**MINERAL NUTRITION**

Plant nutrition is the study of chemical elements that are necessary for the plant growth. In 1804, de Saussure clearly demonstrated that the inorganic mineral elements contained in plant ash are obtained from the soil via root system. He experimentally showed that nitrogen and inorganic mineral elements supplied by the soil were essential to the growth and development of the plant. As the sources of these inorganic requirements are minerals, the elements are known as

 and the nutrition is called **mineral nutrition**. Nitrogen is not a mineral element but it has been included in the list of mineral elements because it is normally obtained by the plants from the soil. A nutrient that is able to limit plant growth according to Leibig’s law of the minimum is considered an **essential plant nutrient** if the plant cannot complete its life cycle without that element.

Plants require a range of transition metals as essential micronutrients for normal growth and development. These metals are essential for most redox reactions which, in turn, are fundamental to cellular function, such as, Fe, Cu, Mn, Zn, Ni and Mo, which are key components of proteins and enzymes of photosynthesis, respiration, lignification and other metabolic functions of plants. When any of these metals are in short supply, a range of deficiency symptoms appear and growth is reduced. However, although essential, these metals can also be toxic when present in excess with the production of reactive oxygen species and other oxidative injuries. Thus their concentration within the cell must be carefully controlled, and thus plants possess a range of potential mechanisms for metal ion homeostasis and tolerance, including membrane transport system.

There are 16 essential plant nutrients. Carbon and oxygen are absorbed from the air, while other nutrients including water are obtained from the soil.

* The three **primary macronutrients** obtained from soil are nitrogen (N), phosphorus (P) and potassium (K).
* The three **secondary macronutrients** are calcium (Ca), sulphur (S) and magnesium (Mg).
* Another macronutrient is silicon (Si).
* **Micronutrients** or trace elements are boron (B), chlorine (Cl), manganese (Mn), iron (Fe), zinc (Zn), copper (Cu), molybdenum (mo), selenium (Se) and sodium (Na).
* Macronutrients are consumed in larger quantities, concentration varying from 0.2% to 4.0%.
* Micronutrients are present in plant tissue in very low quantities, 5 to 200 ppm, or less than 0.2% of dry weight.

According to the criteria of essential it’s there are 14 essential plant nutrients. In addition, plants take up other elements that are not essential for their growth and development and do not meet the criteria for essential plant nutrients. These substances are referred to as the **beneficial elements**. They can perform important functions in yield, quality or stress tolerance, but can be replaced by other elements. Nevertheless, they often play an important and essential role in humans and animals living on plants. Beneficial elements can compensate for toxic effects of other elements or may replace mineral nutrients in some other less specific function such as the maintenance of osmotic pressure. Sodium, selenium, cobalt and silicon are examples of beneficial elements.

The beneficial elements have not been deemed essential for all plants but may be essential for some. The distinction between beneficial and essential is often difficult in the case of some trace elements. Beneficial elements reportedly enhance resistance to abiotic stresses (drought, salinity, high temperature, cold, UV stress and nutrient toxicity or deficiency) and biotic stresses (pathogens and herbivores) at their low levels. Cobalt, for instance, is essential for nitrogen fixation in legumes. Silicon, deposited in cell walls, has been found to improve heat and drought tolerance and increase resistance to insects and fungal infections. Silicon, acting as a beneficial element, can help compensate for toxic levels of manganese, iron, phosphorus and aluminium as well as zinc deficiency. However, the essential-to-lethal range for these elements I somewhat narrow.the effect of beneficial elements at low levels deserve more attention with regard to using them to fertilise crops to boost crop production under stress and to enhance plant nutritional value as a feed or food. A more holistic approach to plant nutrition would not be limited to nutrients essential to survival but would include mineral elements at levels beneficial for optimum growth.

**Criteria for essentiality:**

A precise set of criteria were established by Arnon and Stout in 1939, stating that an essential element-

* Must be required for the completion of the life cycle of the plant
* Must not be replaceable by another element
* Must be directly involved in plant metabolism, that is, it must be required for a specific physiological function.
* The element must be required by a substantial number of plant species, not just a single species or two

The concentrations of essential elements in plants may exceed the critical concentration, the minimum concentration required for growth, and may vary somewhat from species to species.

Chemical analysis of plant body reveal the presence of a large number of mineral elements which are listed below-

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| **Essential elements and their critical concentration** |
| **Elements** | **µg/gm or ppm** | **Percentage(%)** |
| **Macro-elements** |  |  |
| Nitrogen | 15000 | 1.5 |
| Potassium | 10000 | 1.0 |
| Calcium | 5000 | 0.5 |
| Magnesium | 2000 | 0.2 |
|  |  |  |
| Phosphorus | 2000 | 0.2 |
| Sulphur | 1000 | 0.1 |
| **Microelements** |  |  |
| Molybdenum | 0.1 | 1x10-5 |
| Copper | 5 | 6x10-4 |
| Zinc | 20 | 2x10-3 |
| Manganese | 50 | 5x10-3 |
| Iron | 100 | 1x10-2 |
| Boron | 20 | 2x10-3 |
| Chlorine | 100 | 1x10-2 |

**Framework elements**

Carbon, Hydrogen and Oxygen are the most important plant nutrients from the standpoint of bulk, and constitute 90% or more of the dry matters of common plant materials. These elements make up cellulose and lignin, the protective waxes, the reserve foods and most of the protoplasm of plants. These are called the framework elements. These elements are normally furnished free by air and rainfall.

**Protoplasm elements**

In addition to Carbon, Hydrogen, Oxygen, the proteins and other compounds which make up protoplasm, plants require Nitrogen, Phosphorus and sulphur. These are absorbed as anions. Nitrogen and Phosphorus are the most important fertiliser elements. Calcium is known to occur in certain cell wall constituents and magnesium in chlorophyll, although both elements appear to have other uses. Two tentative groupings may be made on the basis of probable functions-

1. **Balancing elements-** the basic elements, absorbed as cations, are in some way concerned with the maintenance of ionic balance in the plants. Magnesium, calcium and potassium come in this group and sodium should be included for the plants growing in the saline environment. Chlorine is found to function as anions in the maintenance of this balance. There is considerable evidence that potassium and magnesium may function in the following groups also, acting as inorganic catalysts, rather than as enzyme formers.
2. **Catalytic elements-** Elements like molybdenum, copper, zinc, magnesium, iron, boron and chlorine are used by plants in small quantities and have been assigned catalytic or enzyme forming roles. Because of the small requirements (less than 100µg/g), these elements have been termed **infinitesimal nutrients** or **micronutrients**. The elements which are required comparatively in greater amounts which is equal to or higher than 1000µg/g of dry matter are termed **major elements** or **macroelements** or **macronutrients**.

**Methods of Detection**

There are three methods to determine the mineral requirements of plants, which are as follows-

1. **Plant analysis-** The plant material is dried in an oven at a temperature of 70-800C. At higher temperature some of the sulphur and nitrogen containing compounds may be converted into gaseous form and may be lost. The dried sample is then powdered with aporcelain morteriella and pestle. This powdered plant material is subjected either to wet digestion or to ash analysis.
2. Wet digestion- In this method, to a small quantity of concentrated sulphuric acid the powdered sample is taken and heated on a low flame. The materials dissolve and a clear solution is obtained.
3. Ash preparation- Ash is prepared keeping the powdered sample to high temperatures (6000C) in a muffle furnace. All the volatile and non-volatile organic compounds are burnt into gases, leaving a white powder called ash. Chemically ash consists of oxides of metals. The as content of different plants and tissues varies from 1% to 4% of fresh weight. The ash content is maximum in halophytes and xerophytes and minimum in hydrophytes. Ash is dissolved in warm dilute hydrochloride acid or nitric acid. Detection and quantification of the elements are done by some physical, Chamera like and physics-chemical methods. The improved methods are atomic absorption spectrometry, optical emission spectrometry etc.
4. **Hydroponics-** in 1860, W. Pfeffer, Julius Sachs and W. Knop grew plants this way which is referred to as **hydroponics** or **solution culture**. This method provides an excellent means for controlling the quantity and relative properties of mineral salts given in an experiment. In this method mineral salts are dissolved in double glass distilled water. Every time only one element is left out from the solution and the plant is grown on it. If, without that particular element, the plant shows some deficiency symptoms and if those symptoms disappears on supplying the missing element, the element is considered to be essential. There are two advantages for using solution cultures in mineral nutrition studies-
5. Water is an excellent solvent for the mineral salts,
6. Water can be easily freed from contaminations.

In spite of such advantages, the technique has some disadvantaged as well-

1. Root aeration is not sufficient in the solution
2. The solution has to be replaced every day or two for maximum growth because the solution composition changes as certain ions are absorbed more rapidly than others.
3. This selective uptake also causes pH changes.
4. It is almost impossible to eliminate the contaminating influences from the water, the containers and the dust in the surrounding atmosphere.
5. **Solid Medium Culture-** To avoid some disadvantages of liquid culture, solid medium cultures are generally used. Highly purified silica sand or crushed white quartz sand or garages is easier to work with as a solid medium, because they are very low in available trace elements. In this method, the roots can easily anchor the solid substratum and no supporting device needs to be provided to the plants. Nutrient solutions are provided in three different ways: (i) by pouring over the solid medium **(slop culture)**, (ii) dripping onto the solid medium at suitable intervals **(drip culture)** and (iii) by forming solution up from the bottom of the container **(sub irrigation culture)**. In all these techniques, the solutions that are added, drain out through an outlet in the bottom of the container. In the sub-irrigation technique, recirculating solutions that flow through the solid medium around the roots, are used. The unabsorbed solution flows down into a reservoir in which the pH and solution composition can be monitored and adjusted automatically and then the solution is pumped up to drain down again bathing the roots.

The slop culture is the easiest method to operate but exposure of roots to constant amount of essential elements and water cannot be controlled. In drip culture the amount of solution being added should be equal to the amount of solution drained off. So this system allows for a continuous and more or less constant nutrient and water supply. The sub-irrigation system which operates automatically, is the most desirable of the three systems, but it is most costly and needs sophistication.

Several formulations of nutrient solutions have been developed and named after the workers like Knop, Hoagland, Evans, Shive, Sachs etc. the most important formulations are Hoagland’s solution and Shive’s solution which are listed below.

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| **Two nutrient solutions in Hydroponic Culture** |
| **Hoagland’s solution** | **Shive’s solution** |
| Salt | Molar concentration | Mg/ltr | Salt | Molar concentration | Mg/ltr |
| KNO3 | 0.01 |  | Ca(NO3). 4H2O | 0.005 |  |
| Ca(NO3)2 | 0.003 |  | K2SO4 | 0.0025 |  |
| NH4H2PO4 | 0.23 |  | KH2PO4 | 0.0005 |  |
| MgSO4.7H2O | 0.49 |  | MgSO4. 7H2O | 0.002 |  |
| Mixture of 0.5% FeSO4 and 0.4% tartaric acid  | 0.6ml/l added 3times /wk |  | Fe-versenate |  | 0.5 Fe |
| MnCl2. 4H2O |  | O.5Mn, 6.5Cl | KCl |  | 9.0 Cl |
| H3BO3 |  | 0.5 B | MnSO4 |  | 0.25 Mn |
| ZnSO4. 7H2O |  | 0.05 Zn | H2BO3 |  | 0.25 B |
| CuSO4. 5H2O |  | 0.02 Cu | ZnSO4 |  | 0.25 Zn |
| H2MoO4. H2O |  | 0.01 Mo | CuSO4 |  | 0.05 Cu |
|  |  |  | Na2MoO2 |  | 0.02 Mo |

**General functions of essential elements-**

Essential elements perform the following functions in plant life-

1. The essential elements serve as the framework elements or building materials for protoplasm, cell wall, enzymes and so on.
2. Osmotic pressure in plant cells is developed by essential elements.
3. Certain ions like phosphate, bicarbonate and carbonate may act as buffers and thus resist marked change in pH. Plant tissues usually control the degree of acidity and buffer action primarily by organic acids.
4. Desirable degree of hydration of cell colloids is maintained by the essential elements. In general monovalent cations increase hydration whereas divalent or polyvalent cations decrease it.
5. Permeability characteristics of membranes is regulated by the essential elements. It is influenced by cations and anions in the medium with which the membrane is in contact. Some ions have decreasing effect on the permeability while others have an increasing effect.
6. Essential elements show antagonistic effect. Antagonism pertains to those interactions in which the normal effect of one ion is counteracted or neglected by that of another ion.
7. Elements like iron, copper, zinc, magnesium etc. act as catalysts in various enzymatic reactions in plants.