

## Nutrient Dynamics in Relation to Soil Plant System

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### SUMMARY

Nutrient dynamics is broadly defined as the way nutrients are taken up, retained, transferred, and cycled over time and distance, in an ecosystem (Hauer and Lamberti, 2006; Allan and Castillo, 2007). Nutrients are defined in the broad sense as all chemical elements vital to biological functions (e.g., survival and reproduction) (DeAngelis et al., 1989). Organisms require macronutrients in large quantities such as carbon (C), hydrogen (H), nitrogen (N), phosphorus (P), potassium (K), sulfur (S), and calcium (Ca); other nutrients such as silicone (Si) are used for critical cellular processes. Micronutrients, such as copper (Cu) and zinc (Zn), are needed in lesser quantities (Smith and Smith, 1998). In nature, various elements can limit primary productivity of an ecosystem at a given place and time. The productivity of most aquatic ecosystems is controlled by the concentration, molecular form, and stoichiometry of the macronutrients N and P (Officer and Ryther, 1980).

### INTRODUCTION

Plant growth and development largely depend on the combination and concentration of mineral nutrients available in the soil. Plants often face significant challenges in obtaining an adequate supply of these nutrients to meet the demands of basic cellular processes due to their relative immobility. There are thirteen essential nutrients which plants get from soil. The six that the plants need the most of are called Macronutrients. They are Nitrogen, Phosphorus and Potassium, which are abbreviated N-P-K, Calcium, Magnesium and Sulfur. The other nutrients, which are needed only in trace amounts, are called Micronutrients. They are Iron, Manganese, Boron, Zinc, Copper, Molybdenum and Chlorine. The nutrients are identical whether they come from organic or synthetic sources, but the source will affect how fast the nutrients are available to plants. Nutrient dynamics is broadly defined as the way nutrients are taken up, retained, transferred, and cycled over time and distance, in an ecosystem (Hauer and Lamberti, 2006).

### Nitrogen

There are three major forms of nitrogen in soil: a) organic nitrogen associated with the soil humus, b) ammonium nitrogen fixed by certain clay minerals, and c) soluble inorganic ammonium and nitrate compounds. Most of the nitrogen in surface soils is associated with the organic matter. In this form it is protected from rapid microbial release, only 2-3% a year being mineralized under normal conditions. About half the organic nitrogen is in the form of amino compounds. The form of the remainder is uncertain. The process of tying up N in organic forms is called immobilization; its slow release – specifically, organic to inorganic conversion – is called mineralization (Fig 1).

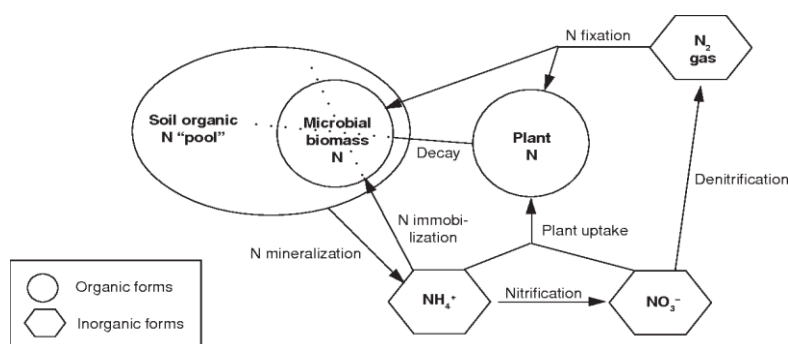


Fig.1 Nitrogen Mineralization and Immobilization

Climate, natural vegetation, texture, drainage and other soil factors and cropping are the main factors influence organic matter and nitrogen. The inherent capacity of soil to produce crops is closely and directly related to their organic matter and nitrogen content. Consequently, the methods of organic matter additions and upkeep should receive priority considerations in all soil management programs. Some of the released during mineralization of organic N is converted to  $\text{NO}_3^-$ . Supply of  $\text{NH}_4^+$ , population of nitrifying organisms, soil pH,

soil aeration, moisture and temperature are the important factors affecting nitrification. Some of the clay minerals (e.g. vermiculite and some smectites) have the ability to fix ammonium nitrogen between their crystal units. The amount fixed varies depending on the nature and amount of clay present. Upto 8% of the total nitrogen in surface soils and 40% of that in subsoils may be in the clay fixed form (Brady and Weil, 2007). Moisture content and temperature of the soil will affect the fixation of  $\text{NH}_4^+$ . Freezing and drying increase fixation. Alternate cycles of wetting – drying and freezing – thawing are believed to contribute to the stability of recently fixed  $\text{NH}_4^+$ . The presence of  $\text{K}^+$  will often restrict ammonium fixation since  $\text{K}^+$  can also fill fixation sites. There is evidence that fixed  $\text{NH}_4^+$  is in equilibrium with exchangeable  $\text{NH}_4^+$ . The amount of nitrogen in the form of soluble ammonium and nitrate compounds is seldom more than 1-2% of the total present, except where large applications of inorganic nitrogen fertilizers have been made. This is fortunate since inorganic nitrogen subject to loss from soils by leaching and volatilization. Only enough is needed to supply the daily requirement of the growing crops. The major losses of N from the soil are due to crop removal and leaching, however, under certain conditions; inorganic N can be converted to gases and lost to the atmosphere. The primary pathways of gaseous N losses are by denitrification and  $\text{NH}_3$  volatilization.

### Phosphorus

The availability of inorganic P is largely determined by a) soil pH, b) soluble Fe, Al and Mn, c) presence of Fe, Al and Mn containing minerals, d) available Ca and Ca-minerals e) amount and decomposition of organic matter and activities of microorganisms. The first four factors are interrelated since soil pH drastically influences the reaction of P with the different ion and minerals. The availability of phosphorus to plants is determined to no small degree by the ionic form of this element. The ionic form in turn is determined by the pH of the solution in which the ion is found. Thus, in highly acid solutions only  $\text{H}_2\text{PO}_4^-$  ions are present. If the pH is increased, first  $\text{HPO}_4^{2-}$  ions and finally  $\text{PO}_4^{3-}$  ions dominate. At intermediate pH levels two of the phosphorus ions may be present simultaneously. Thus in solutions at pH 7.0, both  $\text{H}_2\text{PO}_4^-$  and  $\text{HPO}_4^{2-}$  ions are found. The  $\text{H}_2\text{PO}_4^-$  ion is somewhat more available to plants than is the  $\text{HPO}_4^{2-}$  ions. In addition to pH and related factors, organic matter and microorganisms strikingly affect inorganic P availability (Prasad, 2007). Apparently the manure was effective in releasing P after it has been fixed as Fe, Al and Ca phosphates. Even though both phytin and nucleic acids can be utilized as source of P, inorganic source of this element are needed for normal production. Plants commonly suffer from a phosphorus deficiency even in the presence of considerable quantities of organic forms of this element. Just as with inorganic P, the problem is one of availability. In acid soils the phytin is rendered insoluble and thus unavailable because of reaction with Fe and Al. Under alkaline conditions Ca phytate is precipitate and its P is rendered unavailable. The fixation of nucleic acids involves an entirely different mechanism, but the end result – low P availability is the same. Evidently, nucleic acids are strongly adsorbed by clays, especially montmorillonite.

### Potassium

The various forms of K in soils can be classified on the basis of availability in three general groups a) unavailable (feldspars, micas etc), b) readily available (exchangeable and in soil solution) and c) slowly available (non-exchangeable=fixed). The potassium removed by crops is supplied by largely from non-exchangeable forms. Several soil conditions markedly influence the amounts of K fixed. Among the factors are (a) the nature of the soil colloids, (b) wetting and drying, (c) freezing and thawing and (d) the presence of excess lime. The ability of the various soil colloids to fix K varies widely. For example, 1:1 type clay such as kaolinite and soils in which these clay minerals are dominant fix little potassium (Menel and Kirkby, 1987). On the other hand, clays of the 2:1 type, such as vermiculite, smectite and fine grained mica (illite), fix K very readily and in large amounts. The mechanism for K fixation is probably the same as that for fixation of the ammonium ion. These two ions do not have as high an affinity for water of hydration as do other cations such as  $\text{Na}^+$  and  $\text{Ca}^{2+}$ . As a consequence they can easily be dehydrated and then their small size is such as to permit them to fit snugly between the silica sheets of adjoining layers in the 2:1 type clay minerals. Once in place, these ions become trapped as a part of the rigid crystal structure, thereby preventing normal crystal lattice expansion and reducing the CEC of the clay. The larger hydrated ions of cations such as  $\text{Na}^+$ ,  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  are not able to fit between these layers and consequently escape fixation.

## Calcium

Ca in acid, humid region soils occurs largely in the exchangeable form and as primary minerals. Soil factors of the greatest importance in determining the  $\text{Ca}^{2+}$  availability to plants are the following: 1. Total Ca supply 2. Soil pH 3. CEC 4. Percent %  $\text{Ca}^{2+}$  saturation on CEC 5. Type of soil colloid 6. Ratio of  $\text{Ca}^{2+}$  to other cations in solution Total Ca in very sandy, acid soils with low CEC can be too low to provide sufficient available  $\text{Ca}^{2+}$  to crops. High  $\text{H}^+$  activity will impede  $\text{Ca}^{2+}$  uptake. In acid soils, Ca is not readily available to plants at low saturation. The %  $\text{Ca}^{2+}$  saturation decreases in proportion to the total CEC, the amount of  $\text{Ca}^{2+}$  absorbed by plants decreases. High  $\text{Ca}^{2+}$  saturation indicates a favourable pH for plant growth and microbial activity. Also, a prominence of Ca will usually mean low concentration of undesirable exchangeable cations such as  $\text{Al}^{3+}$  in acidic soils and  $\text{Na}^+$  in sodic soils. The type of clay influences  $\text{Ca}^{2+}$  availability; 2:1 clays require higher  $\text{Ca}^{2+}$  saturation than 1:1 clays. Specifically, Montmorillonitic clay require a >70%  $\text{Ca}^{2+}$  saturation for adequate Ca availability, whereas kaolinitic clays are able to supply sufficient  $\text{Ca}^{2+}$  at 40 to 50%  $\text{Ca}^{2+}$  saturation. Ca availability and uptake by plants are also influenced by the ratios between  $\text{Ca}^{2+}$  and other cations in the soil solution. A Ca/total cation ratio of 0.10 to 0.15 is desirable for an adequate  $\text{Ca}^{2+}$  supply to most crops. While  $\text{Ca}^{2+}$  uptake is depressed by  $\text{NH}_4^+$ ,  $\text{K}^+$ ,  $\text{Mg}^{2+}$ ,  $\text{Mn}^{2+}$  and  $\text{Al}^{3+}$ , its absorption is increased when plants are supplied with  $\text{NO}_3^-$ -N. A high level of  $\text{NO}_3^-$  nutrition stimulates organic anion synthesis and the resultant accumulation of cations, particularly  $\text{Ca}^{2+}$ .

## Magnesium

Mg occurs predominantly as exchangeable and solution  $\text{Mg}^{2+}$ . The absorption of Mg by plants depends on the amount of solution  $\text{Mg}^{2+}$ , soil pH, and the % Mg saturation on the CEC, the quantity of other exchangeable ions and the type of clay. The formation of these relatively unavailable forms in acid soils is favoured by the presence of soluble Mg compounds and 2:1 clay. Presumably  $\text{Mg}^{2+}$  could be trapped in the interlayer of expanding and contracting minerals. Coarse-textured soils in humid regions exhibit the greatest potential for Mg deficiency. These soils normally contain small amounts of total and exchangeable  $\text{Mg}^{2+}$ . Soils are probably deficient when they contain less than 25 to 50 ppm exchangeable  $\text{Mg}^{2+}$ . Exchangeable Mg normally accounts for 4 to 20% of the CEC of soils. The critical Mg saturation for optimum plant growth coincides closely with this range, but in most instances, %Mg saturation should not be less than 10%. Reduced Mg uptake in many strongly acid soils is caused by high levels of exchangeable  $\text{Al}^{3+}$ . The availability of  $\text{Mg}^{2+}$  can also be adversely affected by high  $\text{H}^+$  activity in acid organic soils where exchangeable  $\text{Al}^{3+}$  is not a major cause of the acidity. Mg deficiencies also can occur in soils with high ratios of exchangeable Ca/Mg, where this ratio should not exceed 10/1 to 15/1. On many humid region, coarse-textured soils the continued use of high calcic liming materials may increase the Ca/Mg ratio and induce Mg deficiency on certain crops. High levels of exchangeable K can interfere with Mg uptake by crops. Generally, the recommended K/Mg ratios are mechanism of this interaction probably involves the  $\text{H}^+$  ions released when  $\text{NH}_4^+$  is absorbed by roots, as well as the direct effect of  $\text{NH}_4^+$ .

## Sulphur

S is present in soil in both organic and inorganic forms, although nearly 90% of the total S in most non-calcareous surface soils exists in organic forms. The inorganic forms are  $\text{SO}_4^{2-}$ , adsorbed  $\text{SO}_4^{2-}$ , insoluble  $\text{SO}_4^{2-}$  and reduced inorganic S compounds. Solution plus adsorbed  $\text{SO}_4^{2-}$  represents the readily available fraction of S utilized by plants. There are the similarities between the N and S cycles in that both have gaseous components and their occurrence in soils is associated with OM. Solution  $\text{SO}_4^{2-}$  S is absorbed by roots as  $\text{SO}_4^{2-}$  ions that reach roots by diffusion and mass flow. Adsorbed in highly weathered soils can contribute significantly to the S needs of plants because it is usually readily available but not as rapidly as solution  $\text{SO}_4^{2-}$ . Sulphate adsorption is readily reversible and is influenced by the following soil properties a. Clay content and type of clay mineral b. Hydrous oxides c. Soil horizon or depth d. Effect of pH e.  $\text{SO}_4^{2-}$  concentration f. Effect of time g. Presence of other anions h. Effect of cations i. Organic matter.

The proportion of total S existing in organic forms varies considerably according to soil type and depth in the soil profile. There is close relationship between organic C, total N and total S in soils. The C/N/S ratio in most well drained, non-calcareous soils is approximately 120/10/1.4. Generally more variability exists in C/S ratio in

soils than in N/S ratio. The N/S ratio in most soils falls within the narrow range 6 to 8:1. The nature and properties of the organic S fraction in soils are important since they govern the release of plant available S.

## CONCLUSION

Growth of plant is dependent upon the current uptake of externally available nutrient will depend upon the amounts and availability of stored nutrients and the extent to which recycling occurs within the plant. Although plants are non-motile and often face nutrient shortages in their environment, they utilize a plethora of sophisticated mechanisms in an attempt to acquire sufficient amounts of the macro- and micronutrients required for proper growth, development and reproduction. It is clear that the ability of plants to utilize such mechanisms exerts significant influence over crop yields as well as plant community structure, soil ecology, ecosystem health, and biodiversity. Hence, it is useful to have better knowledge about demand, supply and availability of nutrient for better crop growth.

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