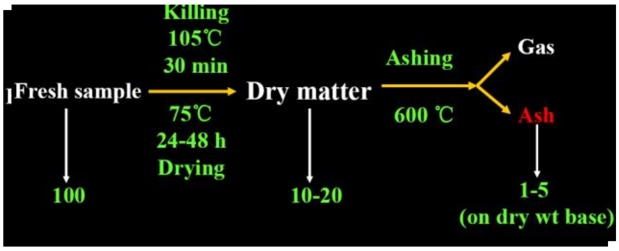
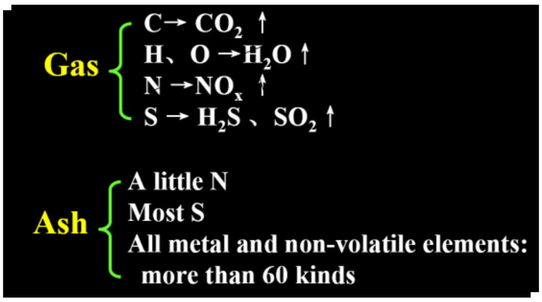
Plant Mineral Nutrition

When plant leaves and stems are dried at 70-80°C for 1 or 2 days, they will lose the water almost completely, and what is left is called the dry weight (D.W.) which usually ranges between 10-20% of the fresh weight. More than 90% of the dry weight of most plant materials consists of C, O, and H, which are the major elements of the organic compound. This means that the various elements in plant material (i.e. mineral elements) represent 10-20% (or 15% as an average) of the dry weight or about 1.5% of fresh weight (F.W.).These elements represent the mineral constituents of the plant. Most of the dry matter of plants comes from the cell walls, while the cytoplasm represents a very small ratio of the dry weight.





Discovery of essential nutrients

In 1699, John Woodward reported that spearmint grown in rainwater grew more poorly than plants grown in water with soil or rotting leaves. Water culture (hydroponic) techniques were subsequently employed to characterize the nature of how plants gained matter. In the nineteenth century, Justus von Liebig advanced the notion that soil per se was not required for plant growth, but that it contributed soluble inorganic constituents. Liebig further concluded that plants would die if their soil solution did not contain potassium, phosphate, and ammonium, postulating the essentiality of potassium (K), phosphorus (P), and nitrogen (N) many years before the fact was proven. Later scientists attempted to determine nutrient essentiality by growing plants in water containing all the elements that were thought to be essential, while excluding one nutrient of interest. A mineral that was found necessary for a plant to complete its life cycle was regarded as essential. The approach worked well for nutrients required in large amounts by plants, referred to as essential macronutrients (nitrogen, sulfur, phosphorus, calcium, potassium, and magnesium)

Methods to study the mineral requirments of plants

In 1860, Julius von Sachs, a prominent German botanist, demonstrated, for the first time, that plants could be grown to maturity in a defined nutrient solution in complete absence of soil. This technique of growing plants in a nutrient solution is known as hydroponics. Since then, a number of improvised methods have been employed to try and determine the mineral nutrients essential for plants. The essence of all these methods involves the culture of plants in a soil-free, defined mineral solution. These methods require purified water and mineral nutrient salts.

After a series of experiments in which the roots of the plants were immersed in nutrient solutions and wherein an element was added / substituted / removed or given in varied concentration, a mineral solution suitable for the plant growth was obtained. By this method, essential elements were identified and their deficiency symptoms discovered. Hydroponics has been successfully employed as a technique for the commercial production of vegetables such as tomato, seedless cucumber and lettuce. It must be emphasised that the nutrient solutions must be adequately aerated to obtain the optimum growth. Fig.1

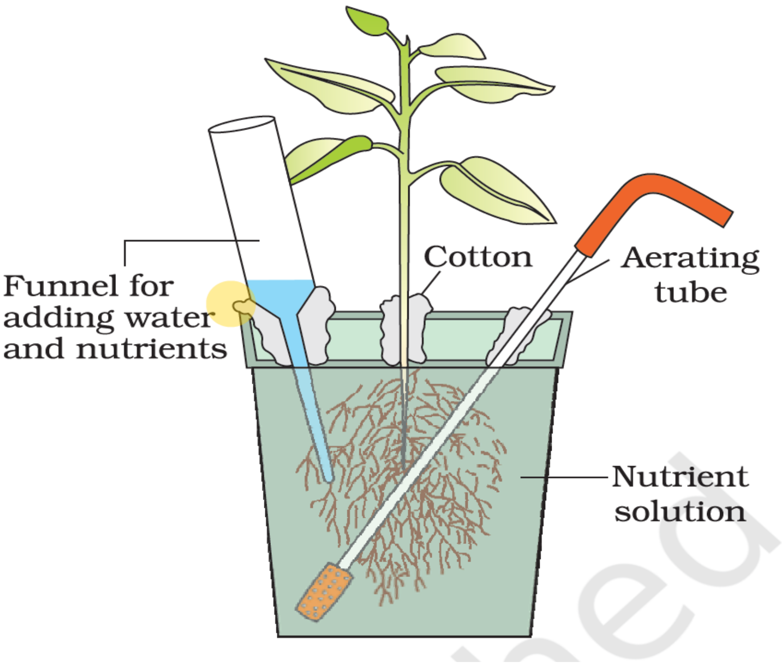


Figure 1:- Above is a diagram of a typical set-up for nutrient solution culture

The Essential Nutrient Element

The presence of any element in the plant does not necessarily mean that this element plays a major role in the life of that plant. The minerals or nutrient elements required for plant growth and differentiation are considered ***Essential Elements***.

A. According to Arnon and stout 1939, the element is considered (Essential) if one of the following cases is present:

1. The element must be absolutely necessary for supporting normal growth and reproduction. In the absence of the element the plants do not complete their life cycle or set the seeds.

2. The requirement of the element must be specific and not replaceable by another element. In other words, deficiency of any one element cannot be met by supplying some other element.

3. The element must be directly involved in the metabolism of the plant.

Or According to Epstein (1972)

1. The plant can not naturally complete its life cycle if it is absent.

2. It is a part of an essential molecule of a plant or its metabolites.

3. A third condition was added later (1989), to include that its role in plant metabolism should be direct.

For the first condition, if the plant cannot produce viable seeds in the absence of that element like (P), then that element is considered essential. For the second condition, if the element is a part of the structure of an essential molecule, such as magnesium (Mg) , for example, it will be considered as essential because it is a part of the chlorophyll molecule. Chlorine (Cl) is also essential because it is an essential element in water oxidation in photosynthesis and so on.

Based upon the above criteria only a few elements have been found to be absolutely essential for plant growth and metabolism. These elements are further divided into two broad categories based on their quantitative requirements.

1. **Macronutrients, and**
2. **Micronutrients**

1-Macronutrients: are generally present in plant tissues in large amounts (in excess of 10 mmole Kg –1 of dry matter). The macronutrients include carbon, hydrogen, oxygen, nitrogen, phosphorous, sulphur, potassium, calcium and magnesium. Of these, carbon, hydrogen and oxygen are mainly obtained from CO_2 and H_2O, while the others are absorbed from the soil as mineral nutrition.

2-Micronutrients: or trace elements, are needed in very small amounts (less than 10 mmole Kg –1 of dry matter). These include iron, manganese, copper, molybdenum, zinc, boron, chlorine and nickel. In addition to the 17 essential elements named above, there are some beneficial elements such as sodium, silicon, cobalt and selenium. They are required by higher plants.

Essential elements can also be grouped into four broad categories on the basis of their diverse functions. These categories are:

A. Essential elements as components of biomolecules and hence structural elements of cells (e.g., carbon, hydrogen, oxygen and nitrogen).

B. Essential elements that are components of energy-related chemical compounds in plants (e.g., magnesium in chlorophyll and phosphorous in ATP).

C. Essential elements that activate or inhibit enzymes, for example Mg_{2+} is an activator for both ribulose bisphosphate carboxylaseoxygenase and phosphoenol pyruvate carboxylase, both of which are critical enzymes in photosynthetic carbon fixation; Zn_{2+} is an activator of alcohol dehydrogenase and Mo of nitrogenase during nitrogen metabolism. For this, you will need to recollect some of the biochemical pathways you have studied earlier.

D. Some essential elements can alter the osmotic potential of a cell. Potassium plays an important role in the opening and closing of stomata. You may recall the role of minerals as solutes in determining the water potential of a cell.

The essentiality of micronutrients to plants can not be easily proved because their minute quantities needed by plant, can be present even in the impurities of water or salt of macronutrients. The number of micronutrients was seven, i.e. Mn, B, Zn, Cu, Mo, Fe and Cl. In addition, there are evidence that Nicle (Ni) is also essential micronutrient because it is a major constituent of the urease enzyme which is present in plants, and assist in the hydrolysis of urea into NH_3 and CO_2. Its deficiency (i.e. Ni) leads to the production of non-viable barley seeds. Hence, the total number of essential elements becomes 8.

Important note: Always remember that classification of elements or nutrients into macro and micronutrients has no relation to do with its significance. All of the elements are essential. This classification is based on the quantity or the concentration needed by plant for its normal growth.

Beneficial Elements: These are unessential elements for the growth of green plants, but they can help the growth and improve it if they are present. They can not be considered as essential elements because the plant can complete its life cycle normally in their absence, and does not affect its biological activities. Some of such elements include:

1- Sodium (Na): Beneficial element for salt-tolerant plants (Halophytes) and some others.

2- Cobalt (Co): Important for algae and microorganisms, and also important for legumes that depend on nitrogen-fixing bacteria (in nitrogen deficiency conditions), but it does not need it (i.e. Co) if nitrogen is available. This explains why no nodules are formed in legumes grown in nutrient solutions that contain an available nitrogen source.

3- Silicon (Si): Beneficial for some grasses and cereals like wheat, rice and sweet corn, where Si represent 1-2 % of the dry weight. It is also beneficial for diatoms. Si accumulates in cell walls of grass epidermis, which protect the plant from infection with fungi and also resist loadging.

The following table shows the classification of essential elements, the form in which it is present in the soil, their percentage and major function in plant.

Table 37.1 Essential Elements in Plants

Element	Form Available to Plants	% Mass in Dry Tissue	Major Functions
Macronutrients			
Carbon	CO_2	45%	Major component of plant's organic compounds
Oxygen	CO_2	45%	Major component of plant's organic compounds
Hydrogen	H_2O	6%	Major component of plant's organic compounds
Nitrogen	NO_3^-, NH_4^+	1.5%	Component of nucleic acids, proteins, hormones, chlorophyll, coenzymes
Potassium	K^+	1.0%	Cofactor that functions in protein synthesis; major solute functioning in water balance; operation of stomata
Calcium	Ca^{2+}	0.5%	Important in formation and stability of cell walls and in maintenance of membrane structure and permeability; activates some enzymes; regulates many responses of cells to stimuli
Magnesium	Mg^{2+}	0.2%	Component of chlorophyll; activates many enzymes
Phosphorus	$H_2PO_4^-$, HPO_4^{2-}	0.2%	Component of nucleic acids, phospholipids, ATP, several coenzymes
Sulfur	SO_4^{2-}	0.1%	Component of proteins, coenzymes
Micronutrients			
Chlorine	Cl^-	0.01%	Required for water-splitting step of photosynthesis; functions in water balance
Iron	Fe^{3+}, Fe^{2+}	0.01%	Component of cytochromes; activates some enzymes
Manganese	Mn^{2+}	0.005%	Active in formation of amino acids; activates some enzymes; required for water-splitting step of photosynthesis
Boron	$H_2BO_3^-$	0.002%	Cofactor in chlorophyll synthesis; may be involved in carbohydrate transport and nucleic acid synthesis; role in cell wall function
Zinc	Zn^{2+}	0.002%	Active in formation of chlorophyll; activates some enzymes
Copper	Cu^+, Cu^{2+}	< 0.001%	Component of many redox and lignin-biosynthetic enzymes
Nickel	Ni^{2+}	< 0.001%	Cofactor for an enzyme functioning in nitrogen metabolism
Molybdenum	MoO_4^{2-}	< 0.0001%	Essential for symbiotic relationship with nitrogen-fixing bacteria; cofactor that functions in nitrate reduction

Nutrient elements in the soil

If we exclude C, H and O which comes from the water and CO_2, the plant gets its nutrient elements in the form of inorganic ions from the soil (i.e. the soil is the medium for plant nutrition). Soils are greatly different in their composition, structure and amounts of nutrient elements they contain. Organic and inorganic soil particles or colloids that **adsorb the nutrient elements release it to the soil solution and becomes available for absorption** by the roots.

The clay colloidal particles are highly negatively charged, and have the tendency to adsorb cations on their surface, as well as anion exchange capacity with the soil solution and the roots. Since clay particles are negatively charged, anion exchange capacity in the soil is weak, and does not catch up by soil particle, but leached or drained down to the underground water. This explains the reason for adding the negatively charged nutrients (or fertilizers) such as nitrates (NO^-_3), in large quantities that may reach almost double the actual need of plant, because a large amount of it is drained to the under-ground water, and then to rivers.

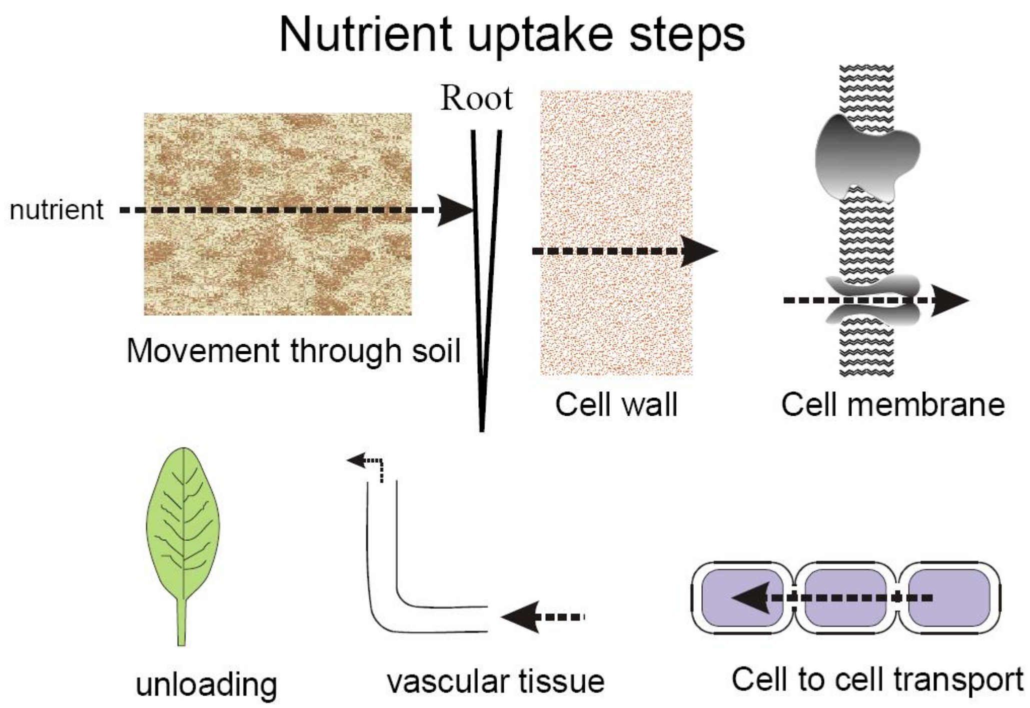
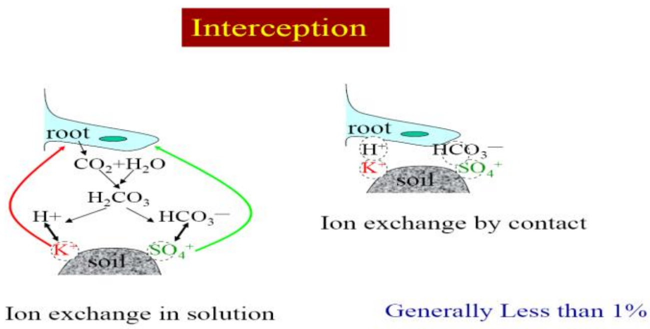
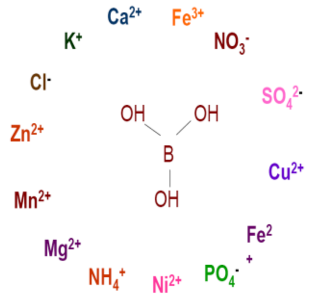


Figure 2:- shows the rout of nutriants movment from soil the leave.

<u>The rhizosphere</u>: Layer of soil surrounding the growing root that is affected by the root usually a few mm wide, up to say 1 cm (no sharp boundary).





Therefore all nutrients except Boron need membrane transporters

The ion uptake (Absorption)

Absorption of mineral elements by plant includes the movement of such element through the plasmalemma which represents the main barrier between the cell and the out side medium, since cell walls and intercellular space does not represent a barrier, and called "free or outer space ". The Volume of this free space represents 10-25% of the volume of the root tissues. The diffusion of ions between the free space and the out-side medium continues without any obstacles until it reaches equilibrium. In addition, the movement of ions from inside to the outside continues freely without obstacles also, as long as there is a concentration difference or gradient.

With the discovery of plasmalemma structure and nature, **three major concepts** were developed to explain how ions are absorbed across the plasmalemma. The three concepts include the simple diffusion, facilitated diffusion, and the active transport, and they represent the essential language of transport of ion across membranes of all living organisms.

1. **Simple diffusion**: According to Fick's low, the rate of diffusion of molecules in a solution from one region to another depends on the difference in concentration. Since the cellular membranes are characterized with lipid nature, the non-polar solute molecules tend to pass or cross the membranes faster. The number of biologically important non-polar molecules is low (i.e. only three: O_2, CO_2 and NH_3) and they have the ability to pass through the lipid bilayers of the cellular membranes,fig.3

2. **Facilitated diffusion**: As mentioned earlier, the polar solute molecules or ions can not pass the lipid bilayer. The charge and high degree of hydration makes the ion non-soluble in lipids. This prevent the entrance or passing of ions through the hydrocarbon layer of the membrane. The cellular membranes contain a large number of proteins. Many of these proteins serves as transport proteins and some of these transport proteins facilitate the diffusion of solutes (especially the charged molecules or ions) into the cell by overcoming the problem of dissolution, fig.3

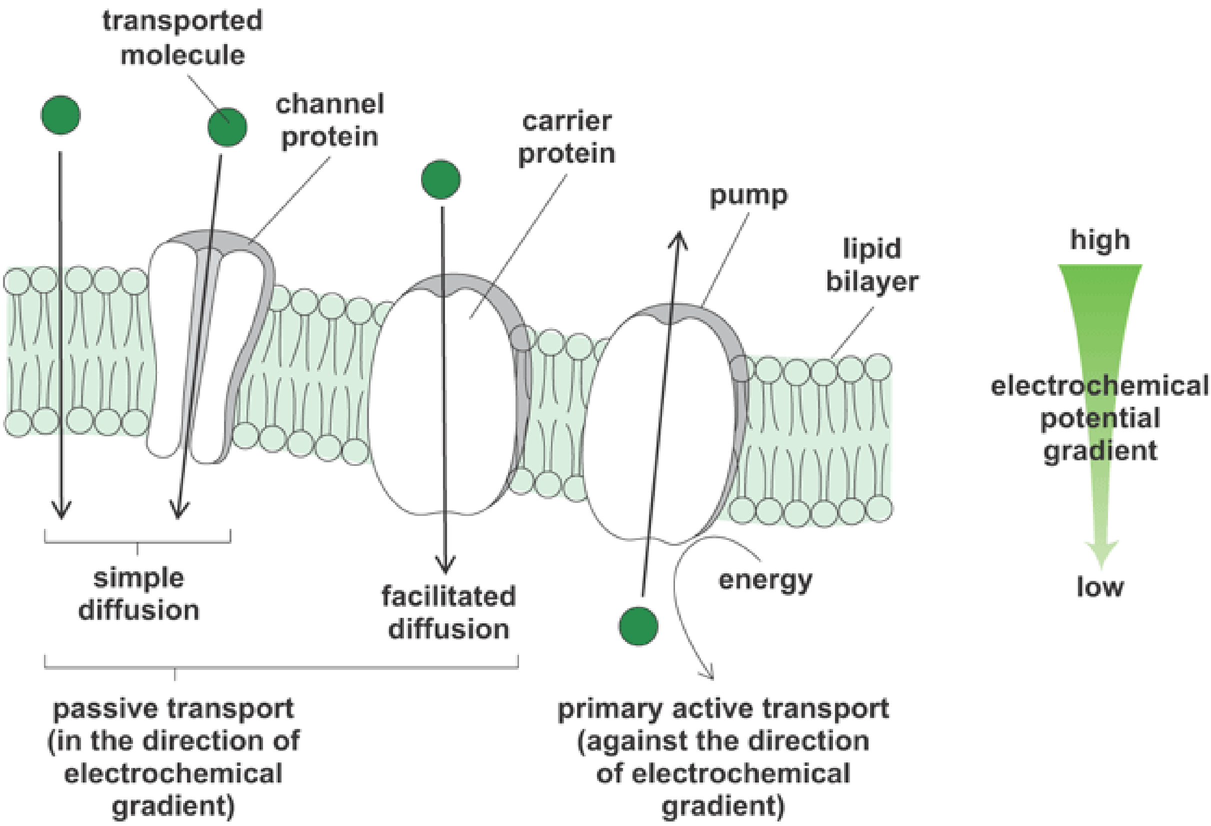


Figure 3:- General schematic of membrane transport proteins: channels, carriers, and pumps.

The term facilitated diffusion is used to describe the process of facilitating the fast diffusion of molecules across the membranes. The direction of facilitated diffusion is determined by the concentration gradient for non-polar molecules, or by electrochemical gradient for polar molecules or ions.

It should be mentioned here that transport by diffusion (both simple and facilitated) is a negative or (passive process) and does not need metabolic energy. The source of diffusion energy comes from the concentration or electrochemical gradient of the transported (or absorbed) substances. Therefore, absorption by diffusion does not lead to the accumulation of substances or ions against the electrochemical gradient.

The major **characteristics** of passive absorption are:

A- Does not need metabolic energy to take place.
B- Reversible: This means that the ions enter and get out as needed (directional).
C- Not selective: Does not differentiate between ions.

Transport protein: Carriers and channels

There are two groups of transport proteins:

1.Carrier proteins: It is also called (carriers) or transporters. They combine specific ions (i.e. each carrier is specific to a specific ion) in a way similar to that of the enzyme-substrate conjugation. Conjugation between the ion and the carrier leads to initiate changes in the shape of the protein which transfers the ion to the other side of the membrane. Liberation of ions to the surface of the other side of the membrane means the completion of the transport (absorption) process. The carrier protein goes back to its original shape to be ready to pick up another ion.

2. Channel proteins: These are proteins that form channels, charged and filled with water that extends through the membrane. These channels are usually recognized by specific ions that can go through them, and this depends on the hydrated size of the ion and its charge. Usually, there are "gates" in these channels that open or close according to the size and charge of the ion. The mechanism of opening and closing of these channels is still unknown; however, it is believed that three-dimensional changes in protein configuration take place. All protein channels and several carriers allow the ions to pass by facilitated diffusion. The significance of carrier proteins relies in their selectivity (i.e. select the molecule or ion that is allowed to pass into the cell or get out of it). The channel protein significance, however, is recognized when a large amount or quantity of molecules, especially charged molecules or ions should be absorbed quickly. A single channel may allow the passage of about 10^8 molecules or ion per second, as compared to 10^4- 10^5 molecules or ion per second in case of carrier protein.

3. Active transport (uptake): - Several absorption processes, usually fast and specialized leads to ion accumulation inside the cell (vacuoles). Accumulation leads to an increase in the concentration or electrochemical gradient, however absorption proceeds against the gradient. Such absorption is known as "active uptake ". It is a non-simultaneous absorption, needs metabolic energy, takes place in one direction, and always takes place through carrier proteins which means it is specialized absorption (selective). Since active transport takes place against a concentration or electrochemical gradient, it is usually called the process of pumping (or pumps),fig4

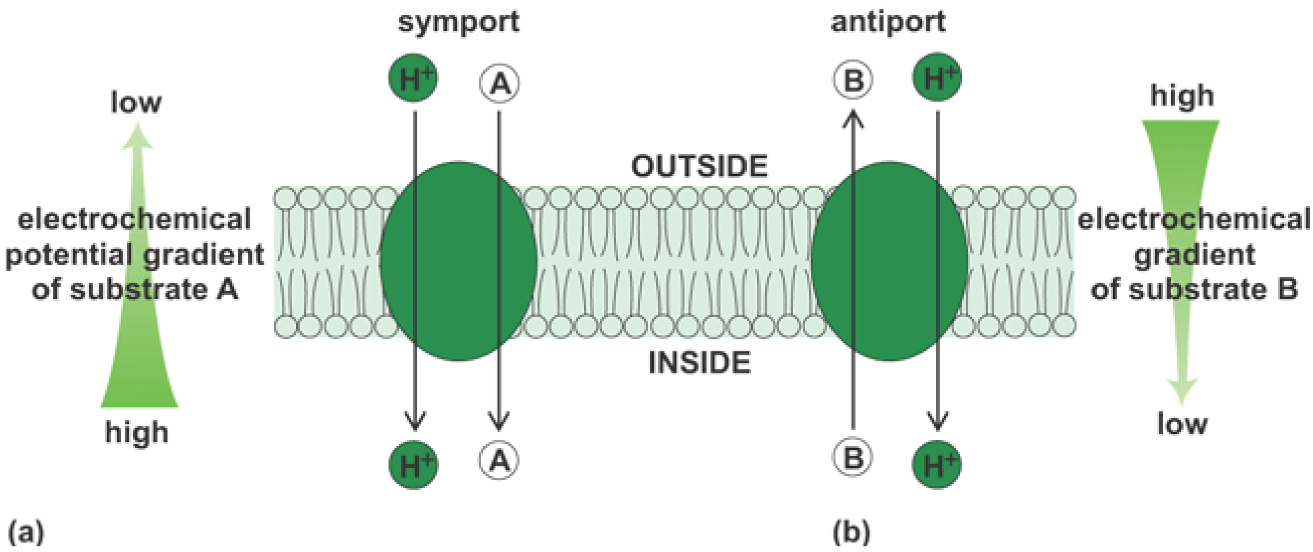


Figure 4:- shows Two examples of secondary active transport: (*a*) symport and (*b*) antiport.

Chemical potential

When discussing potential across a membrane, chemical potential drives ion movement, is determined by both a concentration gradient and by an electrical gradient = electrochemical potential. This means that ions can move against a concentration gradient if a voltage is applied. All living cells maintain an asymmetric ion distribution across the plasma membrane, which results in electrical potential across the membrane or membrane potential.

Absorption of nutrients by plants

In order to utilize mineral nutrients for metabolism, plants must be able to absorb them and distribute them to organs within the plant. One challenge faced by plants is extracting nutrients in the correct proportions required for energy, metabolism, and growth. In most cases, nutrients are present in the soil solution in concentrations that are vastly different from the concentrations required within the plant. Plants can absorb nutrients to much higher concentrations than those in the surrounding growth substrate. For example, phosphorus concentration in soil solution commonly varies from 0.0015 to 0.15 ppm. Yet, in many plants, an adequate phosphorus concentration is more than 10,000 times greater (2000 ppm). Plants must also actively select the specific nutrients to absorb. The seaweed kelp grows in a solution that contains 10,000 ppm sodium and 400 ppm potassium. Through selective absorption, the primary cation within kelp is potassium at 8000 ppm, whereas the tissue sodium concentration is 1150 ppm. These examples illustrate that plant membranes must efficiently and selectively absorb nutrients and hold them within the plant, often against steep concentration gradients

Absorption of nutrients into cells

The plasma membrane, consisting of a double layer of lipids and associated proteins, provides a physical barrier between plant cells and the environment. For mineral nutrients passing from a solution into a plant cell, two phases are noticed. First, nutrients can reversibly enter the space within and between cell walls. For cations, a large quantity of nutrients can be adsorbed into this space, as cations readily displace hydrogen ions associated with cell wall materials. Second, to enter a cell, mineral nutrients must be transported across the plasma membrane. Once inside a cell, nutrients can remain in the cytoplasm, move into organelles such as chloroplasts or mitochondria, or cross the internal cellular membrane (tonoplast) into the vacuole

Energetics of nutrient transport

In some cases, molecules can be transported across a plasma membrane via diffusion, which is passively down a concentration or chemical gradient. Diffusion is enhanced by two types of transmembrane proteins: channels serve as selective pores, whereas carrier proteins bind the molecule on one side of the membrane and release it on the other side. If ions are used quickly once they cross into the cytoplasm (such as incorporation of phosphate into nucleic acids), then the driving force for diffusion may be maintained.

As alluded to earlier, membrane transport often occurs against the potential of an energy gradient. In this case, energy is required to drive nutrient transport. Protein “pumps” located in the plasma membrane use energy from adenosine triphosphate (ATP) or other sources to actively transport nutrients against their gradient of electrochemical potential. A proton pump, termed the plasma membrane H +-ATPase, is responsible for maintaining an electrochemical potential gradient within the cytoplasm. The H +-ATPase uses energy from ATP hydrolysis to extrude H+ protons into the apoplast (the extracellular space in plants surrounded by cell walls) to maintain a gradient in pH and electrochemical potential. The pH of the cytoplasm is commonly 7.3–7.6, whereas the pH in the apoplast is typically 5.5. Similarly, protons are extruded from the cytoplasm into the vacuole (where pH can range from 4.5 to 5.9). A second class of active transporters uses energy stored from the pH gradient, called the proton motive force, to transport nutrients against their gradient of electrochemical potential. Following this line, anions such as chloride and nitrate can enter the cytoplasm via a symporter, which couples the energy from allowing a proton back into the cytoplasm with the energy required to move the anion against the electrochemical gradient (Fig. 3). Likewise, sodium can be extruded from the cytoplasm using a Na^+-H^+ antiporter, which couples the energy required to move the cation, Na^+, out against its electrochemical gradient with the energy gained from allowing a H^+ ion into the cytoplasm

Soil supply of nutrients to roots

While aquatic plants absorb mineral nutrients throughout their surface, and some agronomic crops are supplied with foliar fertilizers, the vast majority of nutrients ending in plant cells must be extracted from the soil by the plant roots. As roots grow through and displace soil, they can directly intercept available nutrients; however, this is not the primary mechanism of nutrient supply. Mass flow is a transpiration-driven process, whereby water and dissolved nutrients flow convectively to roots. Under a high soil solution concentration (as occurs for nitrate and magnesium) and sufficient water flux, supply via mass flow can be substantial. Diffusion, or the movement of mineral nutrients along a concentration gradient, is the other major mechanism for nutrient supply to roots. As roots absorb nutrients along their surface, the surrounding soil solution becomes depleted, thus maintaining a concentration gradient that drives the movement of nutrients to roots. Certain nutrients, including phosphate and potassium, are adsorbed strongly by soil particles and thus do not diffuse readily across long distances in the soil solution. For these nutrients, the growth of new roots and root hairs is essential if the plant is to access sufficient nutrients in the soil volume.

Absorption of nutrients into roots

Nutrients that are absorbed into the roots of plants have important effects on root growth and morphology, as well as influencing root and rhizosphere reactions.

Root growth and morphology

As young roots grow, the meristematic region of the root tip is composed of cells that divide to form new root cells (Fig. 4). Behind the root meristem, cells elongate and begin to differentiate. Progressing farther up the root, older cells continue to differentiate and mature, and eventually suberization (infiltration of plant cell walls by suberin) and lignification (deposition of lignin in plant cell walls) of cortical and endodermal cells reduces their permeability to water and ions. Hence, as roots age, their capacity for nutrient uptake declines because of this deposition of waxy layers, the sloughing off of old and fine roots, and reductions in metabolic uptake. The majority of mineral nutrients are absorbed in a region of the root where xylem elements are mature, but are not enclosed by impermeable outer layers (Fig. 5).

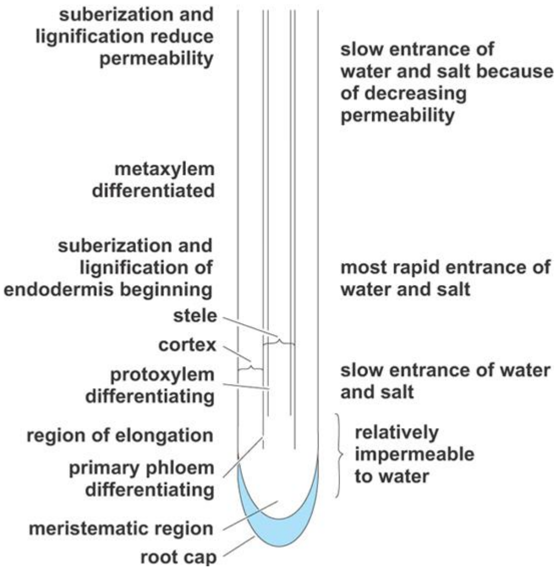


Figure 5:- Diagram of a young root, showing the relation between anatomy (left) and regions that absorb water and salt (right).

The cytoplasmic regions of plant cells are interconnected via plasmodesmata, which are microscopic channels that form a continuous body referred to as the symplast. Water and solutes within the cytoplasm can move freely from cell to cell through osmosis/diffusion across the symplast without having to cross the plasma membrane. Outside the plasma membrane, the apoplast is another continuous body formed from a network of cell walls and extracellular spaces. Water and nutrients can move readily from the soil solution through the apoplast, except where, as at the endodermis, the cell walls are impregnated with waxes. The endodermis thus restricts the apoplastic movement of water and nutrients to the xylem. To enter the xylem for transport to the rest of the plant, mineral nutrients must pass through a plasma membrane (that is, symplastic absorption) external to the endodermis (Fig. 6). Once in the symplasm, nutrients can pass through the endodermis and into parenchyma cells surrounding the xylem. Here, nutrients are extruded into the xylem cells, which are dead at maturity (that is, directly connected to the apoplast), where nutrients enter the transpiration stream and move up to leaves. The mechanisms of nutrient transport noted earlier are involved in this regard: transport into the cytoplasm to enter the symplast and extrusion out of the cell to enter the apoplast. Some nutrients, such as calcium, are primarily absorbed apoplastically in regions of the root where the endodermis is unsuberized. For these nutrients, the maintenance of young, unsuberized root tips and an active transpiration stream is particularly important to drive influx into the xylem via mass flow.

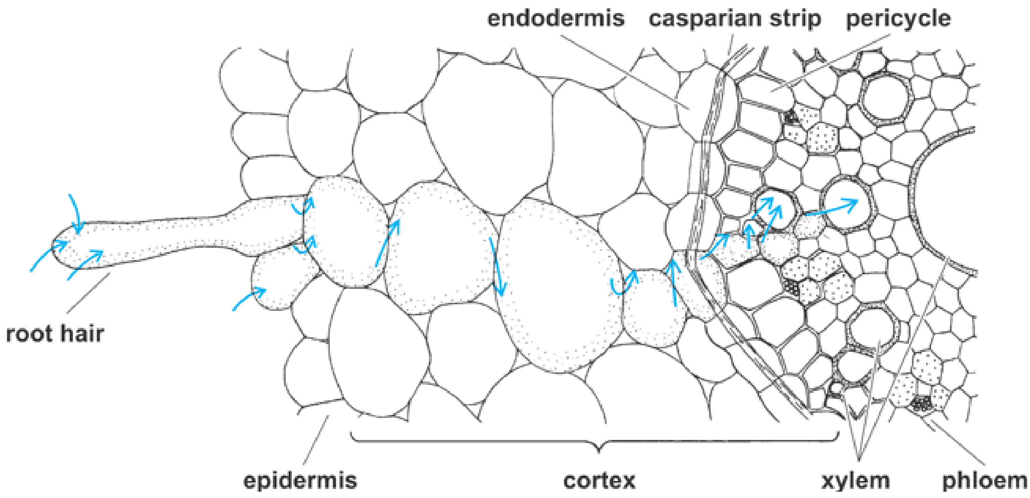


Figure 6:- Part of a wheat root transaction in the region of mineral absorption and transport to xylem (pathways denoted by arrows).

Root and rhizosphere reactions

Plant roots interact with the surrounding environment by excreting ions to control the pH of the rhizosphere (the volume of soil around living plant roots that is influenced by root activity). This, in turn, affects the exchange of mineral nutrients from soil particles to the soil solution. Root excretion of organic compounds can form molecular complexes that enhance the capacity for nutrient absorption, as in the case of iron-chelating complexes (siderophores) formed by grass roots

Some soil bacteria convert atmospheric nitrogen (N2) into a form suitable for plant use, through the process referred to as nitrogen fixation. These bacteria may be free-living in the soil, may be loosely associated with roots, or may form a close symbiotic relationship with roots (such as the one that exists between leguminous plants and *Rhizobium*).

Mycorrhizal root structures, arising from a symbiotic relationship between roots and fungi, contribute significantly to the ability of roots to obtain nutrients that are scarce in the soil solution (such as phosphorus). The majority of plant species form mycorrhizal relationships.

Xylem transport

Nutrients absorbed by the root are loaded into the xylem, where they travel with water in the transpiration stream to stems and leaves (Fig. 6). As the xylem sap reaches the leaf, parenchyma cells surrounding the xylem extract mineral nutrients from the sap. The process followed is again related to protein carriers this time moving nutrients from the apoplast across the cell membrane into the cytoplasm. While the loading and offloading of the xylem are active processes, the rate of water flow to a leaf driven by transpiration also has some bearing on nutrient translocation. For example, organs with poor transpiration may suffer from calcium deficiency even when calcium is adequately supplied to the root, fig7

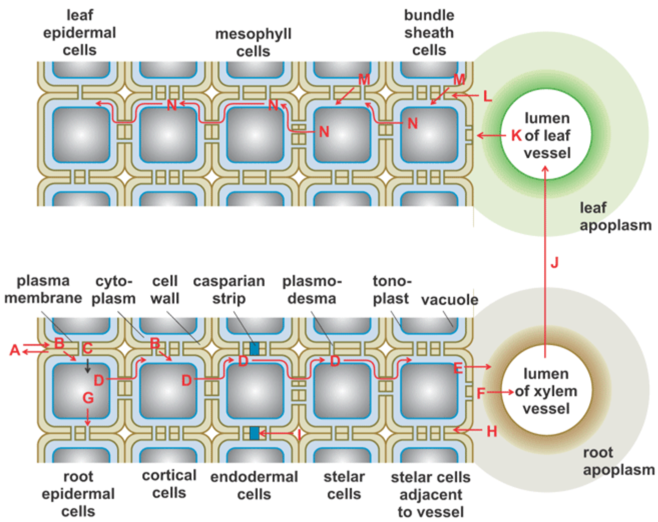


Figure 7:- The movement of inorganic nutrients: (A) from the soil solution, (B–D) across the root into a vessel in the central vascular stele, (E–J) through a xylem vessel, and (K –N) into the cells of a leaf.

Phloem translocation

As sugars and other metabolites are synthesized in leaves, they are transported in the phloem to sink organs (such as roots, fruits, and developing leaves) to fuel the maintenance and growth of cells. Certain mineral nutrients (nitrogen, phosphorus, potassium, sulfur, and magnesium) can also be readily transported in the phloem. The transportable nature of phloem-mobile nutrients is associated with their incorporation into organic compounds that move in the phloem. For example, nitrogen is incorporated into amino acids that are phloem-mobile. Calcium and (in most plant species) boron are not phloem-transportable (referred to as phloem-immobile). The remaining nutrients are intermediate in mobility. The physiological advantage of phloem-mobile nutrients is that they do not need to be continuously supplied from the soil to developing tissues because they can be retranslocated from more mature organs. Likewise, the remobilization of nutrients from senescing leaves is an important mechanism for capturing nutrients for subsequent reuse by the plant.

Nutrient deficiencies and toxicities

The proper concentrations of nutrients are critical for the processes involved with plant growth and metabolism.

Nutrient deficiency

The concentration in dry matter of a given nutrient required for adequate plant growth and metabolism varies from 0.05 to 15ppm. When a nutrient in plant tissue gos below the concentration required for optimal growth, that nutrient is said to be deficient. The metabolic processes that are directly dependent upon the nutrient and the resultant processes are slowed in plant tissue, reducing overall plant growth (Fig. 8).

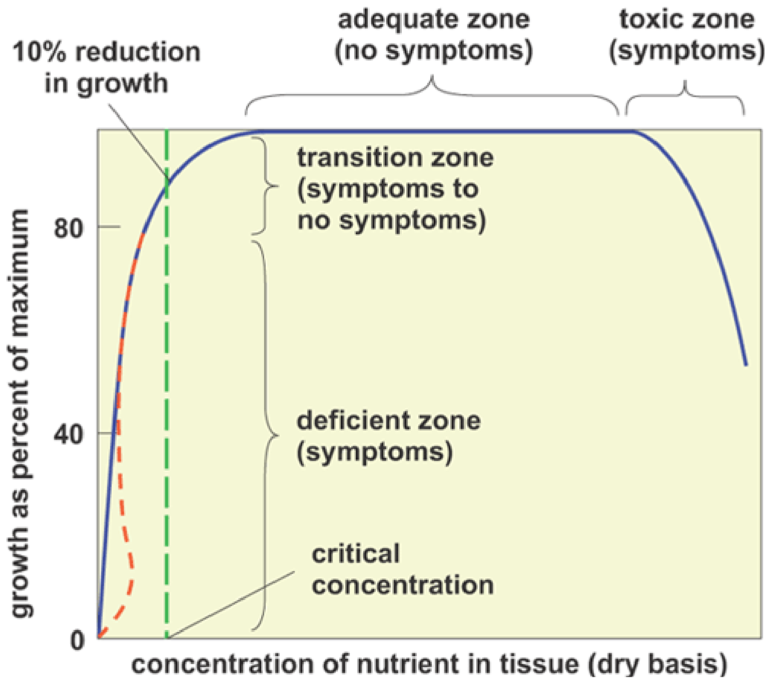


Figure 8:- Plant growth in response to changes in tissue nutrient concentration.

High concentrations of salts in the soil solution or irrigation water can impose osmotic stress, whereby the plants water potential is depressed to such an extent that the plant cannot absorb sufficient water to grow. Plants can partially offset this effect via several mechanisms, including ion sequestration, salt excretion, and production of osmolytes, to counter the water potential difference and maintain turgor. Plants also increase production of osmoprotectants, which help maintain stable hydration of membranes and enzymes exposed to osmotic stress. Soil salinization is estimated to reduce crop productivity on more than one-third of the world's irrigated agricultural land.

Nutrient deficiencies

Mineral nutrient deficiencies occur when the concentration of a nutrient decreases below this typical range. Deficiencies of specific nutrients lead to specific visual, often characteristic, symptoms reflective of the role of the nutrient.

Mineral nutrient status

According to the extent of mineral incorporation into a plant ,three basic nutritional states can be distinguished :-

1. Deficiency
2. Adequate supply
3. Unfavorable excessat nutrient in plant metabolism.

The elimination of minerals

The ascending sap carries minerals into shoot were they gradually accumulated. Most of the deposited mineral substances are eliminated in the course of shedding of various parts of plant like inn leaves and bark thus provide a necessary process of elimination in perennial plants. Minerals also are removed as components of various materials eliminated by the plant.

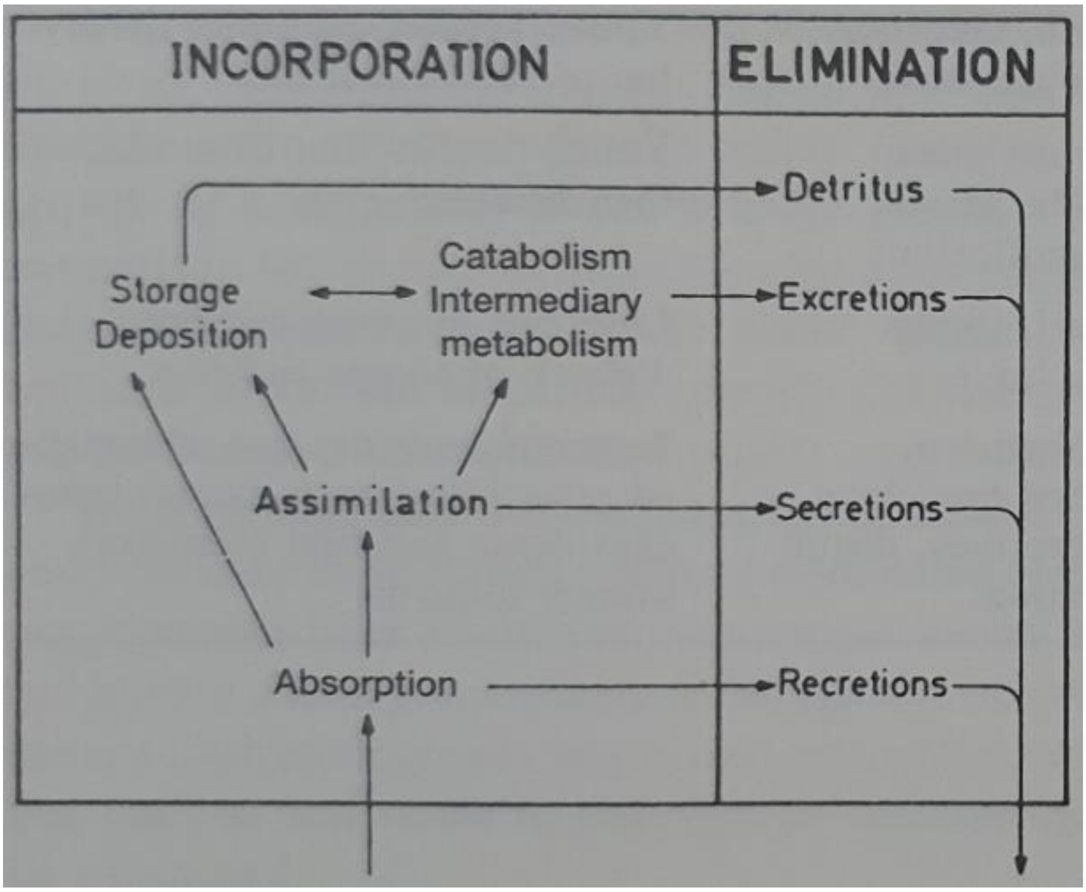
Three process of direct elimination can be distinguished.

1. **Excretions :-** is the removal of the following substances:
   toxic materials, waste products of metabolism, excess substances from organisms. Plants need to excrete excess carbon dioxide and oxygen. Carbon dioxide is a waste product of aerobic respiration in plant cells. Oxygen is a waste product of photosynthesis.

2. **Secretions :-** transfer of certain intermediate or end products of metabolism from one region to another within the cell or out of the protoplast to another part of the plant body. The delivery of proteins to the apoplast
   or protein secretion is an essential process in plant cells. Proteins are secreted to perform various biological functions such as cell wall modification and

defense response.

3. **Recretions:-** is the elimination of minerals in the form in which they where taken up, like the salts removal via whole plant body be washed away by rain ,K,Na, Mg, Mn are easily leached out.



Immobile metals are not easily metabolized or transported minerals. Deficiencies in the soil can be restored by adding fertilizer. Mineral deficiency can occur when the minerals are inaccessible to the plant due to alkaline or acidic pH.

Soil pH and the Availability of Plant Nutrients.

Soil pH is a characteristic that describes the relative acidity or alkalinity of the soil.

Technically, pH is defined as the negative (-) log or base 10 value of the concentration of hydrogen ions (H+). Pure water will be close to a neutral pH, that is 10 to the minus 7 concentration of H+ ions (10-7 [H+]). This concentration is expressed as 7. Any value above 7 means the H+ ion concentration is lower than at a neutral pH and the solution is alkaline and there are more hydroxyl (OH-) ions present than H+ ions. Any value below 7 means the H+ ion concentration is greater than at neutral pH and the solution is acidic. Soils are considered acidic below a pH of 5, and very acidic below a pH of 4. Conversely, soils are considered alkaline above a pH of 7.5 and very alkaline above a pH of 8. Typically, soil pH values are measured when 10 g of air-dried soil is mixed with 20 ml of double-distilled water or 20 ml of 0.01 M $CaCl_2$ solution, and the pH is measured using an appropriate electrode connected to a pH meter. This soil analysis is a regular part of most if not all soil test protocols.

The availability of some plant nutrients is greatly affected by soil pH.

The "ideal" soil pH is close to neutral, and neutral soils are considered to fall within a range from a slightly acidic pH of 6.5 to slightly alkaline pH of 7.5. It has been determined that most plant nutrients are optimally available to plants within this 6.5 to 7.5 pH range, plus this range of pH is generally very compatible to plant root growth.

Nitrogen (N), Potassium (K), and Sulfer (S) are major plant nutrients that appear to be less affected directly by soil pH than many others, but still are to some extent. Phosphorus (P), however, is directly affected. At alkaline pH values, greater than pH 7.5 for example, phosphate ions tend to react quickly with calcium (Ca) and magnesium (Mg) to form less soluble compounds. At acidic pH values, phosphate ions react with aluminum (Al) and iron (Fe) to again form less soluble compounds. Most of the other nutrients (micronutrients especially) tend to be less available when soil pH is above 7.5, and in fact are optimally available at a slightly acidic pH, e.g. 6.5 to 6.8. The exception is molybdenum (Mo), which appears to be less available under acidic pH and more available at moderately alkaline pH values.

In some situations, materials are added to the soil to adjust the pH.

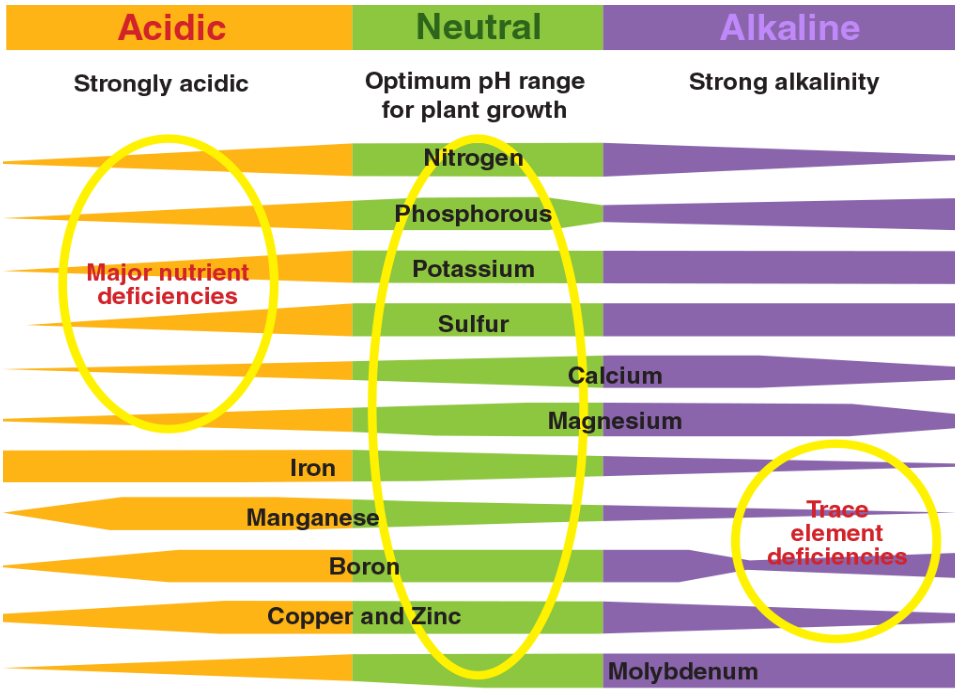
On a field scale, this is most commonly done for acidic soils to raise the pH from 4.5 to 5.5 up to 6.5 or approaching neutrality. This is done by applying and incorporating a liming material, often finely ground calcitic limestone or dolomitic limestone, that is spread using specialized lime spreaders, or spin-spreaders adapted with vibrating systems to prevent bridging of the material in the hoppers of the spreaders. It is possible to lower the pH of a soil using a liquid acid solution, or finely ground elemental S that oxidizes to sulfuric acid through the action of soil inhabiting S-oxidizing bacteria. However, this is rarely done on a field-scale basis because of the high cost. It is more commonly done in horticulture production applications where individual plant containers or limited areas (e.g. <10 to 20 acres) are managed to lower the pH for acidic soil adapted plants such as some flowers, trees, and/or small fruits (i.e. blueberry and cranberry). It is important to note that most on-going crop production will gradually lower the soil pH as the H+ ions are released and converted over to nitrate by soil microbes. This is especially true where N fertilizers such as anhydrous ammonia, ammonium sulfate, and urea are applied.

Whether or not you try to adjust pH, it is important to understand other methods to increase the availability and use of added nutrients.

This can be done in a number of ways for the nutrients mentioned above that are adversely affected by extremes in soil pH, acidic or alkaline. For example, P-containing fertilizer can be applied in or close to the seed-row at planting to facilitate early season uptake of phosphate ions by crop roots before allowing it to react with soil cations that dominate under acidic or alkaline soil pH conditions. Under alkaline soil pH values, the phosphate fertilizer can be applied in bands with fertilizer which generates an ionized form of ammonia (NH_4). That will allow slight acidification of the soil adjacent to the fertilizer band. Another method is to manufacture compound nutrient fertilizer granules that contain the N, P, and even elemental S-containing fertilizers, for application to alkaline soils. The soil adjacent to the granule will also be acidified slightly and allow enhanced P uptake when the crop roots intercept the granules. Yet another example is the foliar application of soluble Fe fertilizer compounds to Fe-deficient crops grown in high pH soils where the fertilizer react so fast with soil that the nutrient is tied up and unavailable to plants. This is why soil applied Fe fertilizers often do not successfully correct Fe deficiencies. By avoiding the soil and applying the Fe to the leaves, the small amount of plant-required Fe is successfully introduced into the crop.

<table>
<tr><th>Soil pH</th><th>Plant Growth</th></tr>
<tr><td>> 8.3</td><td>Too alkaline for most plants</td></tr>
<tr><td>7.5</td><td>Iron availability becomes a problem on alkaline soils</td></tr>
<tr><td>7.2</td><td rowspan="4">6.8 to 7.2 – near neutral
6.0 to 7.5 – acceptable for most plants</td></tr>
<tr><td>7.0</td></tr>
<tr><td>6.8</td></tr>
<tr><td>6.0</td></tr>
<tr><td>5.5</td><td>Reduced soil microbial activity</td></tr>
<tr><td>< 4.6</td><td>Too acid for most plants</td></tr>
</table>

(Source: Colorado State University – CMG Garden Notes #222)



Soil pH and Nutrient Availability

Q:- How are mineral nutrients acquired by plants?

1. Uptake through the leaves. Artificial: called foliar application. Used to apply iron, copper, and manganese.
2. Associations with mycorrhizal fungi. Fungi help with root absorption
3. Uptake by the roots

Q:- Why should root tips be the primary site of nutrient uptake?

*Tissues with the greatest need for nutrients. Cell elongation requires Potassium, nitrate, and chlorine to increase osmotic pressure within the wall. Ammonium is a good nitrogen source for cell division in the meristem. Apex grows into fresh soil and finds fresh supplies of nutrients.