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MINERAL NUTRITION OF PLANTS *

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1. Introduction

The inquiry into processes and factors which control plant life can be traced back to ancient times. These were indeed the simple trials on agricultural practices such as ploughing and tilling which brought about measurable increases of crop yields.

Van Helmot who lived from 1577 to 1644 A.D. is considered to be the first to conduct scientific experiments on plant life to investigate the factors which affect growth.

The rapid developments in the field of chemistry in the nineteenth century opened a new chapter in the study of soils and plants. By the beginning of the century Theodore de Saussures had shown that carbon and elements of water combine together in the plant, and that nitrogen which was so essential for growth was obtained from the soil.

Further progress on plant nutrition awaited the development of new techniques of growing plants under controlled conditions in sand and water cultures. With these developments during the first quarter of the twentieth century, the essentiality of the 10 major elements, C,H,O,N,P,K,Ca,Mg,S and Fe became firmly established.

The introduction of nutrient culture procedures for the study of mineral nutrition provided a convenient method to determine the extent to which an element is essential to normal plant growth.

1.1 General classification and nomenclature

However, with the discovery that elements such as manganese, copper, zinc, boron and molybdenum were also equally important and essential for normal growth, but required in smaller quantities, a broad classification of essential elements was introduced.In this classification, C,H,O,N,P,K,Ca,Mg,S and Fe were generally referred to as "major" elements while Mn,Cu,Zn,B and Mo were called "rare" "trace" or "minor" elements.

1.2 Fundamental features of plant nutrition

The essential feature in the nutrition of plants is the ability of living plant organisms to take up from soil, water and air, the necessary primary ingredients and transform these into complex compounds. The chain of events which take place during this process involves complex physico-chemical reactions, some of which are only partly understood. The fact that no less than fifteen elements (viz.C,H,O,N,P,K,Ca,Mg, S,Fe,Mn,Cu,Zn,B and Mo) participate in these processes indicates the magnitude and complexity of the mechanisms involved. Among the essential elements, carbon, hydrogen and oxygen are obtained almost entirely from water and air, and are hence not regarded as mineral nutrients. Mineral nutrition of plants would therefore involve only those chemical elements which are normally taken up by plants from the soil.

2. Chemical Composition of Soils

2.1 Chemical compostion of the earths crust

Some 14 chemical elements make up 99.5 per cent of the earths crust. Of these, oxygen and silicon make up about 74 per cent in the average composition. If considered by volume, oxygen makes up 90

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per cent of the earths crust, and most of it is combined with silicon and aluminium in minerals.

2.2 Availability of mineral nutrients

The soil is a heterogenous medium made up of solid, liquid and gaseous components in different proportions. In most common soils the solid component which is made up of the minerals and organic matter, makes up about one half of the soil volume. The other half is made up of the soil solution and air (See Figure 1).

A small but an important fraction of the various elements in the soil minerals occur in a form in which they can be replaced by other elements. This fraction in the soil, usually referred to as "exchangeable ions", play a very important role in plant nutrition. The supply of this easily exchangeable fraction of ions is maintained by the gradual weathering of rock minerals; but the rate at which this occurs, and the chemical "activity" of the ions which go into solution depends on the nature of minerals present. Hence it can be said that the mineral composition of the soil can have a very important bearing on the fertility of a soil.

However, the "activity" or the concentration of a cation in solution does not provide any information on the supplying power of these nutrients. Since at the same "activity" of a given cation, the clay-mineral association of a soil can supply the plant much more of that cation than from a true solution. This is chiefly because apart from the nature and concentration of ions present in the medium, their availability to plants is governed by several other factors, of which the following may be considered the more important:-

(a) Nature of the soil colloid
(b) Cation and anion exchange phenomena
(c) Soil pH
(d) Fixation
(e) Effect of complementary ions

3. Functions of Mineral Nutrients

The proof that an element is essential for the normal growth of a plant implies that such an element has a definite and an indispensable function to be performed in the plant.

On the basis of the functions performed by mineral nutrients, these elements could be broadly classified into three main groups. The first of these have as their main function the formation of structural units in cell building. Members of this group are nitrogen and sulphur. The second group has both a structural as well as a catalytic function in metabolism. Elements in this group are phosphorus, calcium and magnesium. The third group comprises of elements which have almost exclusive catalytic functions in plants. All the micronutrients except probably boron falls into this category.

3.1 Catalytic functions of nutrient elements

The nutrient elements which have a catalytic function are associated with enzymes, and these enzymes again are broadly classified into two groups: (i) the metal-activated enzymes, and (ii) the metallo-enzymes.

Among essential elements manganese and magnesium function in many enzyme reactions as activators. On the other hand zinc, iron, copper and molybdenum are often found to be bound firmly to enzymes and functions as metallo enzymes. With regard to the catalytic functions of enzymes, it is interesting to note that in most instances the metal ion associated with an enzyme can perform a catalytic function in its inorgnic state in the absence of the protein component. It is thus said that these elements in their inorganic state possess in a rudimentary or primitive form the functions that they perform so efficiently when combined or associated with an organic radicle. An example is the oxidation of ascorbic acid by salts of copper. When copper forms part of the enzyme called ascorbic acid oxidase, its catalytic function increases a 1000 fold.

3.2 Functions of macronutrients

3.2.1 Nitrogen

Nitrogen is taken up by plants mostly as nitrates, ammonia, urea, or some derivative of these compounds. However, plants with symbiotic bacterial nodules or other microbial associations can take up nitrogen in the elemental form. Whatever the source of nitrogen, during transformations within the plant, ammonia is produced as one of the inorganic intermediate products of metabolism. The ammonia thus formed is received by organic carboxylic acids, forming ultimately amino acids. These are so to say, the building blocks of proteins.

Apart from proteins and amino acids, nitrogen enters into a large number of biologically important compounds, among which are these known as purines and pyrimidines. The proteins also lead to the formation of enzymes and co-enzymes. By entering such a vast range of biologically important compounds in the plants, nitrogen plays a major role in cell building and growth.

3.2.2 Phosphorus

Phosphorus enters the plant as the ortho-phosphate radicle and remains so in both the inorganic and organic compounds of plants. It enters into a large number of compounds and plays a key function in the transfer of energy during the various metabolic processes. In glycolysis the sugars carrying phosphate radicles play a very important role and enters several intermediary breakdown products. It is also associated with several genetically important compounds called nucleic acids.

3.2.3 Potassium

Although potassium is a macro-element and hence required in large quantities, it has not been observed to form any metabolically important compound. In the plant it exists largely as soluble inorganic salts, and to a smaller extent as soluble organic salts. Its absence or deficiency causes many visible symptoms to occur.

3.2.4 Sulphur

Sulphur is taken up by plants mostly from the soil in the form of sulphate. However, if the sulphur dioxide content in the air increases appreciably it may be taken up in the gaseous state through leaves.

Sulphur is a constituent of the amino acids, cystine, cysteine and methionine, and hence enter into the composition of proteins.

3.2.5 Calcium

Although calcium is taken up by plants in relatively large quantities its role is not clearly understood. Being a very immobile element, its deficiency shows a marked effect on the growth and development of young shoots. Curling of young leaves and appearance of chlorotic patches on leaves are typical symptoms of calcium deficiency. Calcium starved plants show retarded root development which consequently weaken the anchorage of plants.

Calcium ions have also been shown to function as an activator of a number of enzymes, and in fact in the case of the enzyme amylase, calcium has been found to stabilize its molecular structure.

3.2.6 Magnesium

Ten per cent of the magnesium present in the leaf is contained in chlorophyll. It is the only metal constituent in the chlorophyll molecule. Deficiency of magnesium results in a loss of the yellow pigments xanthophyll and carotene in addition to chlorophyll. The fact that chlorosis due to a deficiency of magnesium begins with mature leaves indicates that it is a very mobile element.

Magnesium is known to play a very important role in enzyme activities, although a few other elements like manganese can substitute magnesium at least partly in these activities. Magnesium has been implicated to assist the movement of phosphorus from the root to shoot.

3.3 Functions of micronutrients

3.3.1 Iron

Iron has several important functions to perform in the plant. Iron functions through the formation of a complex ring compound called iron porphyrin (or heme) which by association with specific proteins forms a series of very important enzymes and activators.

Iron is also known to occur in forms other than as the heme, for example in the enzyme zanthin oxidase. In general, in many of its reactions involving electron transfer iron is believed to function through the reversible oxidation, reduction change.

3.3.2 Manganese

Manganese seems to be very closely associated with the manufacture of the chloroplasts and chlorophyll. In this role it behaves somewhat similar to iron. Manganese is also associated with molybdenum in the synthesis of amino acids from nitrates.

3.3.3 Zinc

Zinc is known to be a constituent of a number of enzymes of which alcohol dehydrogenase and carbonic anhydrase are the most common. The latter enzyme catalyse the reaction, $H_2O + Co_2 \quad H_2Co_3$

3.3.4 Copper

Copper is a constituent of several enzymes, some of which catalyse the oxidation of substances directly by oxygen. This property of copper containing enzymes is already present in simple copper salts in a very mild form. When metallic copper enters a specific protein to form an enzyme, this catalytic property of the ionic salt is increased several times. A common example is the copper bound enzyme ascorbic acid oxidase which catalyse the oxidation of ascorbic acid to a substance called dehydroascorbic acid and water. It is thought that copper in these enzymes function through the cyclic conversion of cupric to cuprous and back. Other copper enzymes found in plants are, polyphenol oxidase, laccase and probably cytochrome oxidase.

3.3.5 Boron

Boron is thought to be associated with the translocation of sugars.

3.3.6 Molybdenum

Molybdenum is required for nitrate assimilation in plants, and this occurs through the enzyme nitrate reductase, which has molybdenum as one of its specific components. It is interesting to note that molybdenum not only enters the composition of the enzyme nitrate reductase, but also directly assists in its formation.

Molybdenum is also a component of the enzyme system which helps to break down nitrates to nitrites with the release of energy. In this case molybdenum appears to be associated with an enzyme, which has iron in addition to Mo in its composition.

4. Nutrient Requirement of Plants
Methods for the study of nutrient requirements

Simultaneously with the search for factors which control plant growth, efforts were directed to a search for a simple and convenient method to determine the nutrient requirements of plants. Extensive studies during the past 150 years or so have resulted in the near perfection of several interesting techniques to evaluate nutrient requirements in plants. Some of the more important procedures are; (a) fertilizer experimentation, (b) bioassay experiments, (c) sand and water culture experiments, (d) soil analysis, (e) plant analysis and (f) leaf analysis.

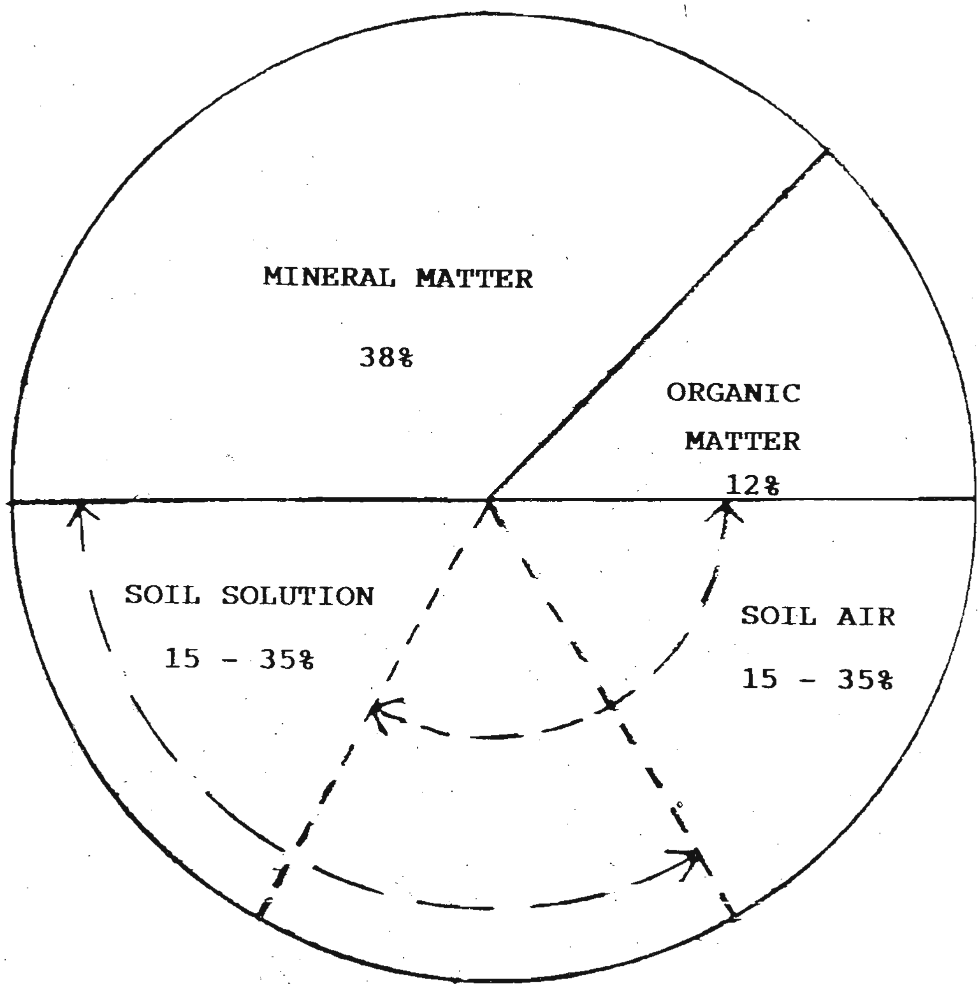

Figure 1 - Diagram showing broadly the distribution of materials in the Earths Crust