COLLEGE OF AGRICULTURE AND NATURAL RESOURSE

Department of Plant Sciences

Soil Science Program

Soil Fertility and Plant Nutrition (SoSc5412)

Hand out

By

Mekonnen Asrat

Debre Markos

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CHAPTER 1

INTRODUCTION

Soil is unconsolidated natural material with particle size of < 2 mm diameter that helps medium for plant growth. Mineral soil contains about half solids (50%) and half pore space (water and air). From the solid parts of soil 45% volume categorized under inorganic or mineral materials while 5% of it is partially disintegrated and decomposed plant and animal residues (organic matter). Water is held within the soil pores with varying degrees of firmness depending on the amount of water present about 20-30% volume of soil, similarly, about 20-30% volume of soil occupied by air. However, the volume of pore space occupied by water and air, they are dynamic in nature which mean that they are inter changeable each other in constituent.

The history of soil fertility

Early scientific investigations and conclusions were made for the study of soil fertility.

- Van Helmont (1652) grows willow in pot of 200 lb soil and after 5 years he obtained 164 lb but the soil is still 200 lb 'less about 2 ounce'. Then he conclude that 'soil contribute noting to nutrition of plant but water.' This conclusion was supported by Francs Bacon, Robert Boye.
- Wood Word (1799) England researcher made an outstanding and advanced progress observation, planting spearmint in rain water, river water, sewage water, sewage and mould mediums. He observed that plant growth was better in fine earth (solute and solid) and concluded that salts in solution (terrestrial matter) improve plant growth rather than water, which supporting Huge Plant observation.
- Boussingault (1835) France agriculturist, disclose that air and rain are primary sources of C, H, O in plant growth.

  In 1840 a German scientist named Liebig proposed a law of the minimum stating that plant growth is proportional to the amount available of the most limiting plant nutrient. He states that plant growth is controlled not by the total amount of resources available, but by the scarcest resource) has been replaced by several mathematical approaches that use different models in order to take the interactions between the individual nutrients into account. The growth of a plant is limited by the nutrient that is in shortest supply (in relation to plant need). Once its supply is improved, the next limiting nutrient controls plant growth. It means that the addition of each successive increment of a growth factor results in an increase in growth. Maximum yield is obtained when all factors are supplied in adequate or optimum amount (Figure 1). A plant can produce to its full potential when all nutrients (production factors in an enlarged sense) are at an optimal level, i.e. without any deficiencies or excesses. In order to produce high yields, plant nutrition requires a continuous effort to eliminate minimum factors and provide balanced nutrition in the optimal range, observe the following figure.

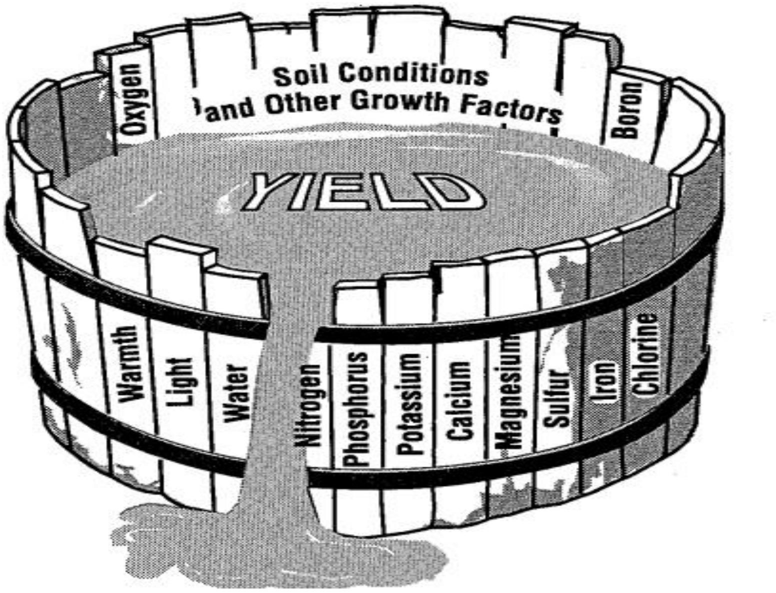
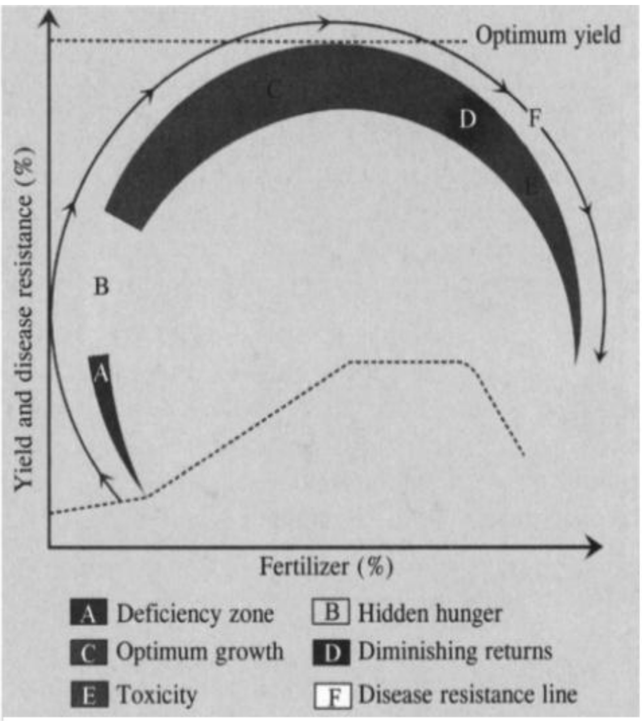
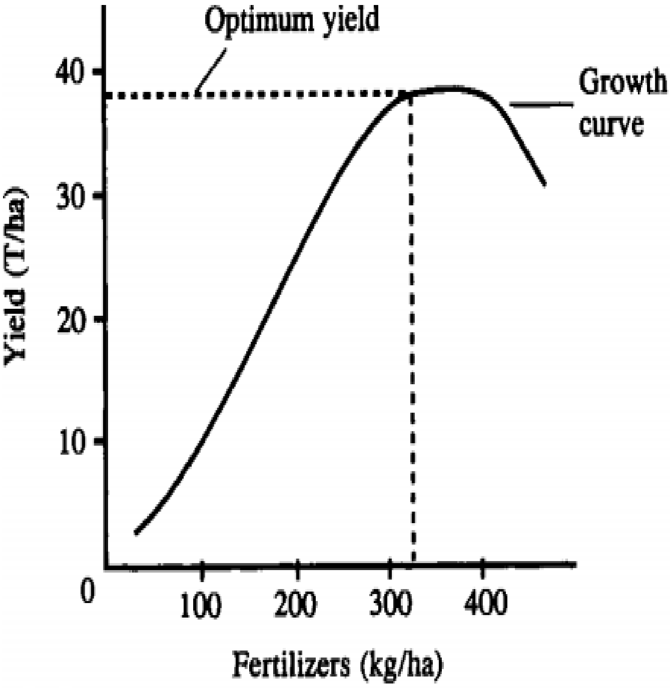


Figure 1. The barrel with staves of different heights demonstrate the law of the minimum

- Mitscherlich: in 1954 a German scientist concluded that plant growth which is governed by limiting element is not proportional as Liebig proposed but rather follows the law of diminishing return. The law of diminishing returns states that increasing an input by the quantity of 1 unit (keeping the other inputs fixed) increases the output (in proportion to the increased input) till a stage is reached when the output begins to fall, observe the following figure. He developed an equation to express this law mathematically: $dy/dx= k(Y - y)$. Where dy is the yield increase resulting from a small addition dx of the limiting factor, k is a constant for a particular crop and growth factor, Y is the maximum possible yield and y is the yield under the actual condition.



A graph (Mitscherlich curve) of yield and disease resistance against nutrient uptake, showing hidden hunger.



A graph of yield against fertilizers showing the law of aiminishing returns.

Mitscherlich's concept states that a plant produces maximum yield if all conditions are ideal. The absence of any essential factor results in corresponding reduction in the yield. Assuming that an increase in the yield per unit increment of the lacking factor is proportional to the decrement from the maximum,

The importance of the course

Soil is the basis for life as it is the foothold for plants on which other lives are dependent. The plant depends on soil not only for anchorage but required elements for its structural build-up and physiological processes. Soil is medium for plant growth, a store house for air, water and nutrients for plant growth and development. It gives a physical support, anchorage to the root system so that the plant does not fall over besides serve as protection medium from toxins substance and it regulates temperature. Properties of the soil often determine the nature of the vegetation present and, indirectly, the number and types of animals that the vegetation can support.

The soil supplies essential nutrients for plant growth. Many nutrients are limited in supply in soils due to chemical, physical, or biological reactions and constraints. In addition, other elements may be found in excess under a variety of circumstances. However, plants can actively affect the supply of nutrients from the soil, to increase the supply in low nutrient environments or reduce their concentration and/or absorption in extreme environments. Understanding these processes is critical in understanding plant nutrient relations.

Land degradation due to erosion, acidity and salinity has become a global, national and regional environmental threat currently drawing widespread attention from the international community. It has an abysmal effect on agricultural productivity especially in developing countries where agriculture remains one of the largest sectors in the economy. In such agriculture-based low-income countries, reversing the deterioration of land productivity resulting from environmental degradation, and ensuring adequate food supplies to the fast growing population is a formidable challenge.

Ethiopia is not only one of the poorest countries in the world, but also one of the most populated countries: it is the 14th largest in the world and the second largest in Africa. To feed the large and growing population, agricultural production has to be increased by improving the agricultural productivity per land area because most of accessible fertile lands have been cultivated.

Agricultural production can be increased through horizontal and vertical options but due to population growth horizontal option becoming limited due to limited area in expansion of agricultural activities but it can be increased through improving the agricultural productivity (vertical option) through intensification (restoration) of soil fertility. The beneficial effect of adding mineral elements to soils to improve plant growth has been known in agriculture for more than 2000 years but implementing scientific management practices is becoming crucial to sustain agricultural production. Therefore, it is essential to look for modern agricultural practices that minimize degradation problem and at the same time increase agricultural productivity. Hence, improving soil fertility management is widely recognized as a critical aspect in addressing food security and poverty through increasing agricultural productivity and at the same time curbing problems of nutrient depletion.

The sustainability of agricultural production is a question of major concern for the human race because agriculture is the prime source of food for an increasing world population. People depend upon plants for food. Maintenance and management of soil fertility is central to the development of sustainable food production systems. The discipline of soil fertility defines and outlines the mechanisms by which nutrients contained in these inputs are transformed, made available to crops, and cycled through the production system. Thus the principles that regulate soil fertility are fundamental to the philosophy of sustainability. Whether the land is plentiful or in short supply, efficient soil fertility management is the key to sustainable agriculture.

Soil fertility research and management is primarily concerned with the essential plant nutrients their amounts, availability to crop plants, chemical reactions that they undergo in soil, loss mechanisms, processes making them unavailable or less available to crop plants, and ways and means of replenishing them in these soils. The objective of this text is to discuss various aspects of soil fertility management for a sustainable agriculture. We will discuss about the nutrient transformations that occur in the soil and how various management practices may be used to regulate and control these transformations.

1.3. Concepts of soil fertility, soil productivity and plant nutrition

Soil fertility is the quality of soil to provide essential plant elements in quantity and proportion for growth of plant. It is an inherent capacity of soil to supply plant nutrients to plants in adequate amounts and in suitable proportions. It is the sum of amount of nutrients in soil and their availability. Soil fertility = amount of plant nutrients + availability of nutrients.

Soil fertility is the ability of the soil to sustain healthy plant growth. Some soils are inherently more fertile than others, and, although soil fertility can be changed by poor and good management, generally soils have an upper limit on how fertile they can be on a sustainable basis.

Soil productivity is dynamic event of soil for producing a specified plant under specified soil fertility, climate condition and management system. Thus, soil productivity = soil fertility + climate condition + management Hence, soil fertility is one factor meanwhile productive is broader. A soil may be fertile but not productive. Soil productivity is affected by farming method and expressed in term of yields.

Plant nutrition is the interrelated steps of plants to assimilate food and uses it for growth and replacement of tissue. Plant nutrition is a term that takes into account the interrelationships of mineral elements in the soil or soilless solution as well as their role in plant growth.

1.4. Criteria for essential mineral nutrients

Essential plant nutrient is a chemical element that is essential for plant growth and reproduction. There are three criteria for determining whether the nutrient is essential or not. The first criterion is the principal of others that the element is essential for a plant to complete its life cycle, has historically been the one with which essentiality is established. This criterion includes the property that the element has a direct effect on plant growth and reproduction. In the absence of the essential element or with severe deficiency, the plant will die before it completes the cycle from seed to seed. This requirement acknowledges that the element has a function in plant metabolism; that with short supply of the nutrient, abnormal growth or symptoms of deficiency will develop as a result of the disrupted metabolism; and that the plant may be able to complete its life cycle with restricted growth and abnormal appearance. This criterion is notes that the occurrence of an element in a plant is not evidence of essentiality. Plants will accumulate elements that are in solution without regard to the elements having any essential role in plant metabolism or physiology.

The second criterion states that the role of the element must be unique in plant metabolism or physiology, meaning that no other element will substitute fully for this function. A partial substitution might be possible. For example, a substitution of manganese for magnesium in enzymatic reactions may occur, but no other element will substitute for magnesium in its role as a constituent of chlorophyll. Some scientists believe that this criterion is included in the context of the first criterion.

The third criterion requires that the essentiality is universal among plants. Elements can affect plant growth without being considered as essential elements. Enhancement of growth is not a defining characteristic of a plant nutrient, since although growth might be stimulated by an element; the element is not absolutely required for the plant to complete its life cycle. Some plants may respond to certain elements by exhibiting enhanced growth or higher yields, such as that which occurs with the supply of sodium to some crops. Also, some elements may appear to be required by some plants because the elements have functions in metabolic processes in the plants, such as in the case of cobalt being required for nitrogen-fixing plants. Nitrogen fixation, however, is not vital for these plants since they will grow well on mineral or inorganic supplies of nitrogen. Also, plants that do not fix nitrogen do not have any known need for cobalt. Elements that might enhance growth or that have a function in some plants but not in all plants are referred to as beneficial elements.

The essential elements are needed for higher plants to complete all life functions and that the deficiency can be corrected by the application only of this specific element causing the deficiency. However, other scientists such as Nicholas believe that an element should be considered essential if its addition enhances plant growth even though it merely substitutes for one of the 16 elements that Arnon declares to be essential. For example, because sodium can substitute in plant nutrition for some potassium, and vanadium for some molybdenum, Nicholas would consider both sodium and vanadium as essential, but Arnon would not. On the basis of the criteria used, Arnon specifies 16 elements while Nicholas disclosed about 20 elements are essential for the growth of higher plants such as cotton and corn. Three other debated nutrients are nickel (urea transformations), cobalt (N_2 fixation), and silicon. However, plant nutritionists and soil scientists are increasingly using a less restrictive definition of essentiality of nutrients for plants.

Accordingly, they have added five more five more elements to the list of essential elements. These are sodium (Na), Silicon (Si), Cobalt (Co), Vanadium (V), and Nickel (Ni)

In addition to the above Na, Si, Co, V and Ni are required by some plant species. Although too restrictive, Na may substitute for K and Br for Cl in some plants. Some plant species, particularly the *Chenopodaceae* and species adapted to saline conditions take up Na in relatively high amounts. Sodium has a beneficial effect and in some cases is essential. The same is true for Si which is an essential nutrient for rice. Vanadium (V) has been established as an essential element for some microorganisms Chlorine is the most recent addition to the list of essential elements for the growth of higher plants (Mengel and Kirkby, 1987).

Assignment 1 discuss the following questions

1. Compare and contrast the essential and beneficial plant nutrients, show some examples?
2. Why is nutrient availability often more important than absolute amount of a nutrient present?
3. Distinguish plant essential elements based on Arnon and Stout (1939) versus Wilson Nicholas (1967) and Mengel and Kirkby (1987) thoughts?
4. The interventions required to modifying the availability nutrients in a soil-plant system?
5. Illustrate sources of plant nutrients terms of soil states?
6. Why you need to study soil fertility course

CHAPTER 2

FACTORS AFFECT PLANT GROWTH AND NUTRIENT AVAILABILITY

2.1. Factors affecting plant growth

Plants convert light energy into biomass through photosynthesis and produce various products of economic value (grain, fibre, tubers, fruits, vegetables and fodder) among others. To do this, plants need sufficient light, suitable temperature, substances such as water, CO_2, oxygen, and a number of nutrients. The survival and well-being of humans and animals depends on plant production, which in turn depends heavily on the availability of mineral and other nutrients. This is why plants and animals (including humans) have several essential nutrients in common.

Plant growth are affected by various factor which can be categorized into two, these are:

I, **Genetic factors** which concern primarily the inherent capability of a given plant to give high yield and desirable characteristics.

II. **Environmental factors** which concern all the external conditions that influence plant growth. It could be climatic, edaphic (soil) or human factors. Environmental factors are the sum total of external factors that affect plant life and development. The environmental factor such as light, temperature, water, and soil are greatly determines growth and geographic distribution of plants. These factors determine the suitability of a crop for a particular location, cropping pattern, management practices, and levels of inputs needed. Plant growth and yield will be affected by various factors. These include:

- Climatic factors- precipitation, temperature, humidity, wind and radiant energy
- Soil factors- organic matter, texture, structure, CEC, base saturation, topography and soil depth, soil management, nutrient content and their availability
- Plant factors- plant species/variety, seed quality, resistance of disease and insect

The climatic and soil factors are environmental factor meanwhile plant factors are genetic (internal) factors that influence crop production.

A, **Light** -sun light is essential for any crop. Dry matter production often increases in direct proportion with increasing amounts of light. The amount of sunlight received by plants in a particular region is affected by the intensity of the incoming light and the day length. The light intensity changes with elevation, latitude, and season, as well as other factors such as clouds, dust, smoke, or fog. The total amount of light received by a crop plant is also affected by cropping systems and crop density. Different plants differ in their light requirements:

- **Full sun plants**- plants thrive in full sun but grow poorly in shade.
- **Partial sun (partial shade) plants-** plants will produce an edible crop when grown in a shady location. However, these plants need at least 50-80% of full sun.
- **Full shade plants-** plants thrive in 30-50% of full sun but weaken in full sun. Shading sometimes is used to inhibit pigment development in crops in which the lack of color is an important quality factor.

  Due to the tilt of the earth's axis and its travel around the sun, the day length (also called photoperiod) varies with season and latitude. Photoperiod controls flowering or the formation of storage organs in some species. Some plants flower when a specific day-length minimum has been passed:

- **Short-day plants**- plants flower when day length decreases.
- **Long-day plants**- plants flower when day length increases.
- **Day-neutral plants**- plants are not affected by day length, and can flower under any light period.

B, **Temperature-** temperature influences photosynthesis, water and nutrient absorption, transpiration, respiration, and enzyme activity. These factors govern germination, flowering, pollen viability, fruit set, rates of maturation and senescence, yield, quality, harvest duration, and shelf life, Different plants have different temperature requirements. However, for most crop species, optimum temperatures usually range around 25ºC. Temperature requirements (usually based on night temperature) of plants are given below by the cardinal values and derived range for "effective growth" (growth range) and "optimum growth".

Based on temperature requirement

- **Hot temperature plants :** growth range 18-35ºC; optimum range 25-27ºC
- **Warm temperature plants :** growth range 12-35ºC; optimum range 20-25ºC

- **Cool-hot temperature plants :** growth range 7-30ºC; optimum range 20-25ºC
- **Cool-warm temperature plants :** growth range 5-25ºC; optimum range 18-25ºC

Depending on the situation and specific crop, ambient temperatures higher or lower than the effective growth range will reduce growth and delay development, and subsequently decrease yield and quality. The extremes may be considered killing frosts at about 0ºC and death by heat and desiccation at about 40ºC.

C, **Water-** water is absolutely essential for any plant species. Water is crucial for crop productivity and quality. However, crop water requirements differ according to plant and soil types. A plant's total sum of water requirement includes the water the crop uses by itself and also the losses due to evapotranspiration (which includes both transpiration and evaporation), water application, land preparation and leaching during plant growth. Plants can be grouped according to natural habitats with respect to water supply:

- **Hydrophyte plants**- plants that are adapted to living in water or in soil saturated with water, such as water hyacinth or blue devil. The hydrophytes usually have large interconnected intercellular gas-filled spaces in their root and shoot tissues (**aerenchyma**) to facilitate air exchange. Hydrophyte plants are growing in a water-nutrient solution without the use of nutrient-rich soil.
- **Mesophyte plants**- are the most common terrestrial plants that are adapted to neither a long wet nor a long dry environment. Depending on the extension of their root systems and other plant features, however, their water requirement varies.
- **Xerophyte plants**- are plants that can endure relatively long periods of drought. The xerophytes usually have special features such as reduced permeability to decrease water loss, swollen tissues to conserve water, or deep and extensive root systems to acquire water.

Water requirement

Water is crucial for crop productivity and quality. However, crop water requirements differ according to plant and soil types. A plant's total sum of water requirement includes the water the crop uses by itself and also the losses due to evapotranspiration (which includes both plant transpiration and soil evaporation), water application, land preparation, and leaching during the crop growth period.

Drought

Drought is defined as a period without significant rainfall or soil moisture. Droughts may lead to plant water deficit (drought stress) and growth may be impacted. Drought stress usually occurs when soil water content is less than 50% of field capacity (i.e., when the soil is full of water, hence 100%). Drought stress symptoms include wilting, droopy, curling or rolling of leaves; or browning of shoot tips. Among the mesophytes, the effect of drought stress varies with the species, variety, degree and duration of drought stress, and the growth stage. The yield formation stage is most sensitive for most vegetables. Periods of even short drought stress during this period can reduce yield.

Flooding

Flooding occurs when water enters soil faster than it can drain away. Intense rainfall, river overflow, increased surface run-off, over-irrigation, and slow drainage through the soil profile all contribute to flooding, especially in lowland regions. Under waterlogged conditions all pores in the soil are filled with water, depriving the soil of oxygen. As a result, plant roots cannot obtain oxygen for respiration to maintain their activities for nutrient and water uptake. Weakened plants are susceptible to soil-borne diseases. Oxygen deficiency in the soil due to water logging also causes death of root hairs, and increases formation of compounds toxic to plant growth. All lead to retarded growth or death of the plant.

D, **Biotic factors**- apart from the preceding discussion on abiotic factors, plant growth is also determined by biotic factors (living organisms), such as soil microorganisms, pollinating insects, pathogens, insect pests, other plants, etc. Diseases and pests have an important impact on crop-nutrient uptake by competing for nutrients, affecting physiological capacity (such as reduction in photosynthesis rates), and diminishing root parameters through root pruning or tissue death.

Plants in a community may compete with other plants for space, water, light, and nutrients. Another type of interaction between plants is called allelopathy since harmful substances released by roots. In this case, some plants release compounds by means of root exudation, leaching, volatilization or decomposition of plant residues in the soil and directly inhibit the growth of others. The presence of disease causing organisms, weeds and other pests determine the growth plants.

The extent of flooding damage depends upon the species or variety, stage of plant development, duration of flooding, water level in the soil, soil texture, temperature, and type of microorganisms present. High temperatures usually accelerate the damaging effects. Most mesophytes and xerophytes are sensitive to flooding. However, some species are able to tolerate flooding because of their abilities to increase porosity of the shoot base, or to replace damaged roots.

E, **Soil** - it is a natural medium that provides anchorage for the plant and supplies water and mineral nutrients for normal growth. Like all organisms, higher green plants need nutrients for their growth and development. Nutrients are indispensable as plant constituents, for biochemical reactions, and for production of organic materials (carbohydrates, proteins, fats, vitamins, etc.) in the process of photosynthesis.

Soil consists mineral matter, organic matter, air, and water, the proportion of these constituents various depending to the types of mineral and organic material which determined by soil properties such as by soil type, pH and fertility. However, this section is focused on the influence of soil on plant growth. Particularly, the ability of the soil to supply plant nutrients (soil fertility) is the major one.

Soil type determines the soil's capacity to store water and nutrients, aeration, drainage, and ease of field operations. Sandy soils are easily tilled, well-drained and aerated but usually have low fertility and water-holding capacity. Clayey soils, on the other hand, are more fertile and have high water retention but are poorly drained and aerated.

Soil pH

Soil pH is a measure of the soil's acidity or alkalinity, and it affects the plant indirectly by influencing the availability of nutrients and the activity of microorganisms. Nutrients are most available at pH levels between 6.5 and 7.5. Nutrients in the soil may be chemically tied up or bound to soil particles and unavailable to plants if the pH is outside this range. Individual plants have pH preferences and grow best if planted in soils that satisfy their pH requirements.

Soil fertility

Soil fertility is the inherent capacity of soil to provide plant nutrients in adequate amounts and in proper balance for the growth of specific plants. A fertile soil is usually rich in nitrogen, phosphorus, and potassium, and contains sufficient trace elements and soil organic matter that improves soil structure and soil moisture retention.

Soil salinity

Soil salinity refers to the presence of excess salts in soil water, which often results from irrigated agriculture. After the plants take up the water, the dissolved salts from irrigated water start to accumulate in the soil. Soil salinity is usually measured as electrical conductivity (EC) of soil solution, and expressed in decisiemens per meter (dS/m). Excess salts generally affect plant growth by increasing osmotic tension in the soil, making it more difficult for the plants to take up water. Excessive uptake of salts from the soil by plants also may have a direct toxic effect on the plants. Soil salinity is most pronounced in arid areas.

Not all plants respond to salinity in a similar manner; some crops can produce acceptable yields at much higher soil salinity than others. This is because some crops are better able to make the osmotic adjustments, enabling them to extract more water from a saline soil. For example, turnip and carrot are among the most sensitive vegetables and can tolerate soil salinities of only about 1 dS/m before yield declines; on the other hand Zucchini can tolerate soil salinity of up to 4.7 dS/m before yield reduces. The ability of a crop to adjust to salinity is extremely useful. In areas where a build-up of soil salinity cannot be controlled, an alternative crop can be selected that is both more tolerant of the expected soil salinity and able to produce economic yields.

2.2. Factors affecting nutrient availability

All these processes are affected by climatic, soil, and plant factors and their interactions.

In general, soil may contain numerous amounts of elements, but only a very small percentage of them are available for plants uses. For example, in actually a soil may contain above 50,000 parts per million (ppm) total iron, however less than 5 ppm Fe may be available for plant. Only a proportion of the total nutrient amount in soil can be taken up and utilized by plants. The magnitude of this available fraction depends on a range of soil, plant and environmental factors. Understanding how these factors can cause nutrient deficiency in crops is important to avoiding excessive use and additional fertilization required when a sound nutrient program is already in place.

Nutrient availability can be influenced by soil chemical and physical properties, including parent material and naturally occurring minerals; soil pH, type of soil colloids, organic matter; microbial activity and soil physical conditions such as aeration, compaction, permeability, water holding capacity and drainage. Besides the environmental conditions such as temperature, light intensity, disease and pest and moisture content has significant impact on the availability of nutrients moreover the crop characteristics such as root system has an important influence on nutrient availability.

2.2.1. Soil physical and chemical properties

2.2.1.1. Soil physical properties

The physical nature of the soil affects the growth of an established plant through its influence on various factors such as aeration and moisture supply. In addition, such physical properties alter the resistance offered to root elongation and enlargement, proliferation and water uptake, which in turn affect plant nutrition.

A, Soil texture

Soil texture, influences to a large extent several components of soil fertility such as the amount of nutrient reserves and their proportion to the available nutrient fraction. It also influences several properties such as pore space distribution, aeration, water holding capacity (WHC) and drainage characteristics. The broad relation of soil texture with soil fertility can be stated as follows:

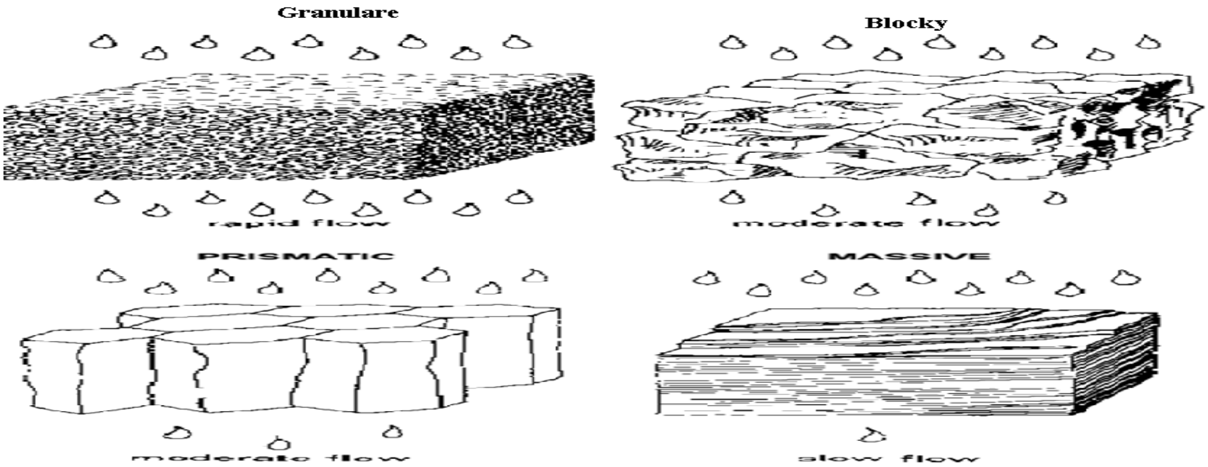
- Sandy soils are generally poor in nutrient reserves and have a low WHC, but provide favorable conditions for root growth, soil aeration and drainage of surplus water.
- Clay soils are often rich in nutrient reserves (but not necessarily in plant available forms), have high WHC because of the many medium and small pores, but soil aeration is restricted.
- Loamy soils have intermediate properties and are generally most suitable for cropping.

On the other hands, base cations such as Ca^{2+}, Mg^{2+}, and K^{+}: limited by leaching and low in soil pH. All may be unavailable in coarse textured soils.

B, Soil structure

The arrangement of soil particles forms different sizes and shapes of aggregates that terms soil structure.

There are single grain as well as massive structure based on shape different types of soil structure such as spheroidal (granular), blocky, prismatic and platy in shape. Soil structure affects water permeability, thus single grain and granular structure with good water permeability; blocky and prismatic structure with medium water permeability; and platy or massive structure with slow water permeability (Fig. 9). For agricultural use, the best type is a stable or large granular “crumb” structure. Improving and maintaining soil structure will aid in nutrient retention and soil biological health.



C, Soil air and temperature

Soil air is generally similar in composition to atmospheric air except that it has 7–10 times higher concentration of CO_2 than does the atmosphere (0.2% compared with 0.03%). As a result of the respiration by roots and micro-organisms, the oxygen in the soil air may be consumed quickly and CO_2 produced, which is unfavorable for both root growth and functions. For most crops, the soil air should contain more than 10% oxygen but less than 3–5 percent CO_2.   Soil aeration - poorly aerated and poorly drained soils can limit root system development. Soil temperature has a substantial influence on root growth thus it has significant influence on the absorption of nutrients, see the following figure.

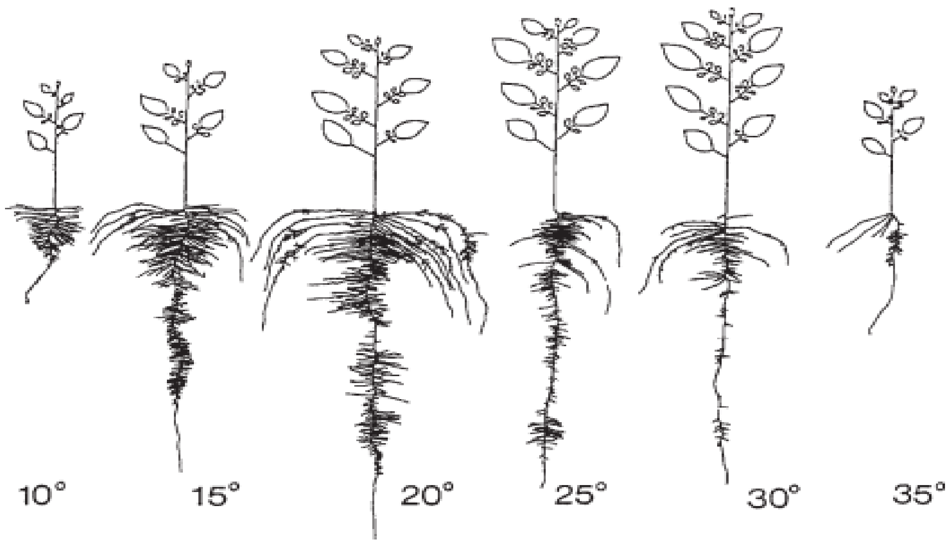


Figure Potato root morphology and shoot growth at different root zone's temperature

D, Soil compaction - it can limit or completely restrict root penetration and effectively reduce the volume of soil, including nutrients and water, which can be accessed by the plant. To limit soil compaction, avoid entering fields that are too wet, and minimize the weight per axle by decreasing load weight and/or increasing tire surface area in contact with the soil.

E, Bulk density

Bulk density is an indirect measure of pore space within a soil. The higher the bulk density, the more compact is the soil and the smaller is the pore space. In addition to absolute pore space, bulk density also affects the pore space distribution (according to size). Soil compaction decreases the number of large pores (> 100 µm) and, as these are the ones through which roots grow most easily, compaction can have an adverse effect on root growth. The effect of bulk density may be altered considerably by changing the moisture content of the soil. As the pore space can be filled with either air or water (containing nutrients) and there is an inverse relationship between these two parameters, an increase in moisture content means a decrease in air-filled pores

F, Soil moisture- it affects the solubility nutrient thereby determine the availability of nutrients. Plants tend to get their nutrients from the water in the soil. This water is usually referred to as the soil solution because it contains dissolved materials (cations and ions) as well as suspended colloids of clay and organic matter. Thus, nutrient availability is dependent on soil water content, which influences nutrient movement in soil. Plant nutrients are either bound to the soil or remain dissolved in the soil solution, the water which surrounds soil particles. From the standpoint of meeting the nutrient requirements of the plant, the soil solution is the most important place to look. The soil solution, that is the water surrounding the soil particles which contains dissolved minerals and salts, typically contains only a few parts per million of the various elements. Nutrients are distributed between solid and liquid or water phases. Here, the nutrients are present in the appropriate ionic form, and readily taken up by the root system. It has to be replenished from the pool of nutrients adsorbed onto soil colloids (exchangeable nutrients) and those bound up in solid form as minerals or organic matter called the stable pool. Major portion of elements are found in amorphous and crystalline structure of minerals, clay minerals, and organic matter. They are not available to plants or microorganisms except through dissolution and weathering processes. But the soil solution can supply the nutrient demands for at most, a few days before it is depleted. For most elements only a very small fraction of that present in soil is available to plants or other biological organisms. In an acre of soil, less than 4 pounds of phosphorous may be present in the soil solution at any one time. Soil solution does not contain sufficient nutrients at any one time to last the life of the plant. Plants roots are in direct contact only a small portion of the available soil volume, and most estimates indicate less than 3% of the total uptake occurs through this mechanism. Soil solution: soil-water in which the ionic forms of plant nutrients are dissolved. The concentration of ionic solutes varies with moisture content of soil. As the moisture content of the soil reduced by evaporation the concentration of soluble salts in the soil solution rises decrease the availability of nutrients.

2.2.1.2. Soil chemical properties

A, **Soil reaction-** soil reaction greatly influences the availability of several plant nutrients. For example, phosphate is rendered less available in the strongly acidic upland soils. Soil pH: directly affects the nutrient availability since the presence of H ions affects the solubility of several nutrients (it located on the following figure) meanwhile soil pH indirectly influence availability of nutrients due to the presence of toxic ions (Al, Mn) which hinders root growth, thus determine the absorption nutrients as a result affect the availability of nutrients

The amount of various micronutrients present in soil is extremely variable from one soil to another soil. Iron is not only the most abundant micronutrient but also one of the most abundant elements in soil, whereas molybdenum at the other extreme is a very scarce element. Iron can be deficient for plant growth even where it is abundant because it forms some very insoluble compounds that make it unavailable to plant. The availability of heavy metal nutrients (Cu, Fe, Mn and Zn) increases at lower pH, except for Mo. Although Al is not a nutrient, it becomes toxic below pH 4 (Fig. 1). Plant nutrient availability is strongly tied to the activity of H+, or pH in the soil solution. Decreasing soil pH directly increases the solubility of Mn, Zn, Cu, and Fe. At pH values less than approximately 5.5, toxic levels of Mn, Zn or Al (a non-nutrient element common in soils) may be released. The availability of N, K, Ca, Mg and S tend to decrease with decreasing pH since conditions which acidify the soil such as weathering and plant uptake also result in removal of these nutrients or in decreased microbial activity. The effects on P and B are primarily indirect as well, since the availability of these nutrients depends on formation of less soluble compounds with Al, Fe, Mn and Ca, which are affected by pH. As a result, P and B availability decrease at both very low and very high pH, with maximum availability in the range of pH 5.5 to 7.0 (Fig. 1). These reactions bind P much more strongly than B, with the result that available B can be readily leached from soils. These reactions are discussed more fully in the sections dealing with individual nutrients.

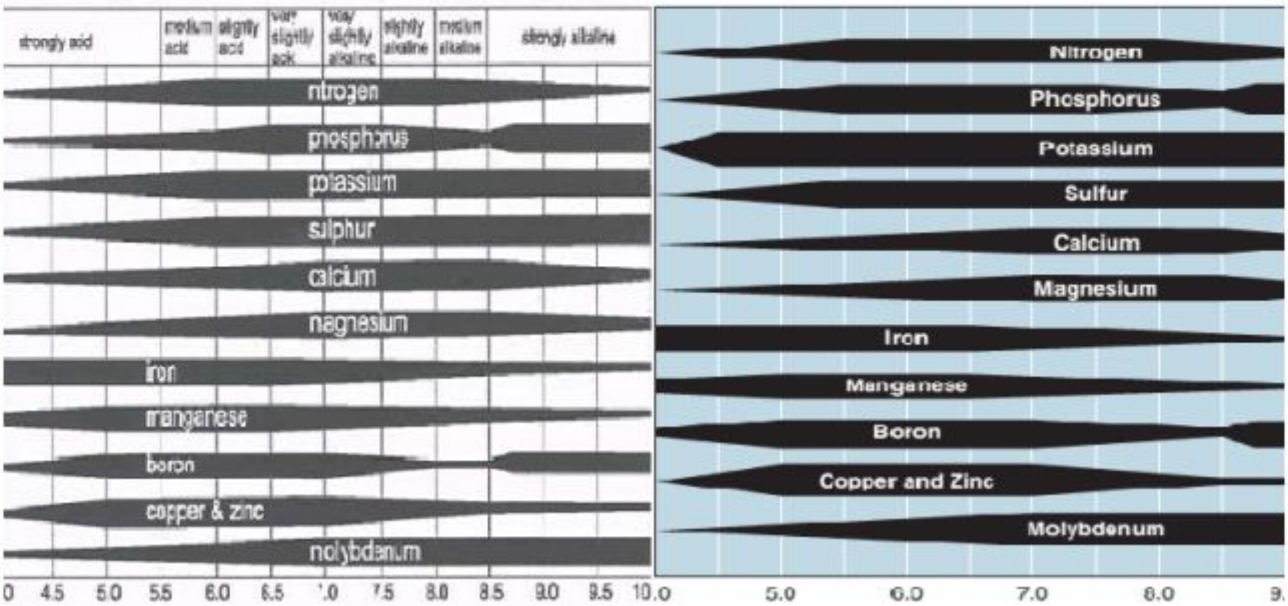


Figure 1. Soil pH and nutrient availability

B, Soil colloids- soil solution holds most nutrients - especially cations - in proportion to the amounts held on the soil solids. Plants absorb both cations and anions from the soil solution, and release small quantities of ions such as H^+, OH^-, and HCO_3^-. These reactions cause changes in the soil solution such that the ions in soil solution are no longer in equilibrium, or balance with ions on the soil solids. The soil solution in contact with the root system must be constantly replenished from the enormous reserves held by the soil colloids through the processes of equilibrium and transport. For example, when a plant removes a cation such as K^+ from solution, this causes an imbalance of K^+ in soil solution relative to that found on the soil. As a result, K^+ ions are desorbed from the soil surface, or dissolved from soil minerals to restore the balance. This equilibrium process, somewhat like balancing a see-saw, is often called buffering, and is the reason that soil solution levels change relatively slowly. The buffering capacity of soil depends greatly on the nature (clay and organic matter content) of the soil. Soils with low amounts of clay are more rapidly depleted of their soil reserves, and thus have less buffering capacity than soils with higher clay contents. Certain clay minerals have higher buffering capacity than others. For this reason, we also need to closely examine the nature of the soil colloids. Soil solution can be affected by a factor other than plant uptake and exchange reactions. Factors which can cause changes in solution concentrations include reactions involving soil air, soil organisms, soil organic matter, rainfall and evapotranspiration, mineral dissolution and precipitation, and addition of plant nutrients as fertilizers and manures.

During soil formation, the soil parent material goes through many physical and chemical changes. Particle size is reduced, and many minerals are dissolved, and reformed as secondary minerals which are more stable under the current weathering conditions. Thus minerals such as feldspars, hornblende and micas are weathered to form new clay minerals, and in the case of mica, reduced to “clay-sized” particles of less than 2 micrometers in size. These extremely small particles are called colloids, and because of their large surface area to volume ratio, are extremely reactive. Colloids may be classed as mineral or organic in nature, although mineral colloids generally greatly exceed organic colloids in all but organic soils. Mineral and organic colloids account for essentially all of the charge and chemical reactivity of soils greatly affect the availability of nutrients. Because of the highly variable and often intermingled nature of sources in soils, the charges are sometimes referred to as the colloidal complex. The extent and type of charge on the soil colloids determines the ability of a soil to retain essential plant nutrients against the forces of water moving through the soil profile cation exchange capacity (CEC).

Cation exchange capacity is generally defined as the ability of the soil to adsorb cations. Many of these nutrients are absorbed in the form of cations. Most soils have at least some ability to hold onto these ions at negatively charged sites within the soil (Fig. 2). The amount that they can hold is called the Cation Exchange Capacity. The cations are held to the edges of particles within the soil. This is referred to as adsorption. The cations in the soil are divided into acids and bases. The acids are predominantly hydrogen and aluminium. The bases are primarily calcium, magnesium, sodium, and potassium. CEC is technically defined as the sum of exchangeable bases plus total soil acidity at a specific pH value, usually 7.0 or 8.0. When acidity is expressed as salt-extractable acidity, the cation exchange capacity is called the effective cation exchange capacity (ECEC) because this is considered to be the CEC of the soil at the native pH value. It is usually expressed in centimoles of charge per kilogram of soil (cmol kg-1) or millimoles of charge per kilogram of soil.

The capacity for a soil to retain NH4, K, Ca, Mg, Zn and Cu and other cations increases with increasing negative charge. The soil acts similar to a magnet, attracting and retaining oppositely charged ions, and holding them against the downward movement of water through the soil profile. The nutrients held by the soil in this manner are called "exchangeable cations" and can be displaced or exchanged only by other cations which take their place. Soils with high CEC not only hold more nutrients, but they are better able to buffer, or avoid rapid changes in soil solution levels of these nutrients by replacing them as the solution becomes depleted. Generally, the inherent fertility, and long-term productivity of a soil is greatly influenced by its CEC. The type and amount of claydetermine the nutrient availability.

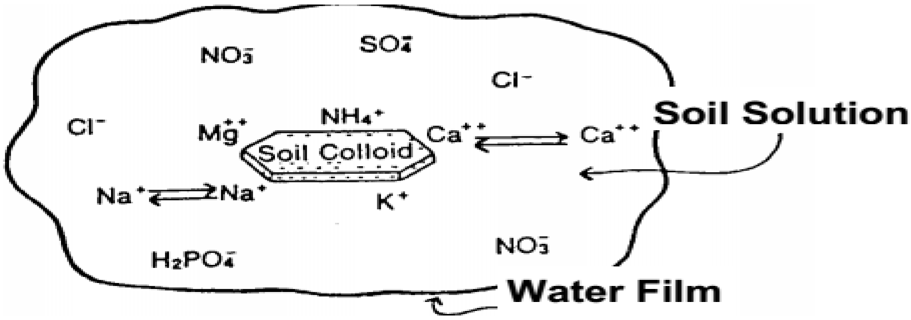


Fig. 2 **A schematic view of cation exchange**

The CEC of the soil is dependent on the following

Amount of clay: Higher amounts of clay mean higher CEC. Type of clay: Certain kinds of clay (smectites, montmorillonite) have higher CEC than others (such as kaolinite). The CEC of a soil depends upon the amount and type of soil colloids present. The clay content, the type of clay minerals present, and the organic matter content determine a soil’s CEC. Amount of organic matter: Higher amounts of organic matter mean higher CEC pH dependent CEC: Amorphous clay minerals and organic matter have a CEC that varies with pH. As pH increases, so does the CEC. For every pH unit above 4.5 there is a 1 cmol kg^{-1} increase for each percent organic matter.

Colloid	CEC, cmol(+) /kg
Kaolinite	3-15
illite	20-40
montmorillonite	60-100
soil organic matter, humus, etc.	100-300

C, Soil nutrient content - the presence or absence of nutrients affect the uptake of nutrient.

2.2.2. Crop characteristics

The availability of nutrients in the soil-plant–atmosphere system is generally more important than the absolute quantities of those nutrients.

Prior to plant utilization of nutrients, several processes have been held in soil-plant system. These processes include application of nutrient to soil or nutrient existing in the soil, transport from soil to plant roots, absorption by plant roots, and transport to plant tops, and finally, utilization by plant in producing economic parts or organs. Root characteristics that define nutrient bioavailability.

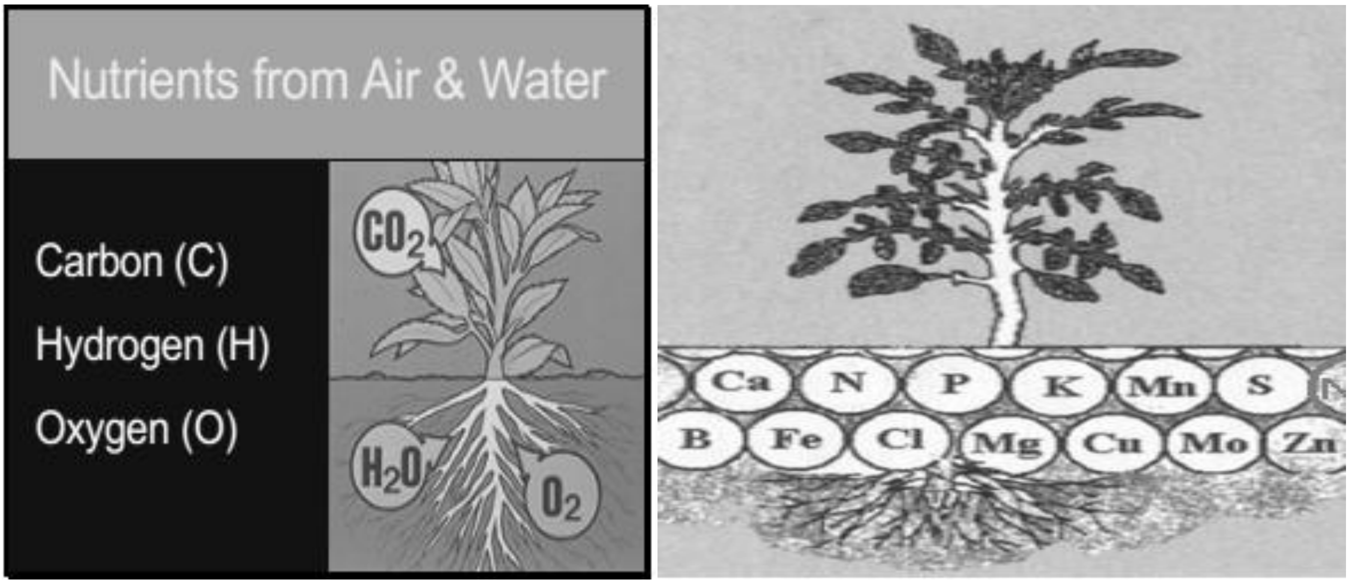
Plants obtain nutrients from soil-water solution through their root system. Rooting pattern and rooting depth of the plant is various in plant type, thus determine the absorption of nutrients as a result affect the availability of nutrients Any factor that restricts root growth and activity has the potential to restrict nutrient availability. This is not because nutrients are not plant-available in the soil, but because the ability of the crop to take up those nutrients is restricted. Understanding how these factors can cause nutrient deficiency in crops is important to avoiding excessive concern about the need for additional fertilization when a sound nutrient program is already in place. Crop rooting patterns, root length and density affect nutrient uptake and fertilizer placement. Although a high root density and long root hairs are important factors in the uptake of nutrients supplied by diffusion, the relationship between root density and uptake rate may be linear.

Plants vary widely in root life span, which has important consequences for nutrient acquisition. The deployment of short-lived roots should correspond to a high surface area: mass ratio (small diameter, low tissue density), high nutrient uptake capacity, and a high respiration rate with a rapid decline in physiological capacity with age. Life cycle of the plant is the factor that determining the availability of nutrients. The available nutrient is those nutrients that are available for uptake during the life cycle of plant. For instance, the nutrients available to Zigba (*Podocarpus gracielor*) in a life span of 200-300-year would not be available to the annual crop such as tef (*Eragrostis teff*) growing in one season.

CHAPTER 3

MAJOR NUTRIENTS

All green plants have the ability to manufacture their own food by using energy derived from the sun to combine chemical elements, taken up in the inorganic ion form, into a multitude of organic compounds. Essential nutrients (elements) are the elements needed by plants for growth and reproduction without which plants cannot complete their life cycle (Vegetative, Flowering and seed production). Plants require at least 17 elements for normal growth and for completion of their life cycle. however more than 110 chemical elements are known to man today. The number of elements considered essential for the growth of higher plants now varies from 17 to 20 or more, depending upon the definition of essentiality. These nutrients are taken up from the soil or from water — irrigation, flood or groundwater — or are supplied via a hydroponic medium (Fig. 3). Essential element is a term often used to identify a plant nutrient. Some of these nutrients combine to form compounds which compose cells and enzymes. Others must be present for certain plant chemical processes to occur. About 75% of green tissue is made up of water while 90% of the remaining dry matter is made up of carbon, oxygen and hydrogen.



A. non-mineral elements B. Mineral elements

Figure 3. Essential elements

Plants require water, air, light, and relatively small amounts of other nutrients to survive and reproduce. Besides, plants are sessile organisms: they grow in one place and cannot move about freely, they couldn't move to a new location if its current habitat becomes uncomfortable or undesirable. Thus, the availability of essential nutrient is determinant for plant growth and reproduction. However, some plants will require a specific element in much higher concentration than others, and others will be able to tolerate a much higher concentration of an essential element that would, to a different species, be toxic. Nutrient deficiencies in plants are often made most evident by plant physiological responses or called a symptom. Nutrient deficiency symptoms tend to occur in three major patterns: localized to the younger tissues, localized to the more mature tissues, or widely distributed across the plant. In each case, the distribution of the symptoms can help a person determine the nature of the deficiency experienced by the plant or, if the deficient nutrient is already known, make an inference about the role the nutrient plays in the plant body. If the ssymptom observed on youngest parts of the plant, one can infer that the nutrient in question is not easily mobile within the plant, and thus reserves of the nutrient cannot be easily translocated to the areas of need. Conversely, if the symptoms of deficiency first appear in more mature tissues, it is reasonable to infer that the nutrient in question is highly mobile and the plant, always seeking to protect its young tissues, sacrifices the health of the older tissue to protect the young, growing organs. The even distribution symptoms can imply that the lack of the nutrient is widespread and systemic, that it functions in a general role equally throughout the plant body, or that it affects the health and vigor of the plant at a large scale.

3.1. Nutrient classification

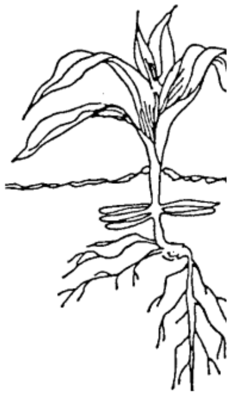
Out of these 17 plant nutrients, these three elements (carbon, hydrogen and oxygen) are obtained from air and water, thus they considered to be **non-mineral nutrient** (Fig. 4). These elements are required in relatively large amounts by plants and it comprises about 95% of the total dry matter of most plants. The remaining 5% of plant's dry matter is made up of **mineral elements (**14 elements) which obtained from soil; it may be taken up in small amounts by the plants but are not know to perform any essential functions within the plant.

These mineral plant nutrients are grouped into three, these are: - primary nutrients, secondary nutrients (macronutrients) and micronutrients based on the amount required by plants. **Macronutrients** (N, P, K, Ca, Mg and S)- these nutrients are required considerable quantities of macronutrients for growth and yield**. They are** accumulated in large amounts (> 50 mg kg^{-1} in dry base mass or in solution cultures with a concentration of > 1 mg l^{-1}) in plant tissues**.** These nutrients are grouped in to **primary and secondary nutrients** based on the amount required also. The **primary nutrient** (N, P and K)- plants required relatively large amounts of nitrogen, phosphorus, and potassium than **secondary nutrient** (Ca, Mg and S) which required in small amount as compared to primary nutrients. Nitrogen, P and K are mainly taken up during active vegetative growth for high photosynthetic activity Thus, primary nutrients should be applied at higher rates than secondary nutrients and micronutrients. Secondary nutrients are macronutrients but are less frequently deficient in soils.

Meanwhile **micronutrients** are required by plants in smaller amount and accumulated in dry biomass of plants in smaller amount (< 50 mg kg^{-1}) or in solution cultures at a concentration of < 1 mg l^{-1} of plant tissues, these are: iron, manganese, zinc, copper, boron, molybdenum, chlorine and nickel (Fig. 3B). But the requirement for the micronutrients: chlorine (Cl) and nickel (Ni) is as yet restricted to a limited number of plant species. Micronutrients are required in even smaller amounts than secondary nutrients. They constitute in total less than 1% of the dry weight of most plants. Micronutrients are equally essential, but present in very much lower concentrations. Micronutrients, also known as trace or minor elements, are required in very small amounts and are less frequently deficient. Even though nutrients are used in different amounts, each of the essential nutrients is equally important for plant growth.

Some elements may stimulate growth or may be required by only certain plants are called beneficial element. These are: silicon (Si), cobalt (Co), sodium (Na), selenium (Se), aluminium (Al), and vanadium (Va) are beneficial elements.

The essentiality of sodium has been established for plants with Cd photosynthetic pathway and for the optimum growth of celery, spinach, sugar beet and turnip. Scientists from Japan, China and Korea have established the essentiality of silicon for rice. Cobalt is required for the microbial fixation of atmospheric nitrogen. Vanadium is required for the functioning of some micro-organisms. Nickel is present in the enzyme urease and is required for the hydrolysis of urea. Sodium is electrolytic components of cells and body fluid, it determine the body's electrical and osmotic status in some desert plants.



From Air

Carbon (C)
Oxygen (O)

From Water

Hydrogen (H)
Oxygen (O)

Mineral Nutrients From Soil

Primary Nutrients	*Secondary Nutrients*	*Micronutrients*	
Nitrogen (N)	Calcium (Ca)	Boron (B)	Manganese (Mn)
Phosphorous (P)	Magnesium (Mg)	Chlorine (Cl)	Molybdenum (Mo)
Potassium (K)	Sulfur (S)	Copper (Cu)	Zinc (Zn)
		Iron (Fe)	Nickel (Ni)

Figure 4 Sources of plant nutrients

3.2. Forms of the availability of macronutrients

Cations in Soil		NUTRIENTS	Anions in Soil	
K^+	Potassium		NO_3^-	Nitrate
NH_4^+	Ammonium		SO_4^{-2}	Sulfate
Mg^{+2}	Magnesium		$H_2PO_4^-$ HPO_4^{-2}	Phosphate
Ca^{+2}	Calcium		Cl^-	Chloride
Mn^{+2}	Manganese		BO_3^{-2}	Borate
Zn^{+2}	Zinc		MoO_3^{-2}	Molybdate
		NON-NUTRIENTS		
Na^+	Sodium		OH^-	Hydroxyl
H^+	Hydrogen*		$H_2CO_3^-$	Bicarbonate
Al^{+3}	Aluminum		CO_3^{-3}	Carbonate

A, Nitrogen

Plants require nitrogen in largest amount than three primary nutrients (N, P and K) but after carbon. Nitrogen is absorbed by plants either in ammonium (NH_4^+) or as nitrate (NO_3^-). Generally, nitrate is present in higher concentrations (1–5 mM) than ammonium (20–200 µM) in the soil solution of agricultural soils. Within the plant, N is translocated as nitrate or amino acids. Nitrate is also more mobile in the soil than ammonium and therefore more available to plants. However plants adapted to soils which are acid (calcifuge species) or have a low redox potential (e.g., wetlands) have a preference for ammonium. In contrast, plants adapted to calcareous, high pH soils (calcicole species) utilize nitrate preferentially. However, highest growth rates and plant yields are obtained by combined supply of both ammonium and nitrate. The rate of N uptake generally exceeds the rate of dry matter production in the early stages.

B, Phosphorus

Soil phosphorus occurs in both organic and inorganic forms. Although most soils contain large amounts of phosphorus, it is present in insoluble forms and makes it inaccessible to the plant. Since it is strongly held by soil iron and aluminum compounds associated with soil clays and Ca of alkaline soil; also, phosphorus forms very sparingly soluble compounds, precipitates in soil the reaction proceed rapidly after fertilizer is applied. Calcium phosphate is dominant in neutral to alkaline soils, whereas phosphates of iron and aluminum occur in acidic soils. Most phosphorus in soil is precipitated, fixed, or adsorbed. These solid phases form phosphate reserves that can replenish the soil solution when phosphorus is taken up by plants, but the reaction is slow. Phosphorus is utilized in the fully oxidized and hydrated form as orthophosphate. However, plants typically absorb either $H_2PO_4^-$ or HPO_4^{2-}, depending on the pH of the growing medium. Only small amounts of phosphorus are present in the soil solution. Phosphorus released to the soil solution from the mineralization of organic matter might be taken up by the microbial population, taken up by growing plants, transferred to the soil inorganic pool, or less likely lost by leaching and runoff. Because of these reactions with soil, P is very immobile, not subject to significant leaching losses. However, P is readily lost through erosion of surface soil and the associated P. Most of the phosphate that is used in fertilizers is derived from rock phosphate, which is a non-renewable resource. Global phosphate resources are predicted to be depleted within the next 50–100 years in an era when more P fertilizers are needed to produce more food and fibre to sustain a growing global population.

C, Potassium

Plant absorbs potassium in the forms of K^+. It is characterized by high mobility in plants at all levels – within individual cells, within tissues, as well as in long-distance transport via the xylem and phloem. Potassium fertilization increases the resistance of plants against adverse biotic and abiotic conditions.

D, Calcium

Calcium is a secondary nutrient; it does not mean that it has a secondary role for the growth and development of plant. Calcium (Ca) is absorbed by plant roots as the divalent cation (Ca^{2+}). Ca is immobile in the phloem thus its deficiency is seen first on growing tips and the youngest leaves. Calcium deficiency is most common in highly weathered acid soils, like Oxisols and Ultisols. Calcium-deficient soils have low cation exchange capacity (CEC) and have high leaching capacity. In such soils, Al^{3+} content is high and sometimes toxic to plants.

E, Magnesium

Plants take up magnesium in the form of Mg^{2+}. Magnesium is mobile within the plants thus its deficiency symptoms first appear in the older parts of the plant. Magnesium is also an essential nutrient for animals. If forage crops, commonly grasses, are low in magnesium, grazing animals may develop hypomagnesia, sometimes called grass tetany.

G, Sulphur

Plant roots absorb S primarily as the sulphate ion (SO_4^{2-}). However, it is possible for plants to absorb sulphur dioxide (SO_2) gas from the atmosphere at low concentrations

3.3. Functions of nutrients

Carbon is the backbone of all organic molecules in the plant and is the basic building block for growth. After absorption of carbon dioxide (CO_2) by the leaves of the plant, carbon is transformed into carbohydrates by combining with carbon, hydrogen, and oxygen through the process of photosynthesis. Metabolic processes within the plant transform carbohydrates into amino acids and proteins and other essential components. Over 80 percent of a succulent, green plant is watery (hydrogen and oxygen), the components of water (H_2O) are needed in the absolute largest quantity. About half of the dry weight of a plant is carbon. A plant takes water and carbon dioxide (CO_2) from the air and energy from sunlight to store energy in the form of carbohydrates (Glucose, $C_6H_{12}O_6$, is the simplest sugar) in the process of photosynthesis. While 14 mineral nutrients are supplied from that stored in soil, thus we applied as a supplement as organic or inorganic form of fertilizer (Fig. 3B).

A, N functions

Nitrogen (N) is the most essential (crucial) nutrient used in relatively large amounts by all living things. It is critically important to plants growth because it is a fundamental part of the chlorophyll molecule and is essential in the formation of amino acids and proteins. Nitrogen plays a central role in plant metabolism as a constituent of proteins, nucleic acids, chlorophyll, co-enzymes, phytohormones and secondary metabolites. Nitrogen is a constituent of amino acids, which are required to synthesize proteins and other related compounds; it plays a role in almost all plant metabolic processes. The major portion of nitrogen in plants is in proteins, which contain about 85% of the total nitrogen in plants. Nitrogen is an integral part of chlorophyll manufacture through photosynthesis. Photosynthesis is the process through which plants utilize light energy to convert atmospheric carbon dioxide into carbohydrates. Carbohydrates (sugars) provide energy required for growth and development. Nitrogen is a part of alkaloids, phosphotides, vitamins, hormones and other plant substances. Nucleic acids (DNA, RNA) contain about 5% to 10% of the total nitrogen. Proteins in turn are present in the plant as enzymes that are responsible for metabolic reactions in the plant.

Nitrogen promotes rapid growth, increases leaf size and quality, hastens crop maturity, and promotes fruit and seed development. Because nitrogen is so important, plants often respond dramatically to available nitrogen. Moreover, it is the important energy source for soil microorganisms. In order to achieve efficient growth, development and reproduction, plants require adequate but not excessive, amounts of N. However, too much nitrogen application result excessive vegetative growth, delays maturity, increases lodging, fosters disease, and poses an environmental threat to surface and ground water. Nitrate (NO_3^-) is readily mobile in the xylem and can also be stored in the vacuoles of roots, shoots and storage organs. In order for the N in nitrate to be incorporated into organic structures, nitrate has to be reduced to ammonium (NH_4^+).

B, P functions

Phosphorus is essential during the initial growth stage of plant life. Phosphate has an additional small peak requirement for early root growth. It is necessary for seed germination, photosynthesis, protein synthesis and almost all aspects of growth and metabolism in plants. Normal plant growth cannot be achieved without phosphorus. Total phosphorus in plant tissue ranges from about 0.1 to 1%. It is a constituent of nucleic acids, phospholipids, the coenzymes deoxyribonucleic acid (DNA) and ribonucleic acid (RNA), and most importantly ATP. It activates coenzymes for amino acid production used in protein synthesis; it decomposes carbohydrates produced in photosynthesis; and it is involved in many other metabolic processes required for normal growth, such as photosynthesis, glycolysis, respiration, and fatty. However, excess P usage cause symptoms that resemble those found with a N deficiency.

C, K functions

Potassium is the primary osmolyte and ion involved in plant cell membrane dynamics, including the regulation of stomata and the maintenance of turgor and osmotic equilibrium. Moreover, a large number of enzymes are either completely dependent on or are stimulated by K. The function of potassium is in enzyme activation. Some 60 enzymes require the presence of K, with high concentrations of K found in the active growing points and immature seeds. The activity of starch and protein syntheses is also highly dependent on univalent cations, and of these K is the most effective. It also regulates the phloem transport, energy transfer, counterbalancing the cation–anion balance of cells, stress resistance and osmo- regulation.

D, Ca functions

It is involved in cell division, growth, root lengthening and activation or inhibition of enzymes. Ca is a part of the architecture of cell walls and membranes. Calcium is a constituent of calcium pectate, which is found in the middle lamella of the cell wall. Calcium protects the plasma membrane from the deleterious effects of H^+ ions at lower pH and also reduces harmful effects of Na^+ in salt-affected soils. Many biotic and abiotic stresses are reduced by the presence of adequate amounts of Ca in the rhizosphere. It has beneficial effects on plant vigour and stiffness of straw and also on grain and seed formation. It has also involved in the metabolism of nitrogen. Calcium promotes ion uptake and the formation of root mitochondria and membrane permeability. Low supply of Ca inhibits the nodulation, growth, and nitrogen fixation of bacteria associated with the root of legumes.

F, Mg functions

Magnesium has major physiological and molecular roles in plants, such as being a component of the chlorophyll molecule. It is associated with the activation of enzymes, energy transfer, and maintenance of electrical balance, production of proteins and metabolism of carbohydrates. About 70 to 85% of the magnesium in plants is associated with the role of magnesium as a cofactor in various enzymatic processes, the regulation of membrane channels and receptor proteins and the structural role in stabilizing proteins and the configurations of DNA and RNA strands. Magnesium may also influence various physiological aspects related to leaf water relations.

G, S functions

Sulfur is an essential element for growth and physiological functioning of plants. S is a part of amino acids cysteine, cystine and methionine. Hence, it is essential for protein production. S is involved in the formation of chlorophyll and in the activation of enzymes. Sulphur increases the size and weight of grain crops and enhances the efficiency of nitrogen for protein manufacture. It is a part of the vitamins biotin and thiamine (B1), and it is needed for the formation of mustard oils, and the sulphydryl linkages that are the source of pungency in onion. Under low S conditions mobility is low as the S in structural compounds cannot be translocated.

3.4. Deficiency symptom of nutrients

A common symptom of nutrient deficiency is chlorosis, the yellowing of the leaves and other green parts of the plant. Often, chlorosis is first evident in the spaces of the leaves between the veins, and then spreads to the veins. In extreme cases, the entire leaf will become yellow and eventually the plant may drop the affected leaf in a process called leaf abscission. Another common symptom of some nutrient deficiencies is an etiolated growth habit. This results in tall, spindly plants with few leaves and a high degree of internodal elongation. This symptom is also typical of plants that are grown in the dark, forced to rely on stored energy from the seed or roots until the plant can reach sun again. The converse of the tall, spindly habit of etiolated growth is the phenomenon of stunted growth. Stunted plants fail to develop normally and often have small leaves and very short or compressed internodes that result in apparent whorls of leaves, with no stem apparent between them. Stunted plants often have greatly reduced productivity and are not vigorous producers of flowers and fruits, if they form them at all. A common and severe symptom of some nutrient deficiencies is necrosis, the formation of dead spots or lesions, often in the leaves, where the plant cannot sustain life any longer.

A, Nitrogen deficient plants

A shortage of nitrogen restricts the growth of all plant organs, roots, stems, leaves, flowers, and fruits (including seeds). When grain crops, such as corn and small grains, are deficient, they generally exhibit yellow leaf tips, stunted growth with spindly stalks, lower biomass in shoot/root ratio, and low yields of poor quality grain but high nutrient supply suppresses root branching (Fig. 5).

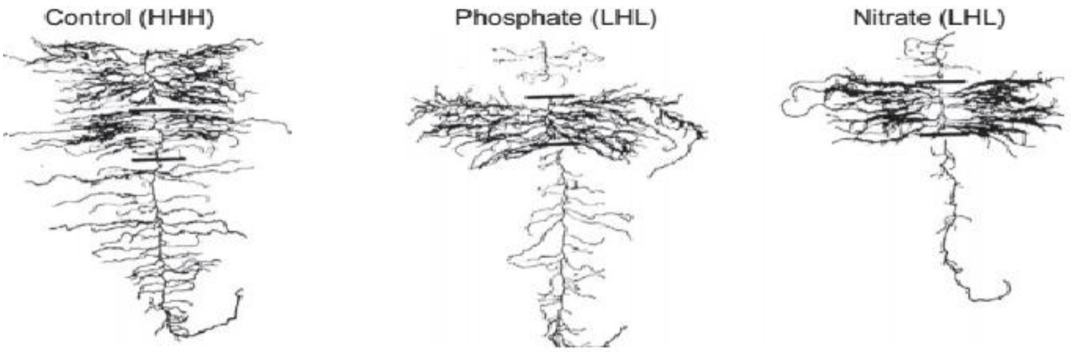


FIGURE 5 Root growth of barley plants with complete nutrient solution to all parts of the root system (*left*) or complete nutrient solution in the middle zone only with the top and bottom parts of the root system supplied with nutrient solution deficient in either phosphate (*middle*) or nitrate (*right*).

A nitrogen-deficient plant appears stunted because of the restricted growth of the vegetative organs. Nitrogen deficiency can be corrected with an application of nitrogen fertilizer. Crop response to fertilization with nitrogen is generally very prompt, depending on the source of nitrogen, stage of plant growth, rainfall, and temperature (Fig. 6).

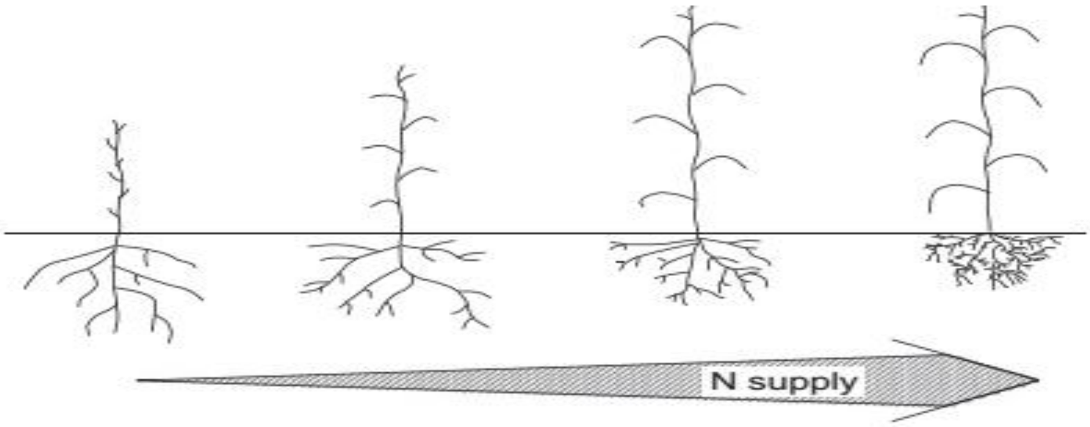


FIGURE 6 Schematic representation of shoot and root growth in cereal plants with increasing N supply.

Nitrogen-deficient foliage is a pale colour of light green or yellow and with narrow leaves. Loss of green colour is uniform across the leaf blade. If a plant has been deficient throughout its life cycle, the entire plant is pale and stunted or spindly. If the deficiency develops during the growth cycle, the nitrogen will be mobilized from the lower (old) leaves and transferred (translocated) to young leaves causing the lower (older) leaves to become pale green in colour. Nitrate (NO_3^-) is highly mobile nutrient in both plants and soils but ammonium (NH_4^+) is relatively immobile in soils. Hence the deficiency symptoms generally appear on the bottom leaves first. In severe cases, the lower leaves have a “fired” appearance on the tips, turn brown, usually disintegrate, and fall off. In leafy crops such as tobacco, vegetables, forage and pasture crops, low nitrogen results in low yield and quality. During the application of fertilizer the attention should be given for minimizing the loss of N since nitrate, being an anion, is the most mobile form of N in soil; it moves within the water as water percolates through soil and is easily lost through this leaching process. But NH_4 and NH_3 forms are cationic and held by cation exchange sites. However, NH_4 and NH_3 forms are converted to nitrate by soil microorganisms, fast reaction in warm moist soils. The reaction rate becomes slower as the soil becomes more acidic. From spring through fall most ammonium fertilizer is converted to nitrate within a few days to a week or two. Urea nitrogen is hydrolyzed to ammonium nitrogen by a soil enzyme and then quickly converted to nitrate provided conditions are right.

B, Phosphorus deficient plants

Phosphorus deficiency suppresses or delays growth and maturity. Although phosphorus- deficient plants are generally stunted in appearance, they seldom exhibit the conspicuous foliar symptoms characteristic of some of the other nutrient deficiencies. P is readily transferred from old to young leaves, thus its deficiency symptoms appear first and are more severe on old leaves. Furthermore, appreciable overlap often occurs with the symptoms of other nutrient deficiencies. Plant stems or leaves are sometimes dark green, often developing red and purple colors. Phosphorus deficiencies inhibited shoot growth (stunted), limit the formation of reproductive organs and delay the flower initiation. A deficient plant may produce only one small ear containing fewer, smaller kernels than usual. Grain yield is often severely reduced.

C, Potassium deficient plants

The beginning of K deficiency in plants is growth retardation, which is a rather nonspecific symptom and is thus not easily recognized as K deficiency. K-deficient plant tissues lead to typical changes in the metabolite pattern: an increase in soluble carbohydrates, particularly reducing sugars, and soluble organic N compounds. The growth rate of internodes is affected. In most plant species, the older leaves show chlorotic and necrotic symptoms as small stripes along the leaf margins, beginning at the tips and enlarging along leaf margins in the basal direction. The leaf margins are especially low in K, and for this reason, they lose turgor, and leaves appear flaccid, it located in the following images.

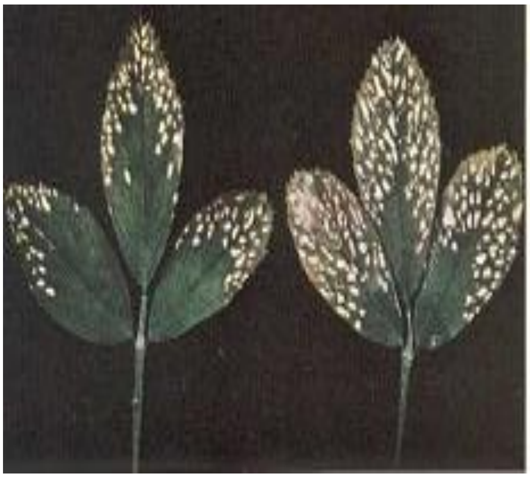


Figure 15-4. Potassium deficiency affects tomato quality and corn maturity.

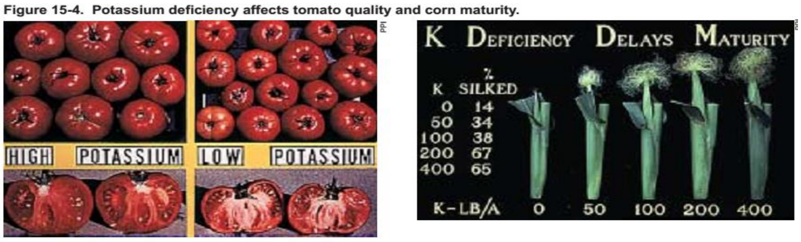


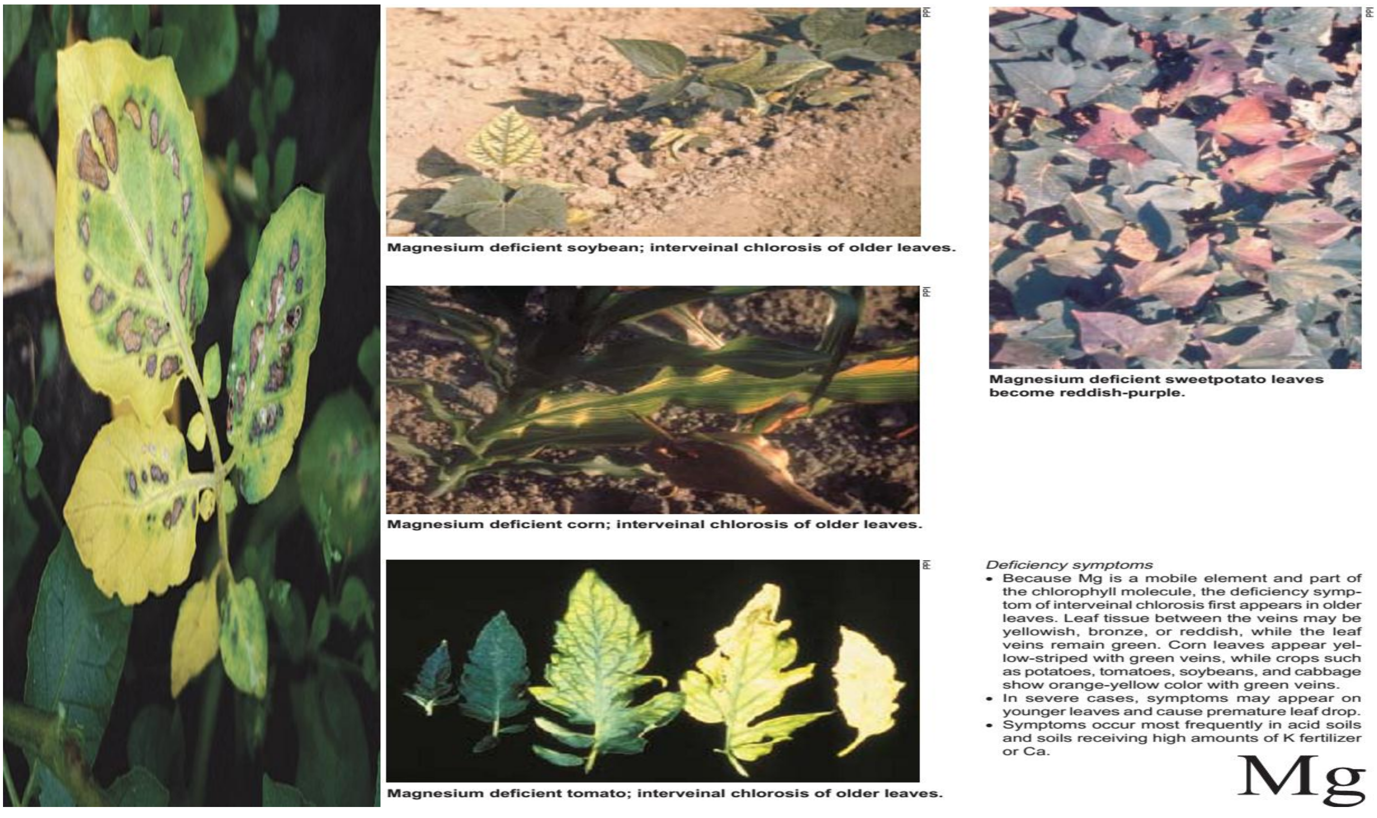
Figure 15-5. Potassium deficiency symptoms in soybean and alfalfa.

D, Calcium deficient plants

Calcium deficiency is seen first on growing tips and the youngest leaves. Calcium deficiency symptoms appear in the meristem regions (new growth) of leaves, stems, buds, and roots. Younger leaves are affected first and are usually deformed. In extreme cases, the growing tips die. The leaves of some plants hook downward and exhibit marginal necrosis. Roots on calcium-deficient plants are short and stubby. In tomatoes and peppers, a black leathery appearance develops on the blossom end of the fruit (a disorder called blossom-end rot). This is the case with all nutrients that are not very mobile in the plants. The Ca-deficiency problems are often related to the inability of Ca to be transported in the phloem. If a plant suffers from a shortage of calcium at any stage, the newly growing parts cannot receive a supply of calcium from older tissues. Ca-deficient leaves become small, distorted, cup-shaped, crinkled and dark green. They cease growing, become disorganized, twisted and tightly curled leaf tips that are usually bent over and sticky or gummy to the touch under severe deficiency, die. Although all growing points are sensitive to Ca deficiency, those of the roots are affected more severely. Shoot–root ratios usually decrease because shoots are affected more extensively than roots. Groundnut shells may be hollow or poorly filled as a result of incomplete kernel development**.** Calcium usually has to be added to acid soils, thus liming is supplying the necessary Ca^{2+} for plant growth.

F, Magnesium deficient plants

Magnesium deficiency is most prevalent on sandy-textured soils, which are subject to leaching, particularly during seasons of excess rainfall. A typical symptom of Mg deficiency is the interveinal chlorosis chlorosis (dark green veins with yellow areas between the veins) of the older leaves in which the veins remain green but the area between them turns yellow. As the deficiency becomes more severe, the leaf tissue becomes uniformly pale, then brown and necrotic. Magnesium deficiency may suppress the overall increase in plant mass or specifically suppress root or shoot growth. Mg deficiencies and toxicities may decrease fruit yield and quality of apple since the effect of magnesium on apple fruit quality may have been due to antagonistic effects on potassium uptake and accumulation. Initially, the deficiency of Mg expressed through the accumulation of starch in the leaves, which may be associated with early reductions in plant growth and decreased allocation of carbohydrates from leaves to developing sinks.



G, **S deficient plants**

In many ways, S deficiency resembles that of N. It starts with the appearance of pale yellow or light-green leaves. Unlike N deficiency, S-deficiency symptoms in most cases appear first on the younger leaves, and are present even after N application. Plants deficient in S are small and spindly with short and slender stalks. Their growth is retarded, and maturity in cereals is delayed.

Sulfur deficient banana; young leaves are uniformly chlorotic.

Sulfur deficient macadamia; young leaves are chlorotic.

Sulfur deficient tomato; young leaves are uniformly chlorotic.

Sulfur deficient sorghum; young leaves are uniformly chlorotic.

Deficiency symptoms
- Younger leaves are chlorotic with evenly, lightly colored veins. In some plants (e.g., citrus) the older leaves may show symptoms first. However, deficiency is not commonly found in most plants.
- Growth rate is retarded and maturity is delayed.
- Plant stems are stiff, thin, and woody.
- Symptoms may be similar to N deficiency and are most often found in sandy soils that are low in organic matter and receive moderate to heavy rainfall.

S

Primary and secondary nutrient deficiency symptoms, the cause and method of correction

Element	General deficiency symptoms	Probable cause of deficiency	Method of correction
nitrogen (N)	yellow leaves, stunted growth, lower leaves turn brown, leaves abort	low soil N, leaching from the soil, inadequate N applied	apply N fertilizer
phosphorus (P)	small plants, reddish-purple leaves, slow growth, loss of plant vigor	low soil P; cool, wet soils; inadequate P applied	apply P fertilizer
potassium (K)	small plants, brown margins on lower leaves, small weak stems, lodging of plants, poor yield and quality	low soil K, leaching from the soil, inadequate K applied	apply K fertilizer
calcium (Ca)	small plants, deformed buds, distorted leaves, failure to grow, poor fruit development.	low soil pH, leaching from the soil, inadequate lime applied	apply lime or Ca fertilizer
magnesium (Mg)	lower leaves—in severe cases, entire plants—turn yellow with green interveinal areas	low soil pH, leaching from the soil, no Mg applied in lime or fertilizer	apply dolomitic lime or Mg fertilizer
sulfur (S)	yellow plants, slow growth, low vigor, no response to applied nitrogen, low crop yield and quality	low soil S, leaching from the soil, low organic matter content, no S fertilizer applied	apply S fertilizer

3.5. Toxicity due to excessiveness of nutrients

The excessive nutrient concentration causes toxicity and a corresponding decline in growth

A, Nitrogen

Excess N may cause plants to remain in a vegetative growth stage and delay initiation of flowering or fruiting, resulting in lowered yields of some crops. Excess N can also encourage tender, succulent plant growth that may be more susceptible to certain plant diseases. An example of this is Glume blotch (Septoria nodorum) which can infect the heads of wheat and cause severe yield reductions. Plants with excess N may also be more susceptible to lodging and breakage than plants without excess N and very often are more likely to be damaged by freezing temperatures. Most perennial plants should not be fertilized with N in the late summer of fall in order that they can "harden off" before cold weather occurs. Likewise, N applied too early in the spring can result in tender growth that is more prone to cold damage.

Excess N supply has some negative effects, especially falls short the supply of P & K

- Tenderness of cell walls makes such plants susceptible to lodging, pest attack and disease
- The ability of vegetables to be preserved is impaired
- Decrease fructification and prolonged growth period
- Decrease in sugar content with increment in protein content. N alters plant composition more than any other nutrient. It increases dry matter, but the content of two major storage carbohydrate (poly fructose and starch) decrease
- Weak fiber

C, Excess

It results in luxury consumption. However, high levels of K interfere with uptake and physiological availability of Mg^{2+} and Ca^{2+}.

Antagonism between nutrients

When talking of nutrient deficiencies or excesses we are talking about fine tuning the balance of each plant food in the soil. Too much of a nutrient may be even worse than too little for the reason that it may be hard to remove excesses (e.g. sodium or manganese). Some of the plant nutrients in excess can cause other deficiencies in plants by interfering with the uptake of a nutrient that would normally be in adequate supply. Overdosing with one plant nutrient may change the availability of others. The following table shows some examples. *Just as it is possible to have too little of a nutrient in the soil, it is also possible to have too much.*

Table Some soil nutrient interrelationships in plants

Nutrient in excess	Induced deficiency
Nitrogen	Potassium
Magnesium	Potassium, nitrogen, phosphorus. Calcium shows as magnesium deficiency
Potassium	Magnesium, sodium, calcium
Sodium	Calcium, potassium
Calcium	Phosphorus, magnesium, trace elements
Boron	Potassium, magnesium
Chlorine	Potassium

. As well as soil nutrients affecting plant health, nutrients supplied to animals from plants grown on the soil also affect animal health. If an arrow points from one nutrient to another, it means a deficiency in the nutrient the arrow is pointing to may be caused by excess of the first nutrient. A nutrient in excess can affect more than one other nutrient.

CHAPTER 4

MICRONUTRIENTS

Trace elements are essential plant and animal nutrients that are required in very small quantities. They are often found in the soil in adequate quantities, but can become depleted over time if not replaced, or become unavailable if soil pH shifts too far either side of neutral. Trace elements can also become toxic if too much is present in the soil and available to plants. This can be caused by soil pH becoming too acid or too alkaline.

Trace elements are required in the correct amounts by plants and animals for healthy growth. They are usually required as part of cell formation, or are involved in the regulation of plant and animal growth. Without them, these chemical processes do not function properly, leading to poor growth and increased susceptibility

4.1. Forms of the availability of micronutrients

A, Boron (B)

The property of boron is intermediate between metals and non-metals, and also shares many features common in plants. Boron is a micronutrient for vascular plants, diatoms, yeast, bacteria and some species of green algae. Plant absorbed boron in the forms of H_3BO_3 and $B_4O_7^{-2}$.

B, Chlorine (Cl)

Chlorine (Cl) is absorbed as the chloride anion (Cl^-). It is highly mobile in soil. Chloride is relatively mobile within the phloem tissues.

C, Copper (Cu)

Copper is taken up as Cu^{2+}. Its uptake appears to be a metabolically mediated process. The critical level required for normal crop production is around 0.5 ppm. Cu is not readily mobile in plant. The critical level required for normal crop production is around 0.5 ppm.

D, Iron (Fe)

Iron (Fe) is generally the most abundant of the micronutrients with a dry-matter concentration. Mineral soils have, on average, a total Fe concentration of 20 to 40 g kg^{-1}. Most crop species remove only between 1 and 2 kg Fe ha^{-1}annually. Fe is absorbed by plant roots as Fe^{2+}. Absorbed Fe is immobile in the phloem.

E, Manganese (Mn)

Manganese (Mn) is taken up by plants as the divalent ion Mn^{2+}. It is immobile in the phloem. Mn deficiency contributed by waterlogged conditions occurring during a portion of the crop year, poorly drained soil and when the soil pH is high (> 6.5).

F, Molybdenum (Mo)

Mo is absorbed as the molybdate (MoO_4^{2-}) and its uptake is controlled metabolically. Mo appears to be moderately mobile in the plant tissue. The requirement of plants for Mo is lower than that for any of the other nutrients. Legumes generally have higher Mo requirements than grasses. In normal plants, Mo usually ranges from 0.8 to 5.0 ppm in the tissue. Deficient plants generally have < 0.5 ppm.

G, Zinc (Zn)

Zn is taken up as the divalent cation Zn^{2+}. Early work suggested that Zn uptake was passive, but more recent work indicates that it is active (energy-dependent). The mobility of Zn is low.

H, Nickel (Ni)

Nickel is chemically related to Fe and Co and it taken up as the divalent cation (Ni^{2+}).

4.2. Functions of micronutrients

The function of iron is crucial role in redox systems in cells and in various enzymes. Manganese (Mn) and copper (Cu) are important for redox systems, as activators of various enzymes including those involved in the detoxification of superoxide radicals, and for the synthesis of lignin. Zinc (Zn) plays a role in the detoxification of superoxide radicals, membrane integrity as well as the synthesis of proteins and the phytohormone IAA. Nickel (Ni) is involved in N metabolism as metal component of the enzyme urease. Molybdenum (Mo) is important for N metabolism as metal component of the nitrogenase (N_2 fixation) and nitrate reductase enzymes. Boron (B) is crucial for cell wall and membrane integrity whereas chlorine plays a role in osmoregulation and stomata movement.

A, Boron (B)

Boron is an enzyme activator and is involved in the production of starch required for production of cellulose. The major function of boron is in sugar transport to meristem regions of roots and tops. Boron has significant roles in enhance membrane integrity and cell-wall development, which affect permeability, cell division and extension; and pollen tube growth. It involved in cell formation and development; nitrogen metabolism; flower fertilization; active salt absorption; hormone, fat, and phosphorus metabolism; and photosynthesis. However, the general consensus is that all of these metabolic processes benefit directly from the influence of boron in sugar transport throughout the plant.

B, Chlorine (Cl)

Chlorine can play an essential role in the regulation of stomata for some species. Opening and closure of stomata is mediated by fluxes of K and accompanying anions such as malate and Cl. Chlorine is necessary for splitting water in photosynthesis, the step that generates oxygen gas breathed by animals. It is thought to be involved in the production of oxygen during photosynthesis, in raising cell osmotic pressure and in maintaining tissue hydration, so it has important functions in osmoregulation, regulation of movement of water and other solutes into and out of cells, influence plant water relation. Chlorine is essential for cell division in leaves.

C, Copper (Cu)

Copper is involved as an enzyme activator such as cytochrome oxidase and is thought to be involved in chlorophyll formation. Cu has roles in respiration, C and N metabolism, and protection against oxidative stress. It participates in lignin formation, protein and carbohydrate metabolism, and is possibly required for symbiotic N fixation. Cu is a part of plastocyanin, which forms a link in the electron transport.

D, Iron (Fe)

It plays a role in the synthesis of chlorophyll, carbohydrate production, cell respiration, chemical reduction of nitrate and sulphate, and in N assimilation.

E, Manganese (Mn)

Manganese activates several enzymes and functions as an auto-catalyst. It is essential for splitting the water molecule during photosynthesis. It is also important in N metabolism and in CO_2 assimilation

F, Molybdenum (Mo)

Molybdenum is involved in several enzyme systems; particularly nitrate reductase, which is needed for the reduction of nitrate, and nitrogenase, which is involved in BNF (biological nitrogen fixation). Thus, it is involved directly in protein synthesis and N fixation by legumes.

G, Zink (Zn)

Zn is required directly or indirectly by several enzymes systems, auxins and in protein and RNA synthesis, seed yield and maturity.

H, Nickel (Ni)

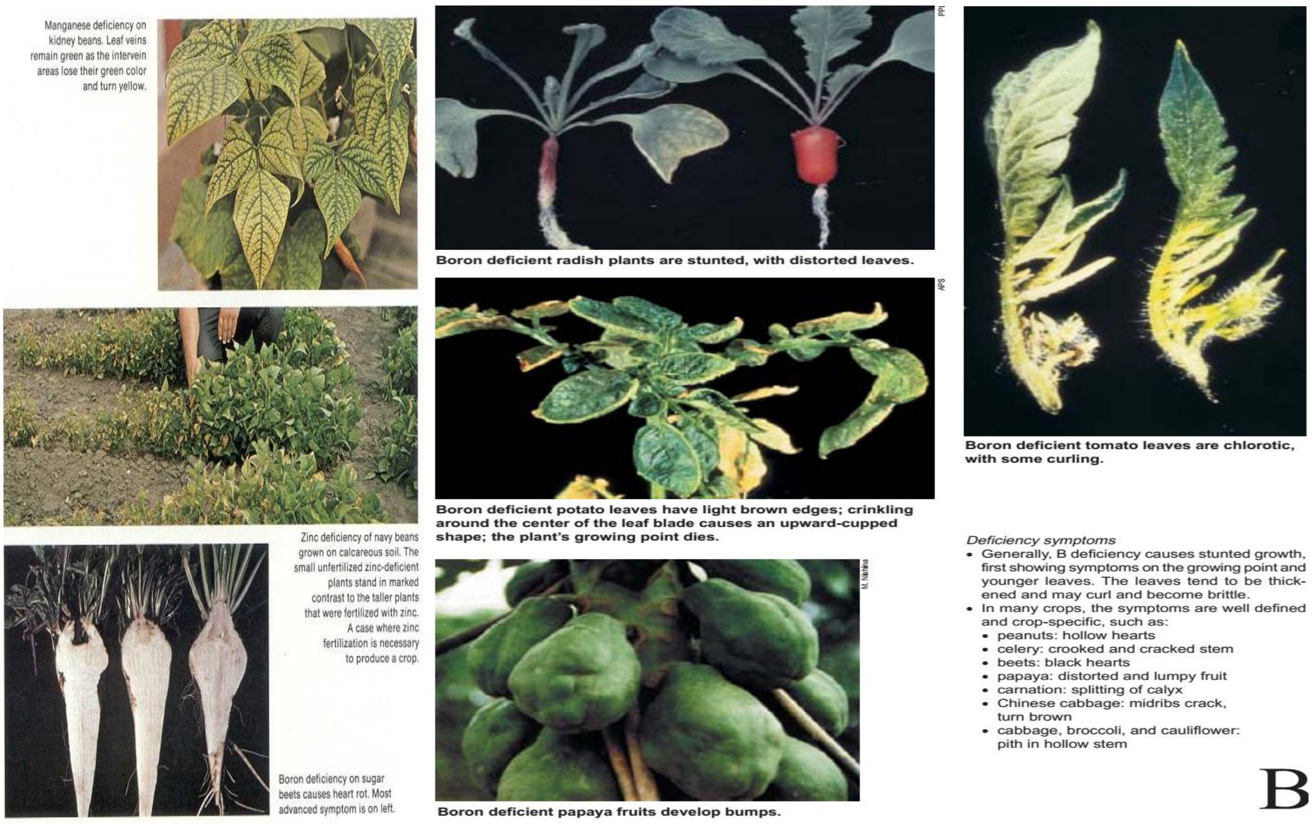
Nickel is involved in the function of at least nine proteins, including methyl-coenzyme M reductase, superoxide dismutase, Ni-dependent glyoxylase, aci-reductone dioxygenase, NiFe hydrogenase, carbon monoxide dehydrogenase, acetyl-CoA decarbonylase synthase and methyleneurease, of which urease and the Ni-urease accessory protein (Eu3) have roles in plants.

4.3. Their deficiency symptoms

Generally Ca, Zn, B, and Mn are immobile nutrients in plant tissue thus their deficiency shown on young organ (upper or new leaves). Meanwhile N, P, K and Mg are mobile in plant tissues and their deficiency observed on older or lower leaves. However, sulphur deficiency usually on across entire plant.

A, Boron (B)

Boron is relatively immobile in plants thus its deficiency symptom appears on the younger leaves. B deficiency usually appears on the growing points of roots, shoots and youngest leaves. Young leaves are deformed and arranged in the form of a rosette, see the following images. The first visible symptom of boron deficiency is death of the growing tips. This disorder is generally followed by growth of lateral shoots, the tips of which may also be deformed or die. Boron deficiency causes internal tissues to disintegrate, causing abnormalities such as distorted, cracked, or hollow stems. Moreover, leaves of boron-deficient plants are usually thick, have a coppery texture, and become curled and brittle. There may be cracking and cork formation in the stalks, stem and fruits; thickening of stem and leaves; shortened internodes or dying of growing points and reduced bud, flower and seed production. Apples have cork spot. Grapes form mixed clusters of small and large fruit, known as "hen and chicks".



B, Chlorine (Cl)

The critical deficiency concentration is 2 g kg^{-1} dry weight which is equivalent to 6 µmol Cl g^{-1} dry weight. Deficiency of Cl leads to chlorosis in younger leaves and overall wilting as a consequence of the possible effect on transpiration. In most plants the principal effects of Cl deficiency are wilting and a reduction in leaf surface area and thereby reduce the dry weight of plant. However, Cl-toxicity symptoms are: burning of the leaf tips or margins; bronzing; premature yellowing; leaf fall; and poor burning quality of tobacco, see the following images.

Chlorine deficient tomato; leaf edges roll upward.

Chlorine deficient sugarbeet; young leaves are chlorotic.

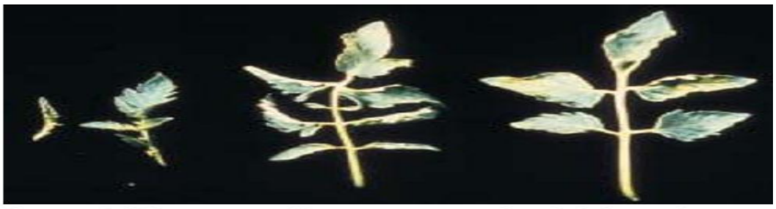
C, Copper (Cu)

Small grains, particularly oats, are more sensitive to copper deficiency than other crops. The first symptoms are yellowing of the youngest leaves accompanied by slightly stunted growth some Cu deficient crop's leaves are narrow, twisted and pale white shoot tips. In cases of severe deficiency, the younger leaves turn pale yellow. Then, leaf tips curl downward, eventually turn brown, and die. This symptom is referred to as "leaf tip die back" and is most pronounced on small grains. In extreme cases, leaves become shrivelled, twisted, broken, and ragged, and ultimately the plant dies. At maturity, panicles/ears are poorly filled and even empty where the deficiency is severe. Copper deficiency can be corrected by adding a small amount of copper fertilizer to the soil.

Copper deficient corn leaf tips bend and droop.

Copper deficient lettuce leaves are stunted and cupped, with darker tissue near the petiole.

Copper deficient onion leaves have white tips and twist in spirals or right angles.



Copper deficient tomato leaves are stunted and deformed.

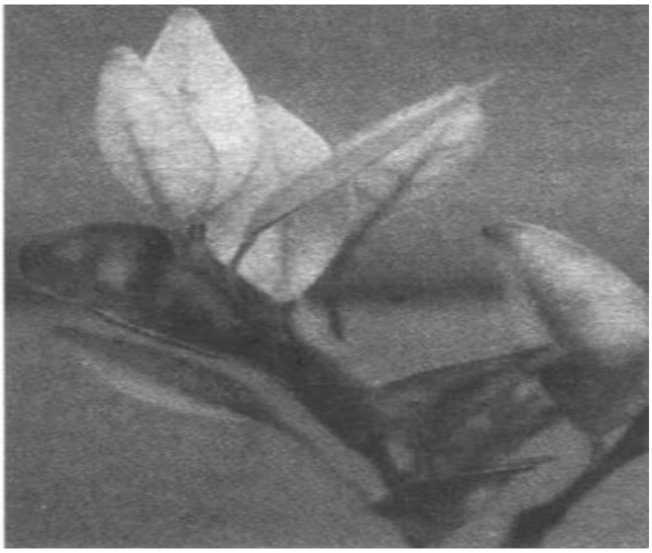
Deficiency symptoms

- Reduced growth, distortion of the younger leaves, and possible necrosis of the apical meristem.
- In trees, multiple sprouts occur at growing points, resulting in a bushy appearance. Young leaves becomes bleached, and eventually there is defoliation and dieback of twigs.
- In forage grasses, young leaf tips and growing points are affected first. The plant is stunted and chlorotic.

Cu

D, Iron (Fe)

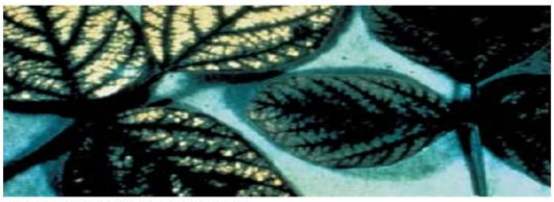
Fe deficiency begins to appear on younger leaves first, observe on the following images. Otherwise, its deficiency symptoms are somewhat similar to those of Mn, as both Fe and Mn lead to failure in chlorophyll production. Yellowing of the interveinal areas of leaves (commonly referred to as iron chlorosis) occurs, as of image on the right side. In severe deficiency, leaves become almost pale white because of the loss of chlorophyll. In cereals, alternate yellow and green stripes along the length of the leaf blade may be observed. Complete leaf fall can occur and shoots can die. Iron toxicity of rice is known as bronzing. In this disorder, the leaves are first covered by tiny brown spots that develop into a uniform brown colour the problem occurred due to flooding of highly reduced rice soils increase the levels of soluble Fe from 0.1 to 50–100 μg/g Fe within a few weeks..



E, Manganese (Mn)

Manganese deficiency is common in soils derived from parent material inherently low in Mn, particularly on high pH soils that containing free carbonates. Mn-deficiency symptoms resemble those of Fe and Mg deficiency where interveinal chlorosis occurs in the leaves. However, Mn-deficiency symptoms are first visible on the younger leaves whereas in Mg deficiency, the older leaves are affected first. Mn deficiency in oats is characterized by “grey-speck” where the leaf blade develops grey lesions but the tip remains green, the base dies and the panicle may be empty. In dicots (e.g. legumes), younger leaves develop chlorotic patches between the veins (somewhat resembling Mg deficiency) besides visual symptoms on the cotyledons are known as ‘marsh spot’ in peas or ‘split seed’ disorder in lupins. Mn-deficient plants, dry matter production, net photosynthesis and chlorophyll content decline rapidly, whereas rates of respiration and transpiration remain unaffected. Mn-deficient plants are more susceptible to damage by freezing temperatures. Mn deficiency can be corrected by application of $MnSO_4$ on soil or foliar.

Manganese deficient tomato; expanded young leaves have green veins with interveinal chlorosis.



Manganese deficient soybean; young leaves have interveinal chlorosis.

Manganese deficient corn; young leaves are olive-green and slightly streaked.

Manganese deficient orange; leaves develop a mottled pattern of light and dark green.

Deficiency symptoms

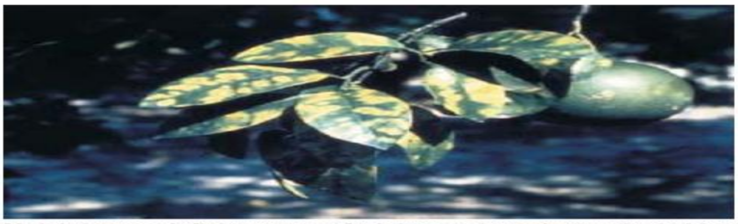
- Symptoms first appear as chlorosis in young tissues. Unlike Fe chlorosis symptoms, in dicots Mn chlorosis shows up as tiny yellow spots.
- In monocots, greenish-grey specks appear at the lower base of younger leaves. The specks may eventually become yellowish to yellow-orange.
- In legumes, necrotic areas develop on the cotyledons, a symptom known as marsh spots.

Mn

F, Molybdenum (Mo)

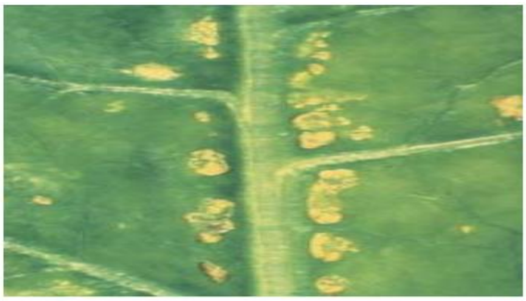
Molybdenum deficiencies often occur in acid and strongly acidic soils, since the toxicities of manganese and/or aluminium and a deficiency of molybdenum are likely. They can also occur in coarse textured soils and soil low in organic matter. Due to mobility nature of the nutrient its deficiency symptoms appear in the middle and older leaves. Mo deficiency in legumes can resemble N deficiency because of its role in N fixation. Mo deficiency can cause marginal scorching and rolling or cupping of leaves and yellowing and stunting in plants. Yellow spot disease in citrus and whip tail in cauliflower are commonly associated with Mo deficiency. The standard Mo fertilizer is sodium molybdate ($Na_2MoO_4.2H_2O$) with 40% Mo, but ammonium molybdate [$(NH_4)6Mo_7O_{24}.4H_2O$] (54 percent Mo) is also suitable.

Molybdenum deficient onion leaves show wilting and dieback.



Molybdenum deficient grapefruit leaves have interveinal chlorosis.

Molybdenum deficient tomato leaves have interveinal chlorosis.



Molybdenum deficient sugarbeet leaf has slight veining and pronounced necrotic spotting.

Deficiency symptoms

- Deficiency symptoms resemble those of N because the function of Mo is to assimilate N in the plant. Older and middle leaves become chlorotic, and the leaf margins roll inwards.
- In contrast to N deficiency, necrotic spots appear at the leaf margins because of nitrate accumulation.
- Deficient plants are stunted, and flower formation may be restricted.
- Mo deficiency can be common in nitrogen-fixing legumes.

Mo

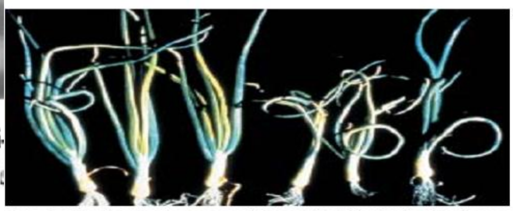
G, Zink (Zn)

The first obvious symptom of zinc deficiency is interveinal chlorosis of the upper (youngest) leaves. The affected plant parts shows a rosette-like appearance then shoot growth slows down. Common symptoms of Zn deficiency are: stunted plant growth; poor tillering; development of light green, yellowish, bleached spots; chlorotic bands on either side of the midrib in monocots (particularly maize); brown rusty spots on leaves in some crops, which in acute Zn deficiency as in rice may cover the lower leaves; and in fruit trees the shoots may fail to extend and the small leaves may bunch together at the tip in a rosette-type cluster. Little-leaf condition is also a common symptom. Internodes are short. Flowering, fruiting and maturity can be delayed. Shoots may die off and leaves can fall prematurely. Deficiency symptoms are not the same in all plants. Zn deficiencies in corn and sorghum are typified by a wide band of white tissue on each side of the leaf midrib. This symptom is known as "white bud." "Little leaf" in cotton is also due to zinc deficiency. Application of Zn containing fungicides and animal and poultry waste products can also add zinc to the soil.

Symptoms of Zn deficiency in apple with typical inhibition of internode elongation ('rosetting') and reduction in leaf size ('little leaf').

Zinc deficient mango shoots have shortened internodes, resulting in leaf rosetting.

Zinc deficient avocado; young leaves have interveinal chlorosis.



Zinc deficient onion leaves are twisted (right); plants at left are normal.

Zinc deficient corn. Young leaves have interveinal, chlorotic stripes on both sides of the midrib.

Deficiency symptoms

- Interveinal chlorosis occurs on younger leaves, similar to Fe deficiency. However, Zn deficiency is more defined, appearing as banding at the basal part of the leaf, whereas Fe deficiency results in interveinal chlorosis along the entire length of the leaf.
- In vegetable crops, color change appears in the younger leaves first. The new leaves are usually abnormally small, mottled, and chlorotic.
- In citrus, irregular interveinal chlorosis occurs with small, pointed, mottled leaves. Fruit formation is significantly reduced.
- In legumes, stunted growth with interveinal chlorosis appears on the older, lower leaves. Dead tissue drops out of the chlorotic spots.

Zn

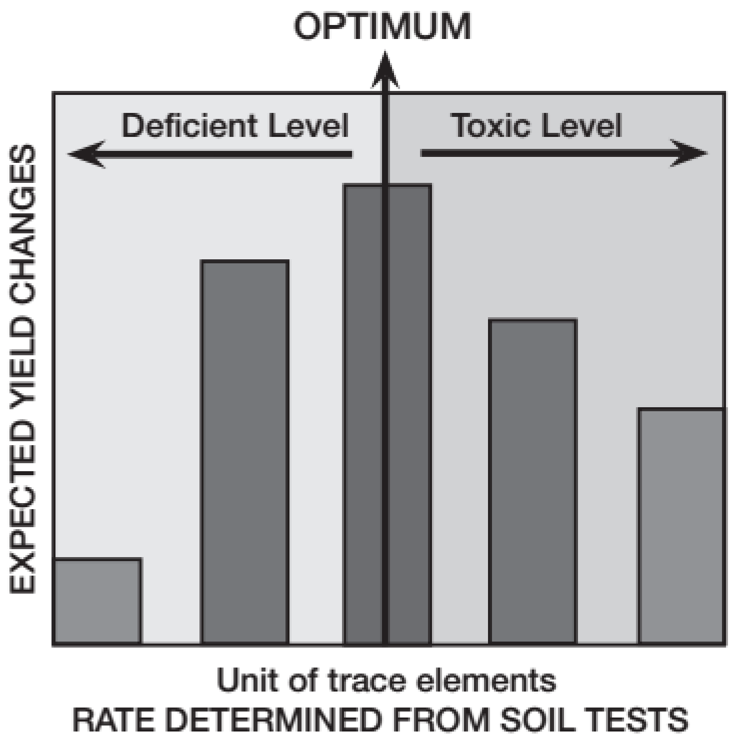
H, Nickel (Ni)

The Ni deficiency observed in pecan trees growing, in sandy, poorly draining soils with low cation exchange capacity of soils. In plants without Ni supply through the roots, urease activity in leaves was low and foliar application of urea led to accumulation of urea and severe necrosis of the leaf tips. In plants supplied with Ni, on the other hand, urease activity was higher and urea accumulation and necrosis lower. In legumes and other dicots, Ni deficiency results in decreased activity of urease and subsequently in urea toxicity, exhibited as leaflet tip necrosis. In graminaceous species deficiency symptoms include chlorosis similar to that induced by Fe deficiency, including interveinal chlorosis and patchy necrosis in the youngest leaves.

In both monocotyledonous and dicotyledonous plants, the accumulation of urea in leaf tips can be used to detect Ni deficiency.

Micronutrient deficiency symptoms, the probable cause and method of correction

Element	General deficiency symptoms	Probable cause of deficiency	Method of correction
manganese (Mn)	interveinal chlorosis of leaves, stunted plants, yellow cast over deficient areas, reduced yield & quality	low soil Mn, high soil pH due to over liming	lower soil pH, apply foliar spray or add Mn to soil
zinc (Zn)	chlorotic leaves, slow growth, reduced vigor, white streaks parallel to leaf blade	low Zn in soil, high soil pH, high soil P	lower soil pH, apply foliar spray, or add Zn to soil
copper (Cu)	reduced growth, leaf-tip dies back, leaf tip breaks down, leaves ragged	low soil Cu, high organic matter	apply foliar spray or add Cu to soil
boron (B)	terminal bud dies, multiple lateral branches (rosette with short internodes, older leaves thick and leathery, petioles short, twisted, and ruptured), hollow heart (in vegetables), small deformed fruit (in grapes), cork spot (in apples)	low soil B, esp. on sandy soils	apply foliar spray or add B to soil
molybdenum (Mo)	reduced growth; pale green color; necrotic areas adjacent to midrib, between veins and along leaf edges; twisted stems	low soil pH, low Mo content in soil	inoculate seed with Mo, apply foliar spray, or add Mo to soil
chlorine (Cl)	reduced growth; stubby roots; interveinal chlorosis; nonsucculent tissue (in leafy vegetables)	low soil Cl, esp. in soils subject to leaching	apply Cl-containing fertilizer



4.4. Beneficial Micronutrients

- **Sodium** is involved in osmotic (water movement) and ionic balance and is required for some plants. Halophyte, predominantly from the family Chenopodiaceae, is that maximum biomass is achieved at moderate-to-high salinity. In other species, growth can be stimulated at low salinity, compared with the absence of salt, but this effect may depend on the overall nutritional status of the plant and the purity of the sodium chloride. In halophytes the role of potassium in generating turgor can be fulfilled by sodium and to some extent, by calcium and magnesium, particularly at low concentrations of potassium. Sodium was reported to be necessary for the growth of some halophyte species.
- **Cobalt** is required for nitrogen fixation in legumes and in root nodules of non-legumes because it is a component of enzymes essential for nitrogen fixation. Deficient levels could result in nitrogen deficiency symptoms.
- **Silicon** is found as a component of cell walls. Plants with supplies of soluble silicon produce stronger, tougher cell walls creating a mechanical barrier to the mouth parts of piercing and sucking insects. Silicon significantly enhances plant heat, drought and cold tolerance. Foliar sprays of silicon have also shown benefits reducing populations of aphids on field crops. Tests have also found that silicon can be deposited by the plants at the site of infection by fungus to combat the penetration of cell walls by the attacking fungus. Improved leaf erectness, stem strength and prevention or depression of iron and manganese toxicity has all been noted as effects from feeding soluble silicon. Silicon is known to be essential to some members of poaceae (grasses) but has shown benefits to a wide variety of plants.
- **Aluminium**-tea crop (Camellia sinensis) is considered to be an aluminium accumulator. Most of the aluminium was localized in the cell walls of the epidermis of mature leaves. Al addition has a growth stimulatory effect on aluminium accumulators. In tea, addition of aluminium and phosphorus increased phosphorus absorption and translocation as well as root and shoot growth. Another well-known aluminium-accumulating plant is hydrangea (Hydrangea macrophylla), which has blue-colored sepals when the plant is grown in acidic soils and red-colour sepals when grown in alkaline soils. But most plant species, particularly crop plants, are aluminium excluders since aluminium is toxic to plants and animals, interfering with cytoskeleton structure and function, disrupting calcium homeostasis.
- **Vanadium**- in an experiment on sand-grown corn (Zea mays), a supply of vanadium increased grain yield, probably because leaf area was increased but also possibly due to physiological effects. Besides supply of vanadium to tomato (Lycopersicon esculentum.) at 0.25 mg L^{-1} of nutrient solution gave greater plant height, more leaves, more flowers, and greater plant mass than supplying no vanadium However, it is toxic to most plants.

4.4. Toxicity (excessive) symptoms

H, Nickel (Ni)

In general, in crop plants there is more concern about nickel toxicity, which may occur after application of sewage sludge which is often high in Ni

. **Assignment 2 discuss the following questions**

1. **Discuss the symptom of N and B toxicity and its management**
2. **Discuss the symptom of P and Cl toxicity and its management**
3. **Discuss the symptom of K and Cu toxicity and its management**
4. **Discuss the symptom of Ca and Fe toxicity and its management**
5. **Discuss the symptom of Mg and Mn toxicity and its management**
6. **Discuss the symptom of S and Mo toxicity and its management**

CHAPTER 5

NUTRIENT UPTAKE PROCESSES AND THEIR CONCENTRATION IN PLANT

The nutrient uptake refers to the process of nutrient movement from an external environment into a plant. Nutrient uptake is the absorption of nutrients by plants. It is one of the fundamental demonstrations of plant's life which involves especially a qualitative change where an abiotic material becomes a component of a cell capable of further assimilation processes, resulting in production of new mass. Nutrient uptake precedes dry matter accumulation because nutrients are required for plant growth and hence dry matter accumulation. For absorption, nutrients should be close to the root surface. Plant roots absorb nutrients in their ionic form. Plant roots absorb nutrients from the water film around soil colloids. The process of nutrient uptake takes place in the rhizosphere or the local soil environment and is influenced by plant roots. As a rule, there is a great discrepancy between the concentrations of mineral nutrients in the soil and the nutrient requirements of plants. The uptake of nutrients by higher plants is characterized by selectivity of transport and accumulation in specific tissues, cells or sub-cellular compartments.

Leaves are organs specifically designed to exchange gases, nevertheless, they can also pose a place where a foliar nutrition of plants can take place. Foliar nutrition of plants is perceived as an uptake and utilization of mineral (as well as organic) nutrients applied in the aboveground plant part in a form of aqueous solutions. Literature ordinarily uses the term foliar nutrition due to the fact that most applied solutions stick to the leaves where there is also the biggest amount of nutrients taken up. It has been demonstrated that other aboveground plant parts including crops are capable of taking up nutrients from a solution. The stated kind of nutrition is necessary to be understood as a supplementary nutrition which enables operative correction of the nutritional status of plants not only according to visual symptoms, but especially based on the analysis of plant biomass.

The foliar nutrition cannot entirely replace the root one since the amout of taken up nutrients is low. It has been demonstrated that plants reliant only on this kind of nutrition lag in development and strongly inhibit the creation of generative organs (blooms, crops). The virtue of foliar nutrition is an elimination of interaction among ions which could significantly affect the acceptability of nutrients during their application in soil and, by that, also the efficiency of supplied nutrients. Nutrient application is also possible connect with (especially regarding nitrogen fertilizers) the treatment of crops by pesticides.

The process of nutrient uptake includes the diffusion of carbon dioxide and oxygen into the plant tissue through the stomata. This is also called foliar uptake. Leaves absorb carbon dioxide, rainwater, dew (moisture) and release oxygen. Other nutrients are also absorbed through stomata as soluble ions from the sprinkled or sprayed fertilizer-enriched water. Foliar sprays are important for aquatic plants. Foliar uptake of the fertilizer is comparable to the uptake by roots. The transport of most nutrients to the roots is mainly restricted to the small soil layer surrounding the roots (the rhizosphere). The process of nutrient uptake starts in the rhizosphere.

5.1. Mechanisms of nutrient uptake

During the process of nutrient uptake there are two mechanisms for the transportation of nutrients from its original site to site to physiological synthesis (food preparation in plant cells), mechanism to reach root zone (rhizosphere) and mechanism of transporting from root surface to place of food synthesis.

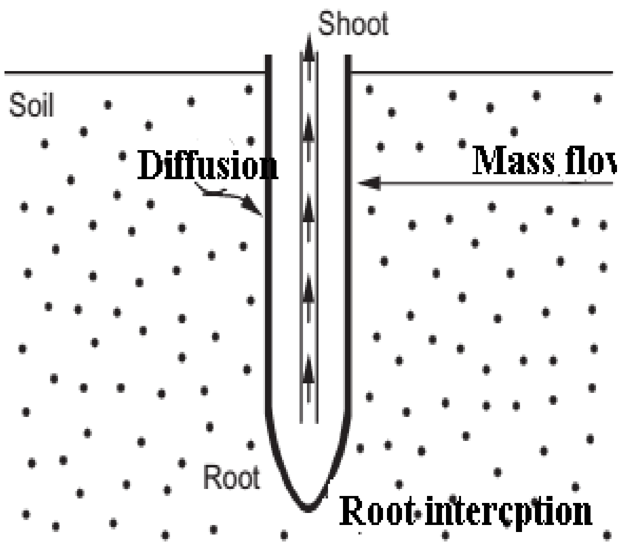
5.1. 1. Transportation of nutrients toward plant root surface

The nutrients reach the root surface by mass flow, diffusion or root interception.These mechanisms are various in degrees

- **Mass flow:** Nutrients flow passively with the water towards the root surface, a movement resulting from the active suction forces of the plant. The movement of fertilizer salts from the surface to the subsoil during a rain, ions moves rapidly through the soil with the free water present in soil pores. Soils with low water holding capacity, mass flow can result in leaching of nutrients from the root zone. Mass flow depends on the concentration of the particular nutrient, the type of interaction between the nutrient and soil colloids, the water holding capacity of the soil, and the degree of water saturation. Mass flow is the convective transport of nutrients dissolved in the soil solution from the surrounding soil to the root surface. Mass flow is more than sufficient to supply Ca in both plant species shown and for supply of Mg in spring wheat. Mobile nutrients in soil move to the root surface largely with the flow of water into the plant, mostly NO_3, SO_4, Cl and BO_3 nutrients (on the following figure at right).

Hence therefore, mobile nutrients can be surface applied, top dressed or applied in irrigation water. .

- **Diffusion**: Here, nutrients move along a concentration gradient towards the root surface where the nutrient concentration is reduced because of uptake. Transport by diffusion is caused by random thermal agitation of the ions. The movement of fertilizers salts from a band of fertilizer in a soil at less than field capacity. All soil particles are coated with a thin layer of water through which ions in solution may move. Ions in soil solution will diffuse from points of high concentration to areas of low concentration. It is a much slower process than mass flow, but is an extremely important pathway in the replenishment of the soil solution, especially for nutrients which react strongly with the soil colloids. Mass flow and diffusion to the root surface usually occur simultaneously, therefore it is not possible to strictly separate these processes. Immobile nutrients in soil move to the root surface mainly through diffusion thus K, PO_4, Mg, Ca and Zn nutrients move by diffusion (on the following figure at right). Hence therefore, immobile nutrients are generally more available to plants if incorporated into the soil or banded near the plant.
- **Root interception**- It is a result of the root growing and occupying more space. As roots grow through the soil, they move into spaces containing available nutrients, for example adsorbed to clay surfaces. About 1-3 % of total topsoil volume occupied by root volume, thus small proportion of the total nutrient requirement can be met by root interception it located on the left side of the following figure. Nutrient uptake by roots is shared by all young root parts and especially by a zone of root hairs which up to hundreds of times increases the surface area of a root. The number of root hairs in 1 mm fluctuates according to humidity, soil areation and plant type. For instance, regarding alfalfa, maize and English ryegrass grown on a light soil 1 mm of the root length comprises the number of hairs of 105, 161, 88 and their total length reached 37, 146, 99 mm.



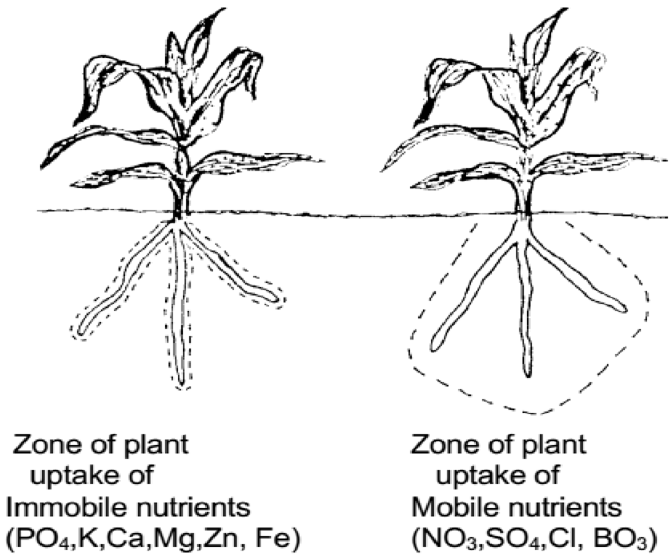


Fig. left. Schematic presentation of movement of elements towards root surface soil grown plants

Fig. right. Zone of uptake by diffusion and mass flow of immobile and mobile nutrients

5.1.2. Nutrient translocation within the plants

The long-distance transport of water and solutes – elements and low-molecular-weight organic compounds – takes place in the vascular system of xylem and phloem. Long-distance transport of nutrients from the roots to the shoots occurs predominantly in the non-living xylem vessels. Translocation of nutrients or upward movement held in the xylem mainly through the transpiration stream. Xylem transport is driven by the gradient in hydrostatic pressure (root pressure) and by the gradient in water potential. Pure free water is defined as having a water potential of zero. Accordingly, values for water potential are usually negative. The gradient in water potential between roots and shoots is quite steep particularly during the day when the stomata are open. Values become less negative in the following sequence: atmosphere ⬅ leaf cells ⬅ xylem sap ⬅ root cells ⬅ external solution. Solute flow in the xylem from the roots to the shoots is therefore unidirectional (Fig. 5). In contrast to the xylem, long-distance transport in the phloem takes place in the living sieve tube cells and is bidirectional. The direction of transport is determined primarily by the nutritional requirements of the various plant organs or tissues and occurs, therefore, from source to sink. In addition, phloem transport is an important component in cycling of nutrients between shoots and roots and for signalling the nutritional status of the shoots to the roots. In terrestrial plants, the stomata are the sites of exchange of gases besides enter rapidly the gaseous nutrients, such as SO_2, NH_3 and NO_2 in the leaves. These gaseous enhance plant growth depending upon the concentration and the plant species. The penetration of leaf surfaces by solutes is a passive process driven by the concentration difference between the surface and the leaf interior.

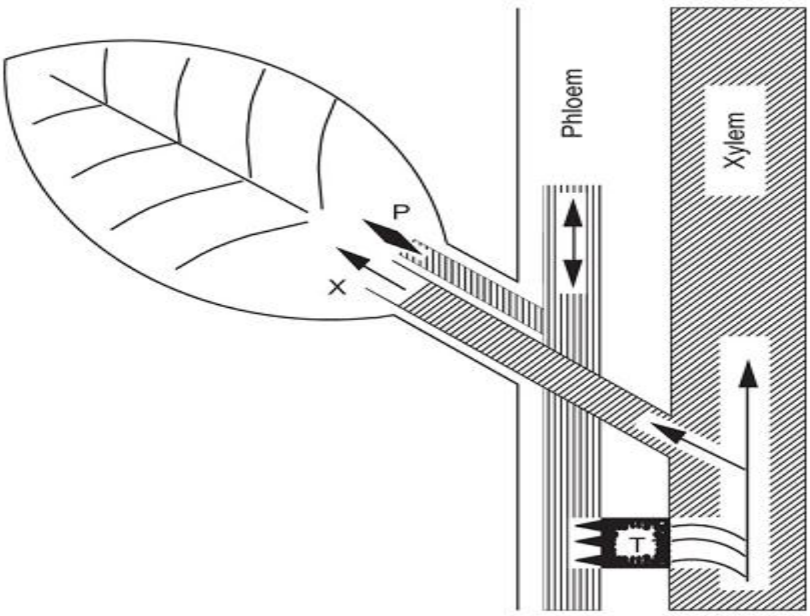
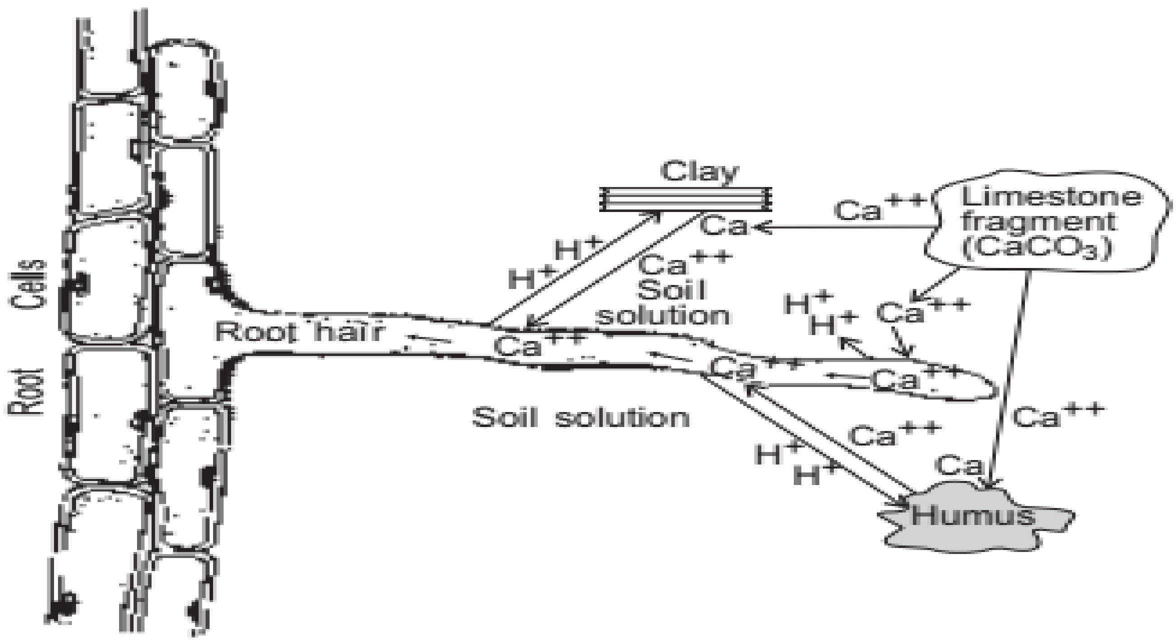


Figure 5. Direction of long-distance transport of elements in the non-living xylem vessels and in the phloem of roots.

The movement of nutrient ions from root surface into the root can be described by two processes:

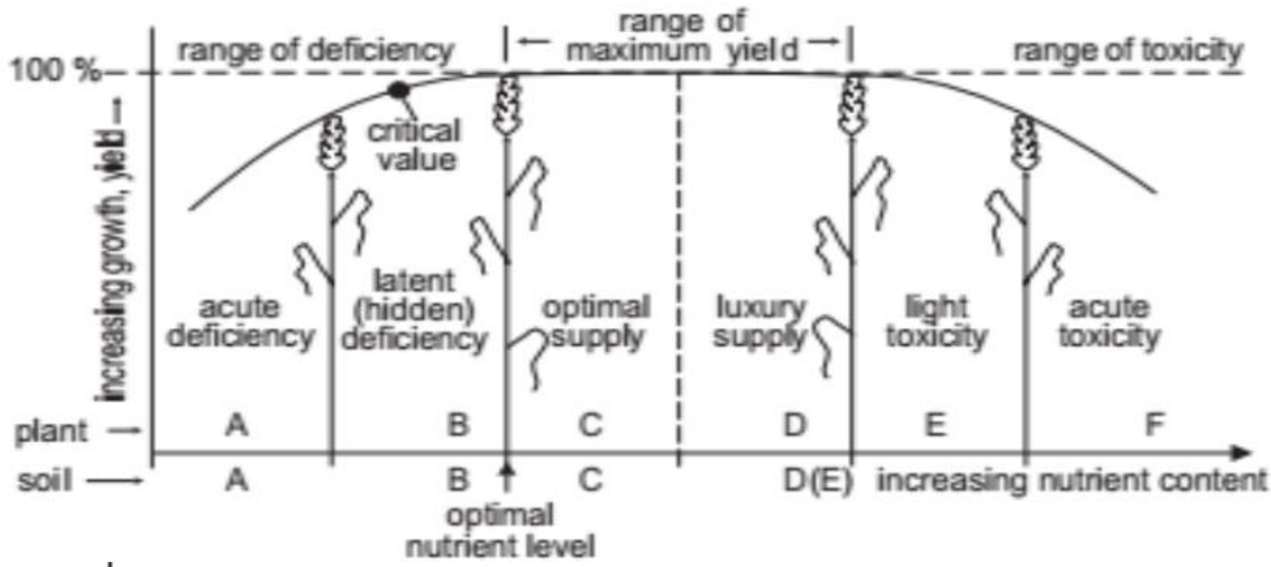
1. Passive movement/transport
2. Active movement/transport

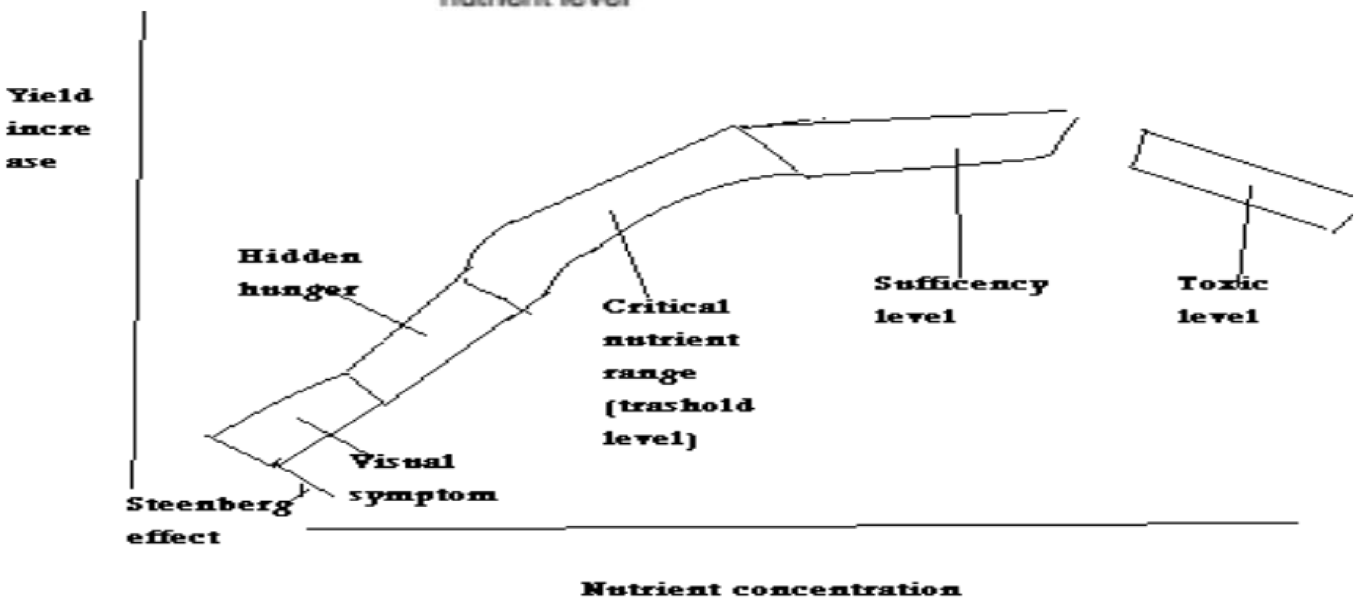
- **Passive movement or transport of ions:** it occurs in the outer or free spaces in the wall of epidermal and cortical cells of roots and is controlled by ion concentration (diffusion) and electrical (ion exchange) gradient. The concentration of ions in the apparent free space is normally less than the bulk solution concentration and therefore, diffusion occurs with concentration gradient, from high to low concentration. Passive transport is non-selective process and does not require energy from the metabolic activities of the plant.
- **Active movement or transport of ions**: it is the movement of an ion against its concentration gradient using energy i.e. when the cell uses energy to pump a solute across the membrane against a concentration gradient. The process of nutrient entry known as ion-carrier mechanism or carrier theory involves a metabolically produced substance (carriers) that combines with free ions. The ion-carrier complex can then cross membranes and other barriers not permeable to free ions and later dissociate to release ions into the inner space of the cell. Active ion transport is selective process such that specific ions are transported across the plasma lemma by specific carrier mechanism. Thus, leaves usually have higher nutrient concentrations than do roots.



5.2. **Concentration of nnutrients in plant**

Plant nutrient concentrations may be inadequate, insufficient, deficient, toxic, or excessive. By definition, when plant growth is satisfactory and optimum yields can be obtained, the amounts are adequate. However, if optimum yields cannot be reached because of nutrient deficiencies, the amounts are said to be insufficient. At nearly adequate levels of nutrient supply, deficiency symptoms are often difficult to detect visually. When a plant nutrient is present in amounts significantly lower than adequate levels, the deficiency symptoms in plants are then expressed and the nutrient is said to be deficient. When the amount of a plant nutrient is present in excess of the plant's need, it may reach the level at which it causes the deficiency of other nutrients or results in environmental pollution. The effects of nutrient concentration of the plant on yield increment illustrated in the following figure.





Nutrient status of a plant

➢ **Acute deficiency:** It is associated with definite visible symptoms and poor growth. The addition of the deficient nutrient usually results in increased growth and yields. This range should be avoided as its occurrence is a sign of low nutrient supply or poor nutrient management and poor crop performance.

➢ **Marginal or latent deficiency (hidden hunger):** It is a small range with or without visible deficiency symptoms. However, growth and yield are reduced. Addition of the yield-limiting nutrient results in higher yields but this may not be visible. Optimal nutrient supply prevents hidden hunger.

➢ **Optimal supply:** This is the range to aim for. Here all nutrients are at the most desired level. In this range, healthy green plants, good growth and high yields with good quality can be expected. This range is generally wide for most nutrients. The optimal supply is reached above the critical concentration, which is generally associated with 90 percent of maximum yield. The critical concentration serves as a diagnostic index for nutrient supply through plant analysis.

➢ **Luxury supply:** Although there is no definite borderline between optimal and luxury supply, it is useful to identify this range of unnecessarily high nutrient supply. Even if there may not be any negative effects on plant growth or yield, nutrient input is wasted and product quality as well as disease resistance may be reduced especially in the case of excess N. Therefore, luxury consumption of a nutrient should be avoided. In other words, optimal supply should be maintained and not exceeded except in special cases, such as the need for protein enrichment in grain for quality considerations.

➢ **Marginal or light (hidden) toxicity**: Here the nutrient concentration is moving towards toxicity. Above the critical toxic concentration, crop growth and yield start to decrease because of the harmful effects of a nutrient surplus, or of toxic substances on biochemical processes and imbalances. No symptoms may be evident, as in the case of hidden hunger.

➢ **Acute toxicity**: This is the other extreme of excessive supply or poor nutrient management. Plants are damaged by toxic levels resulting in toxicity symptoms, poor or no growth, poor yield, low quality and damage to soil and plant health. The disease resistance of plants may also be lowered and the plant may even die. This range should definitely be avoided for any nutrient. A critical range of plant nutrient concentration is varying from crop to crop it located on the following table.
Table 4. Critical nutrient range for macro and micro nutrients for some crops

Element	Unit	Small grain	Maize	Soya bean
N	%	2-3	4-5	4.3-5.5
P	%	0.2-0.5	0.4-0.6	0.3-0.5
K	%	1.5-3	3-5	1.7-2.5
Ca	%	0.2-0.5	0.51-1.6	0.4-2
Mg	%	0.15-0.5	0.3-0.6	0.3-1
S	%	0.15-0.4	0.18-0.4	
Mn	ppm	25-100	40-160	21-100
Zn	ppm	15-70	25-60	21-50
Cu	ppm	5-25	6-20	10-30
B	ppm		6-25	21-55
Mo	ppm			1-5

At such levels the nutrient is present in excessive amounts. When concentration of an essential nutrient or any other element is too high, it may become toxic to the plant. For example, under lowland conditions iron and manganese toxicities are often reported. Whether an element is abundant, insufficient, deficient, excessive, or toxic depends upon crop, soil, and soil-plant ecosystem. The margin between critical deficiency and toxicity limits is quite narrow for trace elements, especially Cu, B, and Fe. Soil fertility management for sustainable agriculture aims at maintaining essential plant nutrients in adequate amounts and includes plans for taking care of insufficiencies, deficiencies, excesses, or toxicities of essential plant nutrients.

Assignment 3

1. Illustrate the root morphological features of the plant affect the absorption of nutrients
2. Illustrate the leaves morphological features of the plant affect the absorption of nutrients
3. Describe the mechanisms of plant's absorption of nutrients from foliar fertilization
4. Why foliar fertilization is required low rate as compared to soil applied fertilizer rates and compare and contrast their effectiveness speed
5. Illustrate how the mobility of nutrient in soil and plant determine uptake of nutrients
6. Discuss the transportations systems during uptake of nutrients

CHAPTER 6
EVALUATION OF SOIL FERTILITY

Optimum productivity of any cropping system depends on an adequate supply of plant nutrients. The quantity of nutrients required by plants depends on factors of plant variety and species, yield level, soil type, environment (water, temperature, sunlight), and management. When the soil does not supply adequate amount of nutrient, it is necessary to add nutrients for the normal development of plants. Fertility evaluation becomes an important bridge between the nutrient requirements of crops and nutrients available in soil. Why? There are various techniques that are commonly used to evaluate the fertility status of soil. These include:

6.1. Methods of soil sample collection

A good sample is the first requirement for reliable soil test. The proper method of collecting and handling samples is determined by (1) the use to be made of the analyses, (2) the pattern and ease of recognition of soil variability, and (3) previous and proposed management practices.

Soils vary in their vertical and horizontal dimensions. These variations result from natural (soil development) and man-caused (fertilization, leveling, irrigation) forces and occur on both micro and macro scales. Micro variation (that within the rooting area of a plant) results from such factors as the localized effects of plants, urine spots, rodent activity, or fertilization and contributes about one-half of the total variance of the sample. It is best averaged by compositing several subsamples into a single sample. Big differences in nutrient levels in samples from different parts of a field are frequently encountered, particularly in intensively managed areas.

Before collecting the samples determination of optimum number of samples and their spatial arrangement of samples is essential. Sampling patterns and intensities will vary widely, depending on site characteristics and on other factors, notably economic considerations. Often, the number of samples required to achieve the desired sensitivity is exceedingly expensive, and the number of sampling points is somewhat arbitrarily reduced. Studies with insufficient sampling points typically lack statistical power to assess treatment effects. Consequently, the ‘‘cost’’ of erroneous conclusions drawn from such data (when the data really are inconclusive) may greatly exceed the ‘‘savings’’ provided by reduced sample numbers.

During soil sample collection the field conditions should be reconsidered i.e. soil type and slope of land. One composite sample made from eight sub-samples are taken per hectare (ha) in a diagonal pattern, look at the following figure. The filed divided in different homogenous units and sampling points in a zig zag fashion or randomly in such a way the whole field should be covered 30-35 samples per ha of land (Fig. 2). The samples will be collected by auger with relative reference point using a GPS (Global Positioning System) receiver. At sampling site, surface litter or debris should be removed through spade then the site is augured up to 15 depth for annual crop field, if soils is hard marked a “V” shape cut upon 15 cm depth and sample collected in a plastic bag. Finally the collected samples labelled with name, sampling date, location, and soil depth. The proper time to take a sample is more than simply "in time to get results back before fertilizer is to be applied. ″ The fertility level of a field is not constant throughout the year. During times of rapid plant growth, high percentages of available nutrients (as N, S, and K) will be in the plant and not in the soil, and low soil test levels will be obtained. To estimate preplant fertilizer needs, samples should be taken during the early stages of seedbed preparation.

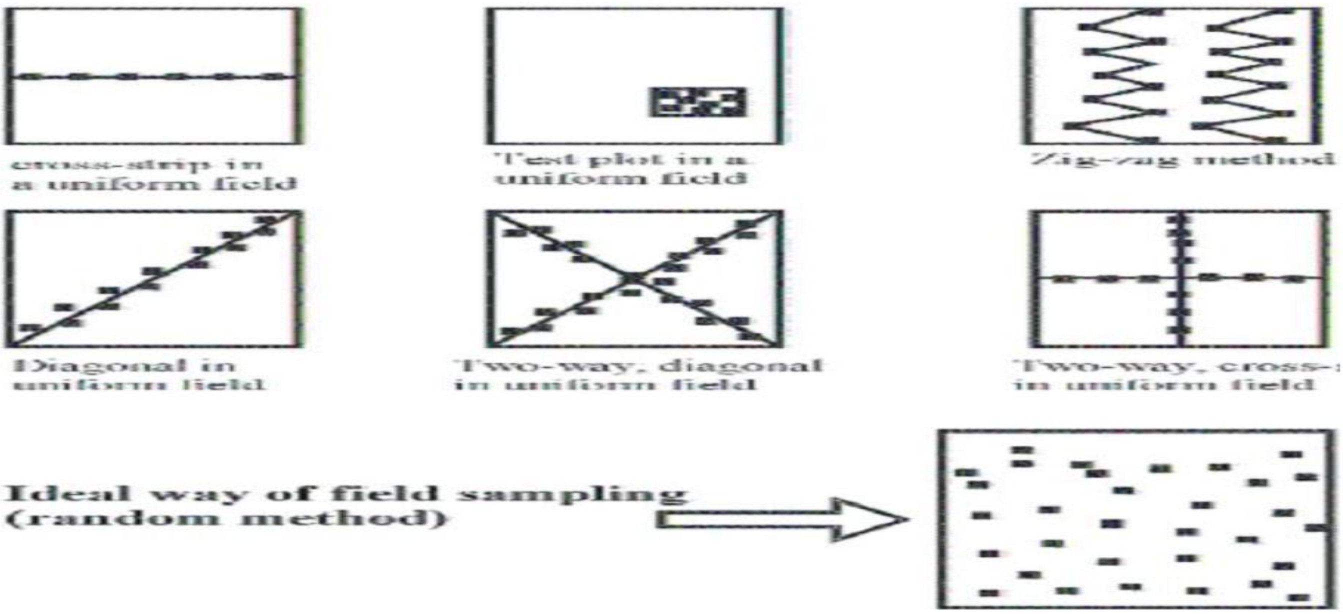
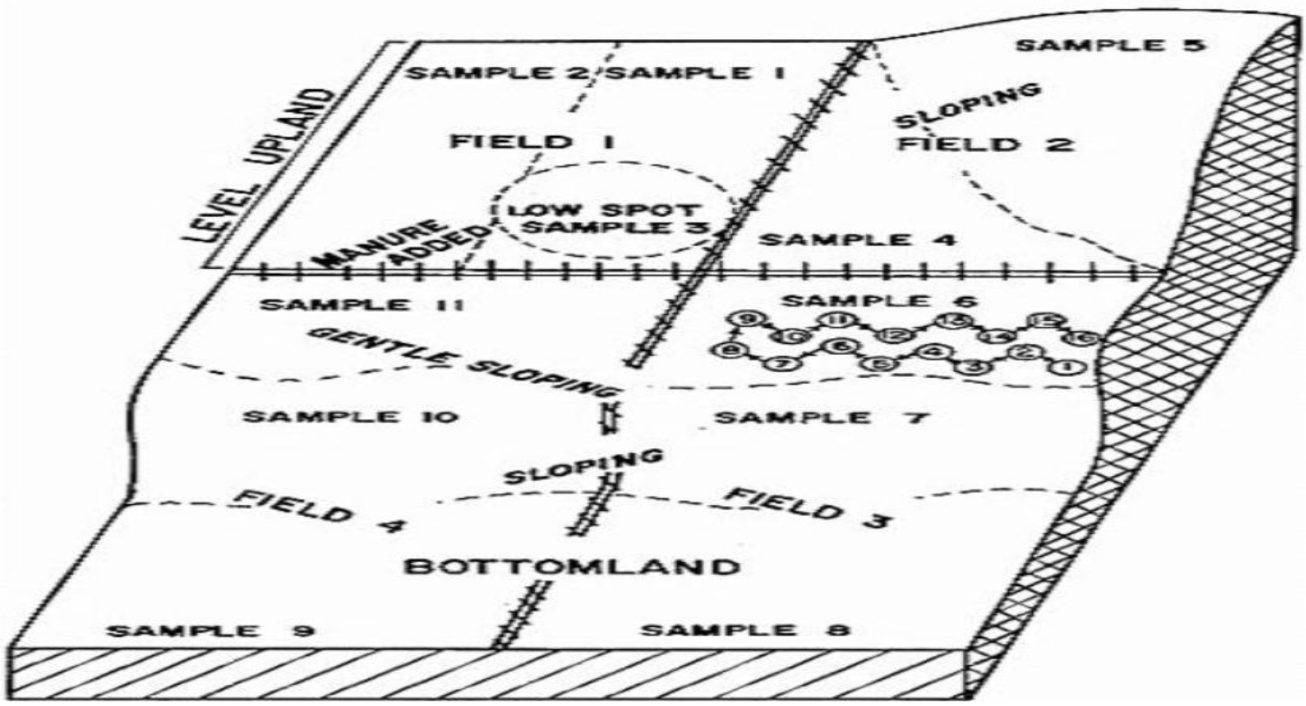


Figure Methods of soil sampling, each dotes represent a sample point with formation of sample pattern within the field



Lower position figure Sampling pattern for soil fertility test in a non-uniform land

6.2. Methods (Techniques) of Soil Fertility Evaluation

There are four methods of soil fertility evaluation these are: visual diagnosis, plant analysis ,biological method and soil analysis.

A. Visual diagnosis

Careful observations of the growth of plants can furnish direct evidence of their nutritional conditions. Metabolic disruptions resulting from nutrient deficiencies provide links between the function of an element and the appearance of a specific visible abnormality. Symptoms of disorders, therefore, provide a guide to identify nutritional deficiencies in plants. Careful experimental work and observations are needed to characterize symptoms. For example, nitrogen is needed for protein synthesis and for chlorophyll synthesis, and symptoms appear as a result of the disruption of these processes. Symptoms of nitrogen deficiency appear as pale-green or yellow leaves starting from the bottom and extending upward or sometimes covering the entire plant. Magnesium deficiency also affects protein synthesis and chlorophyll synthesis, but the symptoms may not resemble those of nitrogen deficiency, which affects the same processes. Experience is necessary to distinguish the symptoms of nitrogen deficiency from symptoms of magnesium deficiency or in the identification of the deficiency of any nutrient. Symptoms on foliage have been classified into five types:

(a) Chlorosis, which may be uniform or interveinal;

(b) Necrosis, which may be at leaf tips or margins, or interveinal ;

(c) Lack of new growth, which may result in death of terminal or axillary buds and leaves, dieback, or rosetting;

(d) Accumulation of anthocyanin, which results in an overall red color; and

(e) Stunting with normal green color or an off-green or yellow color.

Symptoms of deficiency can be quite specific according to nutrient, especially if the diagnosis is made in early development of the symptoms.

Plant exhibits various symptoms on their parts (roots, stem, bud, leaves, fruit, seeds etc). . The appearance of deficiency symptoms on plants has been commonly used as index of nutrient deficiency. Certain symptoms will be observed on different parts of the plant as a result of the deficiency of individual nutrient. This method of evaluation of soil fertility is very simple, in expensive and does not require laboratory equipments. But it becomes difficult to judge the deficiency, if many nutrients are involved, besides deficiency are relative i.e. a deficiency of one nutrient can imply the presence of adequate or excessive quantities of other Mg deficiency is caused due to addition of large quantities of Fe while higher level of N may led to P deficiency moreover some damage caused by diseases and insect resemble certain micronutrients deficiency e.g. alfalfa damaged by leafhopper are similar to boron deficiency. Symptoms of certain deficiencies are not distinct and visible only when deficiency is acute. It requires an experienced people to make proper judgment.

The nutrient deficiency symptoms can be

- Retard growth
- Abnormal color pattern- chlorosis on the leaves
- Necrosis or dying of tissue, dying of edge of leaves in case of K
- Malformation of different parts of plants- Ca, Zn
- Affected by lodging (deficiency of P)
- affected with insect and diseases (deficiency of boron)

B. Plant analysis - Plant analysis is indicating amount of given nutrient in plant for supply particular nutrient which is directly related to the quantity present in soil. Many conditions, however, may alter nutrient uptake even though the nutrient is adequately soluble. These conditions are low soil temperature, rapid plant growth, soil pH, root damage, low soil water content, poor drainage and others.

Antagonistic interaction is non-specific competing occurs between cations species for negative charges of cell wall competition exist between ions with similar physiochemical properties (vacancy and ionic diameter) for specific sites (carrier) on surface of plasma membrane (plasma lemma), in this relationship increases the supply of ion results in lowering the concentration of other. Meanwhile **synergism interaction** is uptake of one specific ions stimulate the other.

The normal growth of plant is determined by supply of soil nutrients. However, there is one disadvantage with this method, shortage of one nutrient can limit growth, and other nutrients may show higher content in cell sap irrespective of supply. For example if maize is low in nitrates the P test might show high, although P also may not be enough. Therefore, it does not indicate if N was applied to maize the supply of P would be adequate.

In plant analysis test there are **two different** types of tests are used as indicators of the nutrient status of plants not with quantitative value i.e. concentration of nutrient in very low, medium, high, very high. The first, **tissue test** is a rapid test for determination of nutrients in fresh tissue is important in diagnosing the nutrient need of growing plants. The concentration of nutrients in cell sap is usually a good indication how well the plant supplied at time of testing plant parts may chopped up and extracted with reagents. Semi-quantitative analysis, mainly used for nitrate, measures unassimilated soluble content of plant sap. The intensity of color developed is compared with supply of nutrients. The cell sap from plant, usually the leaves is extracted and sap is tested for N, P, and K by using of specific reagents which develop the color. The constituents measured are *en route* from the point of entry to site of utilization within plant. These contents are compared with nutrient levels in same parts of normal plants at the same stages of maturity. Usually element composition in leaves various during growth; nitrogen, P, K and Zn levels usually decease as growing season progress, content of Ca, Mg, B, Mn and Fe increase. The part of plant to be tested depending up on that part which gives the best indication of N, with limited supply the upper part of plant show low test for nitrate, because maximum utilization take place in upper part, whereas in case of P and K the reverse is true and lower part of plant become deficient first.

Time of sample also affects the level of nitrate on plant. Nitrates are usually higher in morning than in the afternoon. Nitrates accumulated at night and are used during the day for carbohydrate synthesis.

Generally tissue testing should be done at most critical stage of growth i.e. at the time of bloom or from bloom to early fruit stage. The need of plant is maximum at this stage because the utilization of nutrients is at its peak and low levels at this stage, therefore, more likely to be defected. However from view of correcting deficiency it should be done early enough and then correct for advantage.

The second is **total analysis** that performed on whole plant or in specific parts, after sampling the plant material; grounding dried materials and determining with digesting or ashing plant materials then analytical data taken after analysis.

C. <u>Biological test</u>- There are two methods used to recognized through

C. 1. Higher plants (field test, laboratory and green house test)

Field test is best known biological method. Treatments are selected depending up on the problem that the experimental wants to investigate. Treatment is applied in representative land in random manner with replication to obtain statistical significance. It is applied on state or farmers field levels.

Using indicator plant – all plants can exhibit the deficiency symptoms to greater or lesser degree depending on severity of deficiency. However, some plants are more susceptible for deficiency of a specific nutrient and develop clear symptoms and earlier than other crops, if grown in nutrient deficient soil. These indicator plants are located on the following table.

Table 5. Soil nutrient status indictor plant

Nutrient	Indictor plants
N	Cereals , Mustard, Apple, citrus, cabbage and cauliflower
P	Maize, barley, lettuce, tomato, rapeseed, cotton, tomato,
K	Potato, clover, bean, tobacco, cucurbits
Ca	Lucerne, cabbage and cauliflower and legumes
Mg	Potato, cauliflower, sugar beet
S	Lucerne, clover, rapeseed

Laboratory and green house test- utilize by small amount of soil through pot culture techniques for growth of higher plants.

C.2. Microbiological methods- some microorganisms exhibit similar behavior as higher plant in absence of minerals. Azotobacters were very sensitive to deficiency of Ca, P, and K and could be used to detect the deficiency of these nutrients with greater sensitivity than chemical methods.

Asergillus Niger- used to determine the deficiency of P and K.

D. <u>Soil test</u>

A soil test is a chemical or physical measurement of soil properties based on a sample of soil. Commonly, however, a soil test is considered as a rapid chemical analysis or quick test to assess the readily extractable chemical elements of a soil. Interpretations of soil tests provide assessments of the amount of *available nutrients*, which plants may absorb from a soil. Chemical soil tests may also measure salinity, pH, and presence of elements that may have inhibitory effects on plant growth. A basic principle of soil testing is that an area can be sampled so that chemical analysis of the samples will assess the nutrient status of the entire sampled area.

It is a better method than others since it helps in determining the nutrient needs of plant before crop planted. The quantity of nutrient extracted by soil test should be closely related but not equal to the quantity of nutrient absorbed by the sap. Strong acids extracted lot more nutrients than could be made available to plants growth. Consequently, strong acids were replaced by weaker solutions which extract the same amounts of nutrients as could be extracted by roots under the condition present in soils.

Information gained from soil test is used

- To provide an index of nutrient availability or supply in a given soil
- To predict the probability of obtaining profitable response of fertilizer
- Provide a bases for recommendation of fertilizer apply
- To evaluate fertilizer status of soil

Before under taking soil test care should be taken in sampling of soil. For good judgment it should represents what you want to represent. Examine a field for having difference in soil characteristics (topography, soil productivity, texture, structure, color, drainage) and crop yield. Take samples at depth of

0-30 cm from distinctly different areas. Then at least 10 well distributed spots in field and representative spots in field mixed well and ½ kg of the representative composite sample test to send to laboratory for analysis with labeling. Various chemical analysis used in laboratory to identify amount of total N, available P, K, and micronutrients.

6.3. Interpretation analytical results

Many soil testing laboratories classify the fertility level of soil as very low, low, medium, high, and very high based on the quantities of nutrients extracted.

Table. Rating of soil nutrient level in kg/ha

The result of the analysis carried out in laboratory is reported back usually with recommendations on fertilizers and soil amendments that should be used. The analytical results including numerical results and a rating interpretation of this result will be done. The analytical data is rated according to the following tables whether available quantity in the soil is low or high. Interpretations of soil test data are made for each soil test class rather than for each numerical value. Using soil test classes' permits the pooling of crop response data make sound fertilizer recommendation. Crop responded to fertilizer application occurs when crop is grown on low nutrient content soil than on high. However, it is not easy to provide plants with exactly adequate amounts of all nutrients, and the task is made more difficult by numerous interactions between nutrients. Fertilizer recommendation for proposed crop is given based on soil analysis, manure and fertilizers recently applied. The report should also indicate time and method of fertilizer application.

Table. Interpretation of soil nutrient in soil-test

Type of analysis	Low	Medium	High
N	<272	272-544	>544
P_2O_5	<22.5	22.5-56	>56
K_2O	<136	136-337.5	>337.5

Analysis	Unit	Very low	low	Medium	High	Very high	Analytic method
OM	%	<1	1-2	2-4.2	4.2-6	>6	
N	%	<0.05	0.05-0.125	0.125-0.225	0.225-0.30	>0.3	
Ava.P	ppm	0-5	6-12	13-25	>25		Bray I
	ppm	0-3	4-7	8-11	>11		Olsen's
CEC	Meq	<6	6-12	13-25	26-40	>40	
BS	%	0-20	21-40	41-60	61-80	81-100	
Ca	meq	<2	2-5	5-10	10-20	>20	
Mg	meq	<0.5	0.5-1.5	1.5-3	3-8	>8	
K	meq	<0.1	0.1-0.3	0.3-0.6	0.6-1.2	>1.2	
Na	meq	<0.1	0.1-0.3	0.3-0.7	0.7-2	>2	

Fe	ppm		<2	2.1-4	>4		
Zn	ppm		<0.5	0.6-1	>1		
Fertilizer response		Expected	Expected	Possible	Unlikely	Rarely	

TABLE GUIDE* FOR DIAGNOSING NUTRIENT STATUS OF SOILS FOR DIFFERENT CROPS

Crop and nutrient	Crop yield response likely (less than)	Crop yield response not likely (more than)
	ppm	
Alfalfa		
P	6	10
K	50	80
Barley and wheat		
P	6	12
K	40	60
Zn	0.2	0.3
Cantaloupe		
P	8	12
K	80	100
Zn	0.4	0.6
Corn		
P	6	12
K	50	80
Zn	0.3	0.6
Cotton		
P	5	8
K		
Loamy soils	40	80
Clayey soils	60	100
Zn	0.4	0.7
Lettuce (cool season)		
P	15	25
K	50	80
Zn	0.5	1.0
Onion		
P	8	12
K	80	100
Zn	0.5	1.0

Crop and nutrient (cont.)	Crop yield response likely (less than)	Crop yield response not likely (more than)
	ppm	
Pasture and range		
P	5	10
K	40	60
Potatoes (mineral soils)		
P	12	25
K	100	150
Zn	0.3	0.7
Sorghum		
P	4	7
K	40	60
Sugar beets‡		
P	5	12
K	40	70
Zn	0.1	0.2
Tomatoes		
P	6	12
K	50	80
Zn	0.3	0.7
Other vegetable crops Warm season		
P	5	9
K	50	70
Zn	0.2	0.5
Cool season		
P	10	20
K	50	80
Zn	0.5	1.0

Note : *Available P obtained by extracting soils with either the 0.5 M pH 8.5 $NaHCO_3$ solution
proposed by Olsen, **Exchangeable K and extractable Zn by DTPA (diethylenetriaminepenta-acetic acid)

CHAPTER 7

SOIL FERTILITY MANAGEMENT PRACTICES

7.1. Global and national context

One of the most important challenges facing humanity today is to conserve/sustain natural resources, including soil and water, for increasing food production while protecting the environment. Nutrient depletion from soils is a major form of soil degradation. As the world population grows, stress on natural resources increases, making it difficult to maintain food security. On a global scale, soil fertility depletion is far more widespread than is soil fertility improvement. **S**oil degradation particularly soil fertility, is a major cause of stagnating or even decreasing yields in some countries. Apart from widespread soil erosion, loss of organic matter resulting in reduced biological activity; nutrient depletion as a result of erosion, mining or inactivation of nutrient (e.g. sorption of phosphate); and reduced nutrient retention.

Nonetheless, in large regions, consisting mainly of developing countries, hunger and malnutrition still exist. However, current food shortages are only partly caused by production problems. Disturbances to food production resulting from poor economic conditions, widespread poverty, civil war, inappropriate food pricing policies and logistical constraints contribute significantly to the problem. According to Borlaug (1993): “The dilemma is feeding a fertile population from infertile soils in a fragile world.” Several developing countries in problem areas such as SSA (Ethiopia, Nigeria, etc.) show stagnation in cereal yields (at a low level) or even a declining trend, Ethiopia is among the most populous in Sub-Saharan Africa (SSA), with an estimated 93.8 million citizens and 3.2 percent growth rate per year (CIA, 2012). Despite its rapid economic growth, Ethiopia ranks sixth among the poorest countries in the world; with a US $400 per capita income, it is one of the poorest in SSA. An estimated 39 percent of the population (about 36 million people) survives with an income below the poverty line. Although the Ethiopian economy is diversified, it is heavily reliant on agriculture1 as the main source of employment, income and food security for a vast majority of its population. In 2012, agriculture accounted for 85 percent of total employment, 90 percent of exports and a high percentage of GDP (PIF, 2010). Agriculture's share of GDP at 41 percent represents a decline from about 50 percent since the early 2000s, mainly due to land degradation, particularly in soil fertility depletion. Ethiopia is one of the highest rates of nutrient depletion in SSA. The estimated annual nationwide loss of phosphorus and nitrogen resulting from the use of dung and crop residues for fuel is equivalent to the total amount of commercial fertilizer use. Land degradation and nutrient depletion are further exacerbated by overgrazing, deforestation, population pressure and the poor land use planning and tenure system (PIF, 2010).

To insure long term food security, human beings should have to maintain the balance between increasing crop production and environmental sustainability mainly soil health. Hence therefore, nutrient management is becoming highly popular and accepted approach for its environmental and economical advantages. As most of the additional food required must come from already cultivated land, intensification of agriculture with high (optimal but not excessive) and balanced use of nutrient inputs will be required. Even with a high degree of nutrient recycling through organics, mineral fertilizers will continue to be of central importance for meeting future food demands. The effective implementation of nutrient management can be of significant benefit to farmers and the whole community. Nutrient management strategies help to maximize the economic and biological value of the nutrients. The management strategies can able to minimize the conflict between farm operations and non-farm uses and providing for the protection of environmental resources. Proper implementation of nutrient management helps to increase crop yields, to improve crop quality and productivity, increase farm income, correction of inherent soil nutrient deficiencies, avoiding damage to the environment and restoring soil fertility.

7. 2. Principles of nutrient management

By definition, soil fertility recognizes the ability of soils to provide the essential elements for plant growth in the right amounts and at the right time. Few soils fit required specifications perfectly and most require some additional inputs of nutrients to meet plant needs. This is particularly the case when considering the long-term sustained productivity of the land. In developing a nutrition management system for a cropping system, the following factors need to be considered:

- The uptake by the crop for a reasonable yield;
- The amount that can potentially be supplied by the soil without degrading it;
- The efficiency of utilization of the nutrient from its source.

To satisfy these considerations, a soil may actually require not just the three major elements, N, P and K, but any or a combination of all the others needed to guarantee the best level of nutrition for the crop. Apart from N, P and K, the parent material from which the soil is formed largely dictates the levels of other essential elements present. To a lesser extent, factors determining the development of the profile, such as climatic conditions and topography also influence the nutrient status of soils; these becoming more important as the soil mature. In particular, N and P are associated with the organic matter component in soils and are therefore affected by any activity that influences the status of organic matter. Despite their occurrence in a 15-centimetre layer at levels of thousands of kilograms per hectare, only a small fraction of this amount is actually available for plant uptake. Consequently, N, P and K may need to be supplied to meet crop needs. The actual application of these nutrients also depends on an understanding of their behaviour in the soil. Application issues include: the nutrient carrier or source, the timing of the application, the method of application, and the type of mineral nutrient source.

The primary goal of Nutrient Management is to prevent accumulation of nutrients on the farm to the point they threaten plant growth or the environment. Nutrients come to the farm as fertilizers, feeds and mineral additives. The cost of fertilizers tends to reduce the rate of accumulation of nutrients applied from this source, although very high levels have accrued for high value crops over time. Animals transform feed nutrients into body mass and manure. Unless the manure nutrients are transported off the farm, they will build up to levels that could negatively affect crops, ground water, and surface water supplies. The concentration of nutrients in manure, especially liquids, is low enough that transport very far off the farm as a fertilizer is seldom practical. A land application system on the farm allows manure nutrients to be used to grow crops.

A Nutrient Management Plan is a tool to help you define the nutrient needs of the crops you will grow, and how best to provide the amount sources, placement and timing of those applications to maximize nutrient uptake of the crop, and improve yields. Since fertilizers contain guaranteed nutrient contents, and are for the most part highly available, very precise applications can be made.

Nutrient management plan this involves determining number of acres and types of crops to be grown based on the amount of manure produced and the nutrient requirements of the crops. The process requires estimating the amount of manure produced, and the amount of plant available nutrients the manure contains. Based on these factors, environmentally sound cropping systems are matched with your production and waste handling systems to come up with the most economically acceptable alternatives for land application. Once a plan is written, it still must be implemented.

A Nutrient Management Plan requires careful attention to make it work properly. A properly implemented plan will let you utilize nutrients in a manner that meets crop needs while reducing the effects on surface and ground water supplies. Even for commercial fertilizer sources, this requires careful attention to timing, crop growth and seasonal variations. The inherent variability of manure complicates the process even further. Implementation requires an understanding of the information in a plan, along proper use of analytical tools, monitoring information and equipment calibration to make the plan for implementation.

Best Management Practices (BMPs)

Practices that reduce losses of nutrients and thereby reduce the potential for negative environmental impact are considered BMPs. BMPs may include erosion and sediment control to reduce movement of soil and nutrients into streams from field edges, such as grassed waterways, buffer strips and riparian buffers. Incorporation of nutrients to reduce off-site movement, volatile losses and odors may also be considered best management practices. Using cover crops to scavenge nutrients remaining in the soil could also be an effective best management practice to reduce the loss of nutrients from a land application site.

7.3. Type and application of fertilizers

The term fertilizer is derived from the Latin word fertilis, which means fruit bearing. Fertilizer can be defined as a mined, refined or manufactured product (synthetic origin) or any organic or inorganic material of natural (other than liming materials) that containing one or more essential plant nutrients. Fertilizers are any organic or inorganic material of natural or synthetic origin added to a soil to supply certain elements essential to growth of plants. According FAO Fertilizer is nay natural or manufactured material, which contain at least 5% of one or more of the three primary nutrients (N, P_2O_5, and K2O). Although the use of animal manure was common as far as back agricultural records can be traced, industrially manufactured fertilizers (mineral or chemical) have been extensively employed for little more than 100 years. There is now an economic necessity on many soils. Any inorganic salt, such as ammonium nitrate, or in organic substance such as urea, used to promote crop productivity by supplying plant nutrients is considered to be a “commercial” fertilizer. Fertilizer has been accounted for growth of the total crop production by 30 to 40 percent in the world. Most of the fertilizers are inorganic materials that are the product of sophisticated manufacturing methods and have a uniform composition.

The importance of fertilizer

- **Farming efficiency improvement:** The farmer's income increased by the application of fertilizers. If the use of economic optimum levels of fertilizer is consistent, negative consequences are minimized**.**
- **Improvement of soil quality with adequate fertilization**: The aggregating action from enhanced root proliferation and a greater amount of decaying residues have reportedly made the soil more friable, tillable and water retentive.
- **Crop quality improvement**: The mineral, protein and vitamin contents of crops can be improved by balanced fertilization.
- **Water conservation**: plants well nourished by fertilizers, use water efficiently through their expanded root system, thereby reducing evaporation losses, and conserving this natural resource.

Nutrient composition of fertilizers

Fertilizer may be in the form of a solid, liquid, or gas, its composition is expressed in grade or ratio. Fertilizer grade is the plant nutrients content in percentage through weight base and used in the fertilizer trading for providing the legal guarantee of available nutrients in the order of: N - P_20_5 - K_20. For instance the fertilizer grade with 27-3-9, it contains 27% nitrogen, phosphorus equivalent to 3% P_20_5, and potassium equivalent to 9% K_20. Most of the nitrogen and potassium in fertilizers is water soluble. Fertilizer ratio is the relative ratio of the nutrients in weight base, example 4:1:2 i.e. four fold of N, a fold of P_20_5 and two fold of K_20.

The fertilizer ratio is the relative proportions of primary nutrients in a fertilizer grade divided by the lowest denominator of grade. Commercial fertilizers have a specific ratio of nutrients, known as fertilizer ratio, also called plant food ratio. For instance a fertilizer with 27-3-9 grade has a ratio of 9:1:3. This fertilizer is high in nitrogen, low in phosphorus, and moderate in potassium. Fertilizers that contain only one compound and supply one or two plant nutrients are called fertilizer materials or carriers. Fertilizer carriers or materials that are mixed together and processed to produce fertilizers containing at least two or more nutrient elements are mixed fertilizers.

7.3.1. Classification of fertilizer

Synthetic fertilizers are sometimes referred to as being artificial or chemical fertilizers, implying that these are inferior to those termed natural (mainly organic) products. However, fertilizers are neither unnatural nor inferior products. Many fertilizers are finished products derived from natural deposits, either made more useful for plants (e.g. phosphate fertilizer) or separated from useless or even harmful components (e.g. K fertilizer).

Fertilizer classified various ways

I. Classification based on their chemical composition

A, Mineral fertilizers- containing inorganic or synthetically produced compounds. They are manufactured in liquid or solid form, usually in an industrial process. They can supply main nutrients, secondary nutrients, micronutrients or mixtures of nutrients. Mineral fertilizers have a higher plant nutrient content and a lower bulk than organic sources of plant nutrients. High-grade fertilizers contain more plant nutrients (up to 82 percent) than low-grade fertilizers, producing savings on transport and handling costs.

For instance N fertilizers are:

- Ammonia: It is the starting point and basic intermediate for the production of N fertilizers. It is synthesized by the Haber-Bosch reaction which combines he very stable molecule of atmospheric $N_2$with hydrogen, e.g. from natural gas, under a pressure of 200 atmospheres at 550 °C: air + natural gas + water Aammonia + carbon dioxide O_2+ N_2+ CH_4+ H_2O ANH_3+ CO_2
- Nitrate fertilizers: In this case, nitric acid (HNO_3) is produced by the oxidation of ammonia and then neutralized with materials such as calcium carbonate ($CaCO_3$) to produce calcium nitrate $Ca(NO_3)_2$. Nitrate fertilizers may also be derived from other sources such as Chile saltpeter
- Ammonium nitrate (AN) fertilizers: These are produced by neutralizing nitric acid (derived from the oxidation of ammonia) with ammonia. The solid granulated fertilizer is obtained by spraying the highly concentrated solution in cooling towers.
- AN with lime: It is produced: (i) by mixing AN with calcium carbonate to obtain calcium ammonium nitrate (CAN); and (ii) by the reaction of calcium nitrate with ammonia and CO_2.
- Urea: It is produced by the reaction of NH_3 and CO_2 at 170 atmospheric pressure and a temperature of 150 °C. Care is needed during drying to ensure that the biuret formed is minimum and within the permissible limits set out in fertilizer-quality standards.

B. Organic products - that are produced out of wastes of animal husbandry (stable manure, slurry manure, etc.), plant decomposition products (compost, peat, etc.), or products from waste treatment (composted garbage, sewage sludge, etc.), Biofertilizer is a products containing living or dormant micro-organisms such as bacteria, fungi, actinomycetes and algae alone or in combination, which on application help in fixing atmospheric N or solubilize mobilize soil nutrients in addition to secreting growth-promoting substances. They are also known as bioinoculants or microbial cultures. It includes N-fixing biofertilizers, P-solubilizing/mobilizing biofertilizers, composting accelerators and Plant-growth-promoting rhizobacteria (PGPR). Unlike fertilizers, these are not used to provide nutrients present in them, except in the case of Azolla used as green manure.

C. Soil conditioners -the main function of conditioner is to improve the physical properties of the soil.

II. Classification based on number of nutrients

- **Straight fertilizers**: these contain one of the three major nutrients N, P or K. This is a traditional term referring to fertilizers that contain and are used for one major nutrient as opposed to multinutrient fertilizers. For secondary nutrients, these include products containing elemental S, magnesium sulphate, calcium oxide, etc. In the case of micronutrients, borax, Zn and Fe chelates and sulphate salts of micronutrients are straight fertilizers. However, the term is not often used for micronutrient carriers. This is not a very accurate term because many straight fertilizers also contain other essential plant nutrients, such as S in ammonium sulphate. These can also be termed single-nutrient fertilizers. The term focuses on the most important nutrient for which a product was traditionally used disregarding other valuable constituents. In a strict sense, the term is justified only for products such as urea, ammonium nitrate (AN), and elemental S.
- **Compound or complex or multi-nutrient fertilizers** – it contain at least two out of the three major nutrients and sometimes micronutrients. They are produced by a chemical reaction between the raw materials containing the desired nutrients and they are generally solid granulated products. Compound fertilizers are produced by the blending or chemical linkage of straight fertilizers or nutrients. These include both two-nutrient (NP) and three nutrient (NPK) fertilizers. These are also referred to as multinutrient fertilizers, but do not include fertilizer mixture or bulk blends as no chemical reaction is involved. The term is rarely used for multimicronutrient fertilizers or fortified fertilizers containing both macronutrients and micronutrients or for liquid fertilizers. The term multinutrient fertilizer is more appropriate as it includes both major nutrients and micronutrients. Sometimes, it is mixtures and bulk blends.
- **Micronutrient fertilizers** these containing nutrients required in small quantities by plants

III. Classification based on their states

- Solid fertilizer
- Liquid fertilizer- used for spraying on an existing plant population

7.3.2. Application of fertilizers

7.3.2.1. Solid fertilizer application

A fertilizer should be placed in the soil in such a position that it will serve the plant to the best advantage. During the application reconsidering the movement of fertilizers in soil is practical important since P compounds tends to move very low except in more sandy soils hence the application should be done in the root zone but deeper placement of P compound plant may not benefitted due to immobility of the nutrient. However, K, nitrate N, to an even greater extent, tends to move from their zones of placement. This movement is largely vertical, the salts moving up or down depending on the direction of water movement. These translocations greatly influence the time and method of applying N and K. For example, it is undesirable to supply N in one annual application because of the leaching hazard. Yet this tendency of nitrate to move downward is sometimes an advantage when fertilizer is applied on the surface of soil. Water movement in the latter case carries the dissolved nitrate salts down to the plant roots. However, top dressing of N solutions and urea present problems in some cases because of the danger of volatilization. The movement of N, to lesser degree, K must be considering in the placement of the fertilizer with respect to the seed. Rain immediately after planting followed by a long dry spell encourages such damage to seeding. Placement of fertilizer immediately above the seed or on the soil surface also results in injury, especially to row crops.

Cultivation of row crops such as corn, cotton, and potato usually the fertilizer applied at time of planting. The fertilizer usually is placed in a narrow band on one or both sides of the row, 5-6 cm away and little below seed level. Fertilizers placed directly with seeds can delay and/or reduce germination of seeds. Side dress application resulted in providing nitrogen near the time of maximum plant need and with the least amount of time available for nitrogen loss. When the amount of fertilizer is large, it is wise to spread at least part of it over the soil surface and thoroughly work into soil before planting. Small grain such as wheat, barley and teff planting drill is equipped with fertilizer distributer. Fertilization of pasture and broadcasted crops the fertilizer thoroughly mixed into soil as the seedbed prepared and if necessary apply in top-dress. Orchard fertilization usually treated individually, the fertilizer being applied around each tree within the spread of branches but some feet away from the trunk.

Time of Application

The closer the time of fertilizer application is to the time of maximum plant need, the more efficient plants will be in using the fertilizer nutrients. This is especially true for nitrogen, which is lost by denitrification whenever the soil is anaerobic. Nitrate is mobile and lost by leaching during periods of surplus water, and NH_3 is subject to volatilization when it exists on the soil surface. The time of application of phosphorus and potassium fertilizer is less critical than for nitrogen. However, fixations of phosphorus, and to a lesser extent potassium fixation, reduce their availability and reduce the plant's ability to recover the applied fertilizer phosphorus and potassium. The longer the period of time between application and plant use, the greater is the fixation and inefficiency of the nutrient use. Besides time of the application depend upon farm resources and practical realities (Table).

Table . Recommended fertilizer application times for cereals

Cereal crops			
Fertiliser	**Dryland, low rainfall**	**Dryland, high rainfall**	**Irrigated**
Nitrogen (soil low in N)	(1) Predrill urea or sow with N/P blends (2) Before first node, or if crop yellowing	(1) Predrill urea or sow with N/P blends (2) Before flowering or if crop yellowing	(1) At sowing with N/P blends (2) Up until flowering, or if crop yellowing
Nitrogen (soil high in N)	(1) No N needed (2) If crop yellowing apply as soon as possible	(1) No N needed (2) After first node, or if crop is waterlogged (3) Before flowering	Up until flowering, or if crop yellowing
Phosphorus	(1) At sowing (2) Before first node	(1) At sowing (2) Before first node	(1) At sowing (2) Before first node
Potassium	(1) At sowing (2) Before first node	(1) At sowing (2) Before first node	(1) At sowing (2) Before first node
Calcium (lime)	Prior to sowing	Prior to sowing	Prior to sowing
Trace elements	(1) At sowing (2) If deficiency signs appear	(1) At sowing (2) If deficiency signs appear	(1) At sowing (2) If deficiency signs appear

7.3.2.2. Liquid fertilizers application

Three primary methods of applying liquid fertilizers have been used these are:

- Direct application to soil
- Application in irrigation water and
- Spraying plants with suitable fertilizer solution

Direct application to soil

Direct application of anhydrous ammonia, N solution, and mixed fertilizer to soil is rapidly increasing in developed nations. Anhydrous ammonia and pressure solutions must be injected into the soils with 15 and 5 cm depth to prevent volatilization.

Application in irrigation water

Liquid ammonia, N solution, phosphoric acid and complete fertilizers are dissolved in irrigation stream or overhead sprinkler system. The nutrients are carried into soil solution. Application cost are reduced and relatively inexpensive N carriers can be used/ Some care must be taken to prevent ammonia loss by evaporation. The use of drip irrigation systems has greatly facilitated the application of nutrients in irrigation water

Spraying plants with suitable fertilizer solution

Diluted NPK fertilizers, micronutrients and small quantity of urea can be sprayed directly onto plants, although care must be taken to avoid significant concentration of Cl^- and NO_3^-, which can be toxic to some plants. This type of fertilization is unique it does not involve extra procedures or machinery because the fertilizer is often applied simultaneously with insecticide. Pineapple and citrus trees respond well to urea because much of N is absorbed by the leaves. Moreover, drops and washed off is not lost and may be absorbed by the plants.

Factors affecting kind and amount of fertilizers

Many factors influence to reach to the decision for the kind and amount of fertilizers to be used. The deficiency or excessiveness of soil moisture, besides fertilizers are soluble salts and their effect is to lower the water potential of the soil, thus the rate of water uptake by seeds and roots is reduced. Dryness after fertilization results in a delay in fertilizer nutrient uptake because the applied nutrient cannot be transported to the roots owing to inadequate moisture. Soil reactions also determine the type and amount of fertilizer on acidic soils very low amount of fertilizer should be used.

The type of crop to be fertilized, response of the crop to the added nutrients and by economic value of the crop high valued crops will provide economic return from relatively high rate of fertilizer. Moreover, cereal crops such as corn are quite responsive to N fertilizer high rate of N are economically justified. Very high yield obtainable under fertilization may not give best return on monetary term, due to law of diminishing return of fertilization. Type of soil- soil texture and chemical properties determine the fertilizer usage. The availability of irrigation service also determines kind and type of fertilization. Fertilizers for fertigation must be readily and fully water soluble and the combined solution should be within the acidic pH range (about pH 5) in order to ensure nutrient mobility and availability. Nitrate and urea are better distributed in soils than is ammonium and, therefore, they are more suitable.

Fertilizer guarantee, inspection and control

Laws the fertilizer materials are required to insure the quality of fertilizer on its content guarantee thus the P and K contents be expressed in terms of oxides while N in total N. Fertilizer laws, regulations protect public as well as the reliable fertilizer companies by keeping products of unknown value off the market. The manufacturer is commonly required to print the following information on the bag (container) on authorized tag in the case of bulk shipments.

- The net weight of the fertilizer to a package
- Name, brand and trademark
- Chemical compositions guaranteed
- Potential acidity in terms of pound of calcium carbonate per ton
- Name and address of manufacturer

Cost-effective and environmentally sound plant nutrient management

Nutrients added through fertilizers, manures and composts can have negative as well as positive effects on the environment depending on how poorly or properly these inputs are managed. The added nutrients may be absorbed by crops, immobilized by the soil or lost from the soil system. It depends on various condition of the nutrient; these can be lost to the atmosphere by volatilization, lost through water erosion, lost from the soil profile through leaching. But, loss of N to the atmosphere through denitrification. Crop productivity is highly dependent on climatic conditions and plant nutrition management. Soils vary considerably in their potentials to retain and supply the required nutrients, thus plant nutrition management can modify the capacity of the soil to providing the essential plant nutrients for the growth of plants. A soil nutrient management plan should include analyzing soil deficiencies to determine the application type, rate and interval, and the placement of any nutrients required to optimize short and long term productivity.

The efficient use of plant nutrients ensures high yields than those obtained on the basis of inherent soil fertility and increasing yields per unit area from suitable arable land, application of plant nutrients allows land of low quality thus reduces the pressure on land (deforestation and overgrazing). However, high level uses of inputs, the applied nutrients to the soil are not taken up completely by the growing crop even under the best conditions. Out of the remaining fractions, the soil constituents are able to bind and immobilize most of them so that they do not move freely with soil water and create possible negative impacts on the environment (water and air). Nitrate and, to a lesser extent, sulphate and B are not held strongly by the soil and can leach down with percolating waters and contribute to the undesirable enrichment of water. Phosphate generally moves very little way away from the site of application. Effective management practices can prevent or remedy the negative effects of the applications of plant nutrients, both at low and high levels of input. Optimal fertilization can overcome the problem of nutrient depletion and of mining soil fertility. Judicious management of plant nutrients can prevent pollution, mainly through practices that reduce losses of nutrients into the aquifers or the atmosphere. The excessive use of inputs is not advised.

Consideration of the environmental and economic consequences of soil fertility practices is an essential component in plant nutrition. Work on soil fertility and plant nutrition often involves multidisciplinary research in other areas of soil science and plant physiology. Recommendations for amounts and application of fertilizers are continually modified to optimize economics of production as the costs of fertilizer application, the value of crop yields, and subsidy regimes change. Criteria for interpreting the results of soil testing and plant analyses are developed through field and glasshouse research that relates test results and plant composition to crop yields. Research in soil fertility and plant nutrition also covers application to the land of agricultural, municipal, and industrial wastes and by-products, atmospheric contributions to plant nutrients in soils, short- and long-term availability of plant nutrients, especially nitrogen and phosphorus, and many other factors as well as soil testing and plant analyses.

7.4. Concepts of integrated nutrient management

Crop required adequate amount of nutrients in suitable forms for their growth. Most nutrients are supplied to the root surface, particularly when nutrient demands are high at rapid growth periods. Agricultural intensification requires increased flows of plant nutrients to crops, a higher nutrient uptake and higher stocks of plant nutrients in soils. All nutrient sources should be applied at times that will maximize crop use and minimize the possibility of loss. Ideally, applications will be closely matched to crop nutrient demands. In general, nutrients should be applied at active growing period or within 30 days of planting a crop. Timing is most important factor to minimize leaching loss for application. Applying nitrogen to a sandy soil when there is no crop to remove it will almost certainly result in loss of nitrogen to the shallow ground water. There are potential human health problems when excessive levels of nitrogen reach ground water used for drinking.

Plant nutrition is only one of more than fifty factors which directly affect both crop yield and quality. The availability of required nutrients, together with the degree of interaction between these nutrients play a vital role for crop production. A deficiency in any one required nutrient or, a soil condition that limits or prevents a metabolic function from occurring can limit plant growth. The main nutritional problem, in rain fed dry land farming systems is the shortage of total and available N owing to low soil organic matter content. In order to make the best use of the scarce soil N resource at sowing time, the N requirement of the crop should be adjusted for the nitrate flush occurring from rapid mineralization at the onset of the rainy season. The natural N supply may be sufficient for low yields, e.g. 1–3 tones grain/ha. However, for medium yields, additional N sources such as farm waste materials or even mineral N should be added where there is sufficient moisture. In addition to N, the P supply is often insufficient either because to low available P in the soil or slow mobility towards plant roots. As P is especially required for root growth and as deep rooting may be decisive for crop survival during dry spells, a good P supply is important beyond its actual role as a nutrient. A good K supply is essential to reduce transpiration losses from crops.

The continuous recycling of nutrients in to and out of the soil is known as the nutrient balance, which involves complex biological and chemical interactions. The nutrient balance system has two parts: inputs that add plant nutrients to the soil and outputs that export them from the soil largely in the form of agricultural products (Fig. 8). Important input sources include application of inorganic or mineral fertilizer and organic fertilizer such as manure, plant residues, and cover crops; nitrogen generated by leguminous plants and atmospheric nitrogen deposition. Nutrients are exported from the field through harvested crops and crop residues, as well as through leaching, atmospheric volatilization, and erosion. The difference between the volume of inputs and outputs constitutes the nutrient balance. Positive nutrient balance is occurred when nutrient additions to the soil are greater than the nutrients removed from the soil, it could indicate that farming systems are inefficient and in the extreme, that they may be polluting the environment.

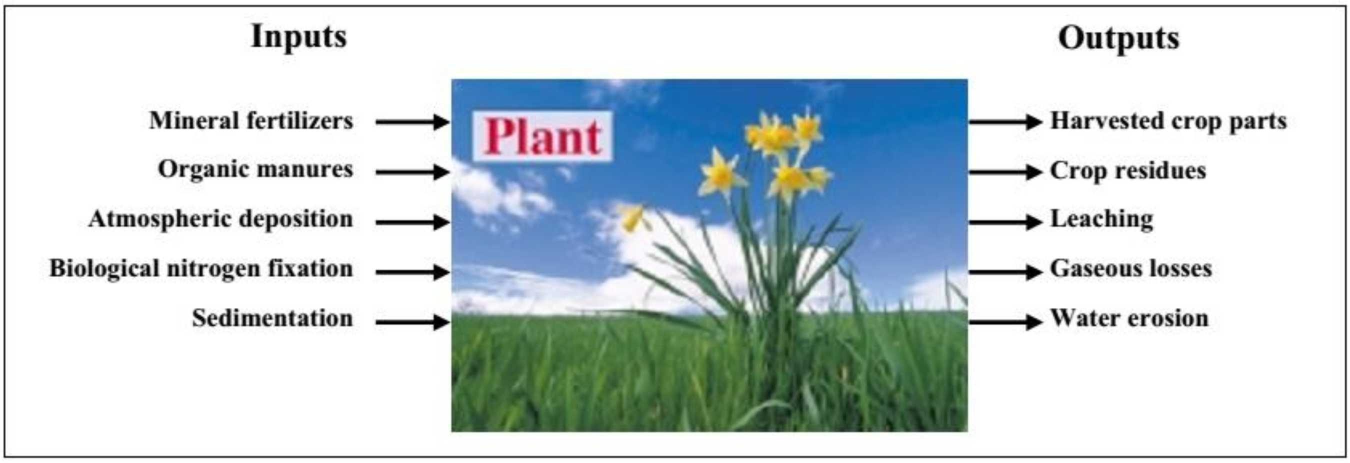


Figure 8 . Plant nutrient balance system

Negative balance could well indicate that soils are being mined and that farming systems are unsustainable over the long-term. In case of negative nutrient balance, nutrients have to be replenished to sustain agricultural outputs and to maintain soil fertility for future. Excessive use of nutrients, inefficient management of cropping systems and the inefficient use of residues and wastes result in losses of plant nutrients, which means an economic loss for the farmer. On the other hand, inadequate or insufficient use of plant nutrients creates an insidious depletion of the stock of plant nutrients on the farm, which will also mean an economic loss for the farmer. Environmental hazards can be created by applying too much nutrient compared with the uptake capacity of cropping systems, while the depletion of nutrient stocks is a major, but often hidden, form of environmental degradation. Plant nutrition management depends largely on prevailing economic and social conditions. Farmers' decisions depend on their economic situation and their socio-economic environment, on their perception of economic signals and on their acceptance of risks. Plant nutrition management can contribute to food security and to the sustainable production of agricultural goods without harm to the environment. The adoption of Integrated Plant Nutrition Systems (IPNS) which enhance soil productivity through a balanced use of local and external sources of plant nutrients in a way that maintains or improves soil fertility and is environmentally-friendly.

Integrated Plant Nutrient Management (IPNM) is based on the principles of optimizing the use of organic fertilizer, supplementing with mineral fertilizer when needed and minimizing losses of nutrients. IPNM is not only concerned with good agronomy, but its success is highly dependent on economic, social and institutional issues. IPNM seeks both increased agricultural production and preservation of the environment for future generations. The concept of INM aims to increase the efficiency of use of all nutrient sources, be they soil resources, mineral fertilizers, organic manures, recyclable wastes or biofertilizers.

Integrated plant nutrition systems (IPNS) is the maintenance or adjustment of soil fertility and of plant nutrient supply to sustain a desired level of crop production. It is achieved by optimizing the benefits from all possible sources of plant nutrients and by improving the overall management of the farm. The main objectives of IPNS are to rationalize plant nutrition management in order to:

- Upgrade the efficiency of the plant nutrient supply in terms of: (i) relationships between crop yields and the quantity of plant nutrients applied; and (ii) the adequacy of the flows of plant nutrients passing through the soil/crop system and the crop's demand for nutrients at any point in time;
- Maintain and improve the stock of plant nutrients in the soil/crop system;
- Limit plant nutrient losses;
- Provide the highest possible economic rate of return for the farmer.

By applying IPNS, farmers will improve their production capacity and income using the best combination of agronomic efficiency and economic profitability. In addition, they will have a more sustainable soil environment for crop growth.

The IPNS methodology is developed at three levels: plot, farm and village/community. Plant nutrient management at the plot level focuses on determining crop response to various application rates, times of application, forms and sources of plant nutrients. Some trials may also examine the residual effects of plant nutrients applied in previous seasons. At the farm level, it addresses the alternative sources of plant nutrients available to the farmer and suggests a suitable mix of them to fit production objectives. Finally, the village level considers the wider farming community, encompassing communal natural resources, environmental issues and farmer groups.

CHAPTER 7

CROP MANAGEMENT ON PROBLEMATIC SOILS

5.1. Crop production on problematic soils

Soil degradation, particularly soil fertility, is a major cause for the declining crop yields in most developing nations. However, soil degradation is widespread in many parts of the world. The basic causes of soil degradation are the result of intensive human activities such as deforestation, overgrazing and poor soil management. Factors that cause soil degradation are interrelated. About 1,200 million ha worldwide are considered to be affected by soil degradation, mostly by erosion. There are widespread problems of soil fertility degradation under many cropping systems even on soils with good initial soil fertility. The result of such a decline is a reduced nutrient supply, which reduces crop yields. Soil fertility problem has significant effect on declining crop production. Soil fertility problem is manifested in the forms of erosion, soil nutrient depletion, acidity, salinity and soil physical degradation.

A. Soil erosion

Soil is the most fundamental and basic resource since it vital to provides food, feed, fuel, and fiber. Essentiality of soil to human well-being is often not realized until the production of food drops or is jeopardized when the soil is severely eroded or degraded to the level that it loses its inherent resilience. Soil is a non-renewable resource over the human time scale.

Soil erosion is the wearing away of the land surface by physical forces such as rainfall, flowing water, wind, ice, temperature change, gravity or other natural or anthropogenic agents that abrade, detach and remove soil or geological material from one point on the earth's surface to be deposited elsewhere. There are two main types of erosion: geologic and accelerated erosion. Geologic erosion is a normal process of weathering that generally occurs at low rates in all soils as part of the natural soil-forming processes. Indeed, low rates of erosion are essential to the formation of soil. In contrast, soil erosion becomes a major concern when the rate of erosion exceeds a certain threshold level and becomes rapid, known as accelerated erosion. This type of erosion is triggered by anthropogenic causes such as deforestation, slash-and burn agriculture, intensive plowing, intensive and uncontrolled grazing, and biomass burning.

Soil erosion is a hazard traditionally associated with agriculture in tropical and semi-arid areas and is important for its long-term effects on soil productivity and sustainable agriculture. Water and wind erosion are two main agents that degrade soils. Water erosion affects about 56% of the total degraded land while wind erosion affects about 28% of the total degraded of the world. Water erosion removes plant nutrients through runoff. Runoff occurs when precipitation rates exceed the water infiltration rates. Both raindrop impact and water runoff can cause soil detachment and transport. Unlike wind erosion, water erosion is a dominant form of erosion in humid, and sub-humid, regions characterized by frequent rainstorms Water erosion occurs in the form of splash/inter rill, rill, gully, tunnel, stream bank, and coastal erosion. On the other hand, in saturated and supper saturated soil conditions plant nutrients removes below plant root zone through leaching.

Erosion reduces productivity by causing loss of top soils that are often very shallow and which contain most of the nutrients in the soil profile. Eroded soils are subject to higher temperatures, have lower porosity and microbial activity. Most of the organic matter is located in the top soil approximately 50% of available P and K. Soil erosion, is a major causes for loss of organic matter resulting in reduced biological activity and cause depletion of soil nutrients. Losing to soil to erosion, therefore contribute to a loss of valuable nutrients and will cause yields to decline over time. On the other hand, higher rates of runoff from eroded surfaces wastes valuable moisture—the principal factor limiting productivity in arid lands. By removing sediment, nutrients and organic matter, runoff can have an adverse effect on water quality. According to Hurni (1988) estimation soil loss rate from cultivated land of Ethiopia is 42 t ha^{1} yr^{1} but currently it reaches at alarming rate. On the other hand, excess removal of forests is contributing to land degradation.

Soil erosion problems resulted through high intensity of deforestation and overgrazing activities. Besides the expansion of agriculture to sloping, shallow, and marginal lands is a common cause of soil erosion. Intensive agriculture and plowing, wheel traffic, shifting cultivation, indiscriminate chemical input, irrigation with low quality water, and absence of vegetative cover degrade soils.

B. Chemical degradation

B.1. Nutrient depletion

Soil fertility is not a stable property but a dynamic one. Nutrient depletion and loss of soil fertility can result in environmental degradation and become worldwide concern. Soil nutrient depletion by cropping (‘soil mining’) is one of the principal biophysical causes for the downward trend of food production in many parts of the developing world. Similarly, soil-fertility depletion in smallholder farms is the fundamental problem that declining per capita food production in Ethiopia. Loss of fertility is manifested through limited recycling of dung and crop residue in the soil, low use of chemical fertilizers, declining fallow periods, soil and organic matter burning, and soil erosion. On the other hand, imbalanced fertilization is inefficient, uneconomic and wasteful.

The nutrient depletion is also aggravated by intensive cultivation, large production of yields through improved crop varieties, erosion and leaching. Whenever nutrient removal exceeds nutrient addition, the soil suffers a net depletion of nutrient reserves. With increasing human population, the production pressure on agricultural land increases and causes widespread and acute nutrient deficiencies.

Crop monoculture or continuous cropping involves the growing of a single crop at one time, year after year in the same region, can potentially result in nutrient depletion besides soil sickness, caused by the combination of the build-up of soil pathogens such as stock borer of maize. Thus, a monoculture crop usually requires large amounts of fertilizers, pesticides.

B.2. Acidity

Acid soils, which are defined by a pH lower than 5.5 in their surface layers, comprise about 30% of the total ice-free land, primarily in humid climates. Plant growth inhibition and yield reduction on acid soils results from a variety of specific chemical factors and their interactions. Soil acidity limits plant growth not only because of the deficiencies of P, Mo, Ca, Mg, etc. but also due to toxicities of Al, Mn and H ions. In acid mineral soils the major constraints to plant growth are toxicity of protons, Al and Mn and deficiency of Mg, Ca, P and Mo. Soil toxicities have been recognized as one of the most common causes of reduced yields in acid soils, however, it is not a single factor but a complex of factors that may affect the plant growth through different physiological and biochemical pathways. Toxicities of Al^{3+}, Mn^{2+} and low pH (H^+ toxicity) are important growth limiting factors associated with acid soil infertility. These toxicity factors may act independently and/or together to affect plant growth. The practice of liming acid soils to reduce phytotoxic levels of Al and Mn has long been recognized as necessary for optimal crop production in such soils. The primary reason for liming is to neutralize toxic elements in acid soils, rather than simply to raise soil pH. Liming, through addition of hydroxide (OH^-) decreases the solubility of Al^{3+}, Mn^{2+}, and Fe^{3+} (as well as Zn and Cu), causing them to precipitate as sparingly soluble silicate clays, oxides and hydroxide. Lime also supplies significant amounts of Ca and Mg, depending on the source. Indirect effects of liming include increased availability of P, Mo and B, and more favorable conditions for microbially mediated reactions such as nitrogen fixation and nitrification, and in some cases, improved soil structure. Acidic soils cannot make the best use of the nutrients applied in the absence of suitable amendments.

B.3. Salinity

Salinity problems are caused from the accumulation of soluble salts in the root zone. These excess salts reduce plant growth and vigor by altering water uptake and causing ion-specific toxicities or imbalances. The salts are white, chemically neutral, and include chlorides, sulfates, carbonates and sometimes nitrates of calcium, magnesium, sodium and potassium Salinity is measured by passing an electrical current through a soil solution extracted from a saturated soil sample. Yields of most crops are not significantly affected where salt levels are 0 to 2 dS/m. Generally, a level of 2 to 4 dS/m affects some crops. Levels of 4 to 5 dS/m affect many crops and above 8 dS/m affect all but the very tolerant crops. Saline soils cannot these problems, but salinity problems are often more complex. Proper management procedures, combined with periodic soil tests, are needed to prolong the productivity of salt-affected soils. To manage saline soils salts can be moved below the root zone by applying more water than the plant needs. This method is called the leaching requirement method.

C. Soil physical degradation

Soil physical degradation such as poor structure, compaction and crusting has great impact on soil water content finally decreasing crop production The availability of water is primary factor for crop production, Water requirement means the quantity of water needed for transpiration from the green plants, evaporation from the soil and other water losses during application. Crops require 300–800 liters of water for transpiration in order to produce 1 kg dry matter. The amount of water consumed is both plant specific and climate dependent. However, water logging is also declining or limiting crop production of the area. Most crop production undertaken out of swampy and water logged environments except rice cultivation. On poor drained soil water logging is major problem for crop yield.

5.2. Site specific cultural practices

The wide ranges of soil fertility management practices provide a chance to improve soil fertility on various problematic soils to improve soil fertility conditions. The better the fertility of a soil is understood, the more correctly it is possible to develop and adopt nutrient management strategies. Only very few soils are ideal for plant growth by nature and supply nutrients in adequate amounts for high yields. In fact, most soils are in the wide medium-fertility range and many must be considered as poor. There may be many soils with high natural fertility, but in practical agriculture, these must be seen in the context of specific requirements of the crops to produce high yields. From a practical point view, most soils can be considered as requiring some degree of intervention and amelioration.

Soil erosion prevention is far better than curing of soil erosion. Site-specific soil erosion managements has played great role on controlling the risk of erosion, thus attention should given towards protection of soil erosion through minimizing the intensity of deforestation and overgrazing activities Site-specific soil erosion managements can comprise of different mechanical and biological soil conservation methods. Mechanical soil conservation methods include contour band, deferent types of terraces and contraction of waterways. Mean while biological soil conservation comprises of using cover crop, mulching by organic residues, planting soil and water conserving plants and grass spp. However, integrating use of mechanical and biological soil conservation measures has significant impact to control soil erosion. Besides, wise resource management on cultivated lands has significant effect on soil fertility and crop production.

Fertilization of depleted land through mineral and organic sources improve soil quality and crop yield, hence site-specific fertilization enhance soil fertility. The application of fertilizers to soil to protect it from the depletion of nutrients and to enhance the environment requires several conditions to be satisfied.

Farmers use various nutrient inputs, including fertilizers and manures, to reverse nutrient depletion and increase soil productivity, food production and food security. Imbalanced fertilization is inefficient, uneconomic and wasteful, and it should be avoided. Balanced crop nutrition is not the same as balanced fertilization. For example, only soils equally poor in available N, P and K should be fertilized with these three nutrients in balanced amounts. Where a soil is rich in one nutrient, fertilization should be directed to the deficient nutrients in order to make balanced crop nutrition possible. Thus, the goal is not balanced fertilization as such but balanced crop nutrition through balanced nutrient application in order to supplement those nutrients that are deficient in the soil. Follow optimum fertilization program to avoid over-fertilization since it reduces crop yield and crop quality but also produces suboptimal economic returns.

Besides minimizing the rate of removal of nutrients from the cultivated lands improve its fertility. Application organic sources materials has also significant impact on soil-physicochemical properties. Organic materials promotes soil structure improvement thus leading to higher water holding capacity, better soil aeration and protection of soil against erosion. Moreover, organic materials influences nutrient dynamics, through mineralization process it releases ample amount of nutrients such as N, P, S and Zn. Application of organic materials can increase the microbial contents of soils besides it minimizes the toxicity of elements by its chelating effects. Residues from processed products of plant or animal origin are increasingly important as nutrient sources and lead to nutrient saving by recycling. In addition, a very wide range of products obtained from the recycling of crop, animal, human and industrial wastes can and do serve as sources of plant nutrient. A significant amount of N is made available through biological nitrogen fixation of micro-organisms either independently or in symbiosis with certain plants. On the other hand, to reduce leaching loss of nutrients on low water holding capacity soils and on humid soils split applications of N are beneficial since these soils shows low in nutrient storage capacity.

Site--specific amelioration techniques can improve soil’s chemical properties, particularly soil acidity and salinity problems. Application of soil amendment must precede fertilizer usage. On acidic soils without correcting soil pH no amount of balanced nutrient application can result in high yields or superior nitrogen use efficiency. Acidic soils can be ameliorated through liming. Management strategies for them must accomplish the dual task of neutralizing excess acidity (making the soil profile hospitable to plant roots) and correction of nutrient deficiencies. The basis for optimizing plant nutrition in such soils is provided by neutralization. Increasing soil pH by application of lime can reverse the acidity problem, since low available nutrients such as N, P, Ca, Mg, K and Mo, in contrary the toxicity of Cu, Fe, Mn and Zn minimized through liming. Application of plant-ash from burning trees may serve as a substitute to some extent. In fact, soil amendments should precede nutrient application. Once the soils have been amended, the crops grown on them can make efficient use of the nutrients applied and high yields can be obtained on a sustained basis. Selection of acid-tolerant is also beneficial where the soil cannot be acidity amended adequately.

Saline soils can be improved through proper drainage techniques while sodic or saline sodic soils either chemically treated with gypsum or combine application of gypsum with properly drainage system can alleviate the problem. Gypsum is the most commonly used amendment. The main purpose of these amendments is to remove excess exchangeable Na from the root zone, which also results in an improvement in soil physical properties. Green manuring of such soils is useful for optimizing plant nutrition and sustaining productivity. Without the amelioration of such soils, yields are low and nutrient application is wasteful. Selection of salt-or sodium tolerant crops is also beneficial where the soil cannot be amended adequately.

Water logged areas can be improved through implementation of proper drainage technologies. Otherwise, waterlogged areas should put under cultivation of rice crop. Water logging causes loss of N through denitrification of nitrate. In flooded-rice soils, nitrate levels can be kept low by placing ammonium or amide source of N, such as urea. Ammonia volatilization from urea and some ammonium-containing fertilizers is influenced by temperature, soil reaction and soil water status. Under very dry conditions, little loss occurs, and in stable wet soil conditions, ammonium remains in solution. However, where soil moisture status is intermediate, or where the soil or floodwater loses water rapidly by evaporation, volatilization of ammonia can be appreciable. This is particularly observed where urea is surface broadcast without incorporation on alkaline soils with inadequate moisture during periods of high temperature. To improve crop yields of water deficient areas supplementary irrigation is vital, besides mulching, proper agro-forestry management can improve yields on water deficient areas. Otherwise, water deficient area should be put under cultivation of drought tolerant crops to improve crop of the area.

An important measure for improving the structure and opening up the subsoil is correct tillage. Poor soil structure can be improved through application of organic matter and mulching. On other hand, applying deeper cultivation for compacted soil and mechanical destruction of surface crusted soil's layers can improve these soil problems. However, application of lime and organic manures can also improve soil structure indirectly.

Overall assignments for the groups out of 20%

Group 1 – Present the potassium (K) cycle in agricultural soil (10 points) + Mention some crop management practices that should be carried on saline soils (10 points) = (20%)

Group 2 – Illustrate the calcium (Ca) cycle in agricultural soil (10 points) + Illustrate some crop management practices that should be carried on fertility depleted soils (10 points) = (20%)

Group 3- Present the magnesium (Mg) cycle in agricultural soil (10 points) + Show the importance of constriction of mechanical structure that helps to minimize soil erosion (10 points) = (20%)

Group 4- Show the sulphur (S) cycle in agricultural soil (10 points) + Illustrate some biological soil conservation methods minimizing soil erosion (10 points) = (20%)