acid soils and increases as pH rises. This change is thought to have many sources. There are SiOH and AlOH groups at the broken edges and external surfaces of silicate clay. There are also carboxyl (COOH) and phenol (phenyl-OH) groups on the humus colloids. These groups each contain covalent-bonded hydrogen which is not dissociated at low pH values. As the pH increases, hydrogen dissociates, leaving a negative charge on the colloid. The hydrogen is then replaced by metallic cations, which in turn are exchangeable.

In acid soils, complex aluminum and iron hydroxy ions are tightly adsorbed on clays. These ions block some of the negative charge sites of the colloid, reducing its cation exchange capacity. As the pH is raised, the complex ions are removed, forming insoluble Al(OH)$_3$ and Fe(OH)$_3$ and releasing the exchange sites.

Under very acid conditions much aluminum becomes soluble and is present in the form of aluminum or aluminum hydroxy cations. The absorbed aluminum is in equilibrium with aluminum ions in the soil solution. Aluminum ions contribute to soil acidity through their tendency to hydrolyze. The hydrogen ions released give a very low pH value in the soil solution and are a major source of hydrogen in most very acid soils.

Adsorbed hydrogen is a second source of hydrogen ions in very acid soils. Hydrogen ions, which may be held by covalent bonds with some iron and aluminum, are so tightly adsorbed that it contributes little to the soil solution.

In moderately acid soils aluminum and hydrogen compounds also account for soil solution hydrogen ions. These soils have somewhat higher percentage base saturations and pH values. The aluminum can not exist as Al$^{3+}$ ions but are converted to aluminum hydroxy ions by reactions such as:

$$\text{Al}^{3+} + \text{OH}^- \rightarrow \text{Al(OH)}^{++}$$

$$\text{Al(OH)}^{++} + \text{OH}^- \rightarrow \text{Al(OH)}_2^+ \quad \text{(aluminum hydroxy ions)}$$

In moderately acid soils, with the rise in pH, some hydrogen ions which were strongly held through covalent bonds by organic matter and clay are now subject to release in association with the pH dependent sites.

Soils that are neutral to alkaline in reaction are no longer dominated by either hydrogen or aluminum ions. The permanent charge exchange sites are now occupied primarily by exchangeable bases, both the hydrogen and the aluminum hydroxy ions having been largely replaced.

Obviously, the factors responsible for soil salinity are far from simple. However, there are two dominant groups of elements in control. Aluminum and hydrogen generate acidity, and most of the other cations combat it.

**Sources of Hydroxyl Ions (Alkalinity)**

When adsorbed hydrogen and aluminum are replaced from acid soils by cations such as calcium, magnesium, and potassium. The
hydrogen concentration in the soil solution decreases the concentration of hydroxyl ions and will simultaneously increase since there is an inverse relationship between the hydrogen and hydroxyl ions. These "base forming" cations become sources of hydroxyl ions merely by replacing the adsorbed hydrogen.¹

The metallic cations such as calcium, magnesium, and potassium also have a more direct effect on the hydroxyl ion concentration of the soil solution. A definite alkaline reaction results from the hydrolysis of colloids saturated with these cations. Under natural conditions the reactions to furnish hydrogen and hydroxyl ions to the soil solution occur at the same time, that is, hydrogen and aluminum ions and the basic cations are held at one time.¹ The pH of the soil solution will depend upon the relative amounts of absorbed hydrogen and aluminum compared to adsorbed metallic cations. Where the effect of hydrogen and aluminum are dominant, acidity results. Excess bases yield alkalinity, and at just the right balance, the pH of the soil solution will be 7 (neutral).

As exchangeable calcium and magnesium are lost by leaching, the acidity of the soil gradually increases. In humid regions, there is a direct correlation between the pH and the amounts of the two elements. When the pH of a mineral soil is low, large amounts of aluminum, iron, and manganese are soluble. In fact, they may become toxic to certain plants due to their high solubility. However, as pH is increased, precipitation takes place and the amounts of these ions in solution becomes less and less. At neutrality plants may suffer from lack of available manganese and iron.

Copper and zinc are affected in the same way by a rise in pH, the critical point being near pH 7, above which their availability declines. Boron is different and more complicated. Neither the soil untreated nor lime alone, appreciably precipitate boron, but the two in combination fix it markedly.¹ Too much calcium in plant cells might interfere with boron metabolism, even if plenty is present.

Molybdenum availability is dependent on pH. It is quite unavailable in strongly acid soils. It becomes available at pH 6 and above.

The kind of phosphorus ion present varies with soil pH. Where soil is alkaline, the HPO₄⁻ ion is most active.¹ As pH is lowered and the soil becomes slightly to moderately acid, both the HPO₄⁻ ion and the H₂PO₄⁻ ion prevail. At still higher acidities, the H₂PO₄⁻ ion tends to dominate. Under conditions where soil acidity increases and there is a rise in iron, aluminum, and manganese, phosphates are strongly fixed as complex and insoluble compounds.

If the pH of a soil is raised much above 7, the solubility of both the native and applied phosphorus may be impaired. Additionally, a pH above 7, the excess calcium that forms may hinder phosphorus absorption and utilization by plants.

Between pH 6 to 7, phosphorus fixation is at a minimum; conversely, phosphorus availability is at a maximum for most plants.¹ It is therefore important to keep pH near the 6 to 7 pH for the best nutrition for crops.²

Nitrification and nitrogen fixation take place vigorously in mineral soils only at pH values well above 5.5.¹ However, mineralization, although reduced, will still proceed at lower pH because fungi are able to effect these enzymatic transfers at high acidities.²

Biologically, soil in the intermediate pH range presents the most satisfactory regime. Nutrient conditions are favorable without being extreme and phosphorus availability is at a maximum.

Soil pH and how it affects nutrient availability through direct and indirect means, can be very complex. Understanding how certain pH factors affect nutrient availability plays an important role in the proper management of crop and forage production. Overall, based on my findings, it would seem very important to attempt to keep soil pH at or near neutral for best overall nutrient availability and plant nutrition.
