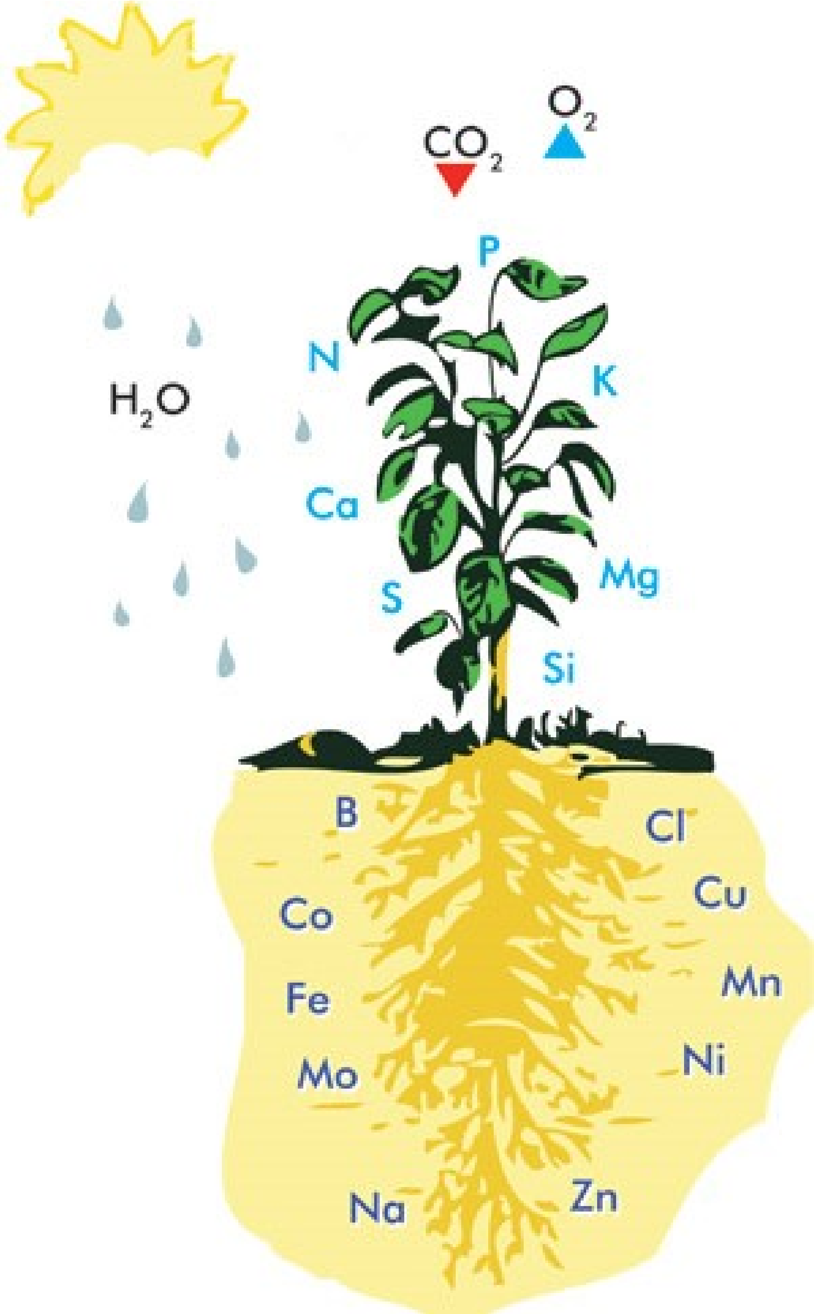
Plant Physiology

Princy



Mineral absorption

- Mineral nutrients are elements such as nitrogen, phosphorus, and potassium etc. that plants acquire primarily in the form of inorganic ions from the soil.

- Although mineral nutrients continually cycle through all organisms, they enter the biosphere predominantly through the root systems of plants, so in a sense plants act as the "miners" of Earth's crust.

- The large surface area of roots and their ability to absorb inorganic ions at low concentrations from the soil solution increase the effectiveness of mineral absorption by plants.

- After being absorbed by the roots, the mineral elements are translocated to the various parts of the plant, where they are utilized in numerous biological functions.

- Other organisms, such as mycorrhizal fungi and nitrogen-fixing bacteria, often participate with roots in the acquisition of mineral nutrients.

- **The study of how plants obtain and use mineral nutrients is called mineral nutrition.**

- Only certain elements have been determined to be essential for plants.

- **An essential element is defined as one that is an intrinsic component in the structure or metabolism of a plant or whose absence causes severe abnormalities in plant growth, development, or reproduction**.

- If plants are given these **essential elements**, as well as **water** and **energy from sunlight**, they can synthesize all the compounds they need for normal growth.

- Essential mineral elements are usually classified as

  macronutrients

  micronutrients **(**required in small amounts **)**

- according to their relative concentrations in plant tissue.

Macronutrients	*Micronutrients/trace elements*
1. Carbon	1. Boron
2. Hydrogen	2. Chlorine
3. Oxygen	3. Copper
4. Nitrogen	4. Manganese
5. Phosphorus	5. Molybdenum
6. Sulphur	6. Zinc
7. Potassium	
8. Calcium	
9. Magnesium	
10. Iron (some workers consider Fe as trace element)	

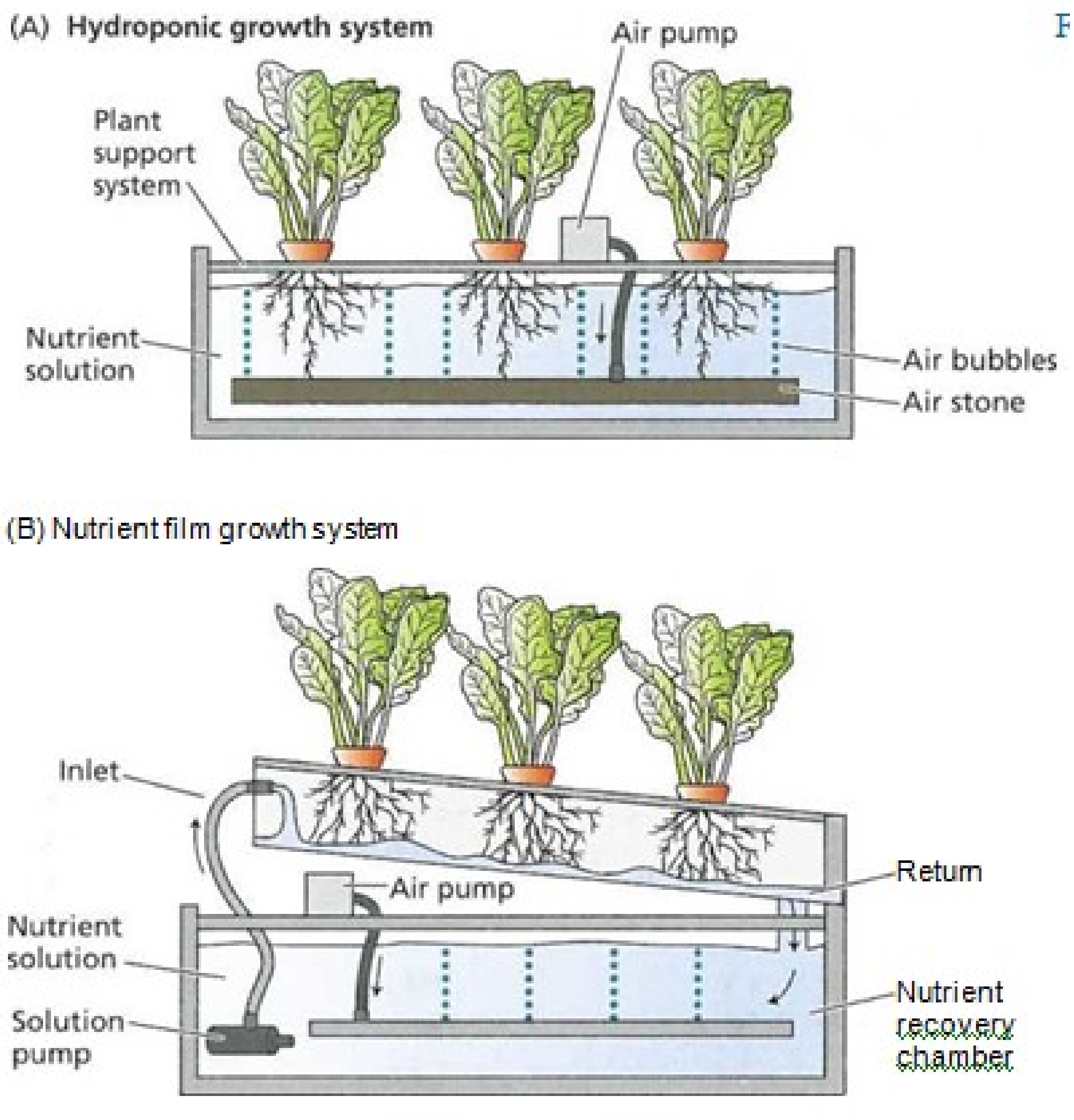
Special techniques are used in nutritional studies

- To demonstrate that an element is essential requires that plants be grown under experimental conditions in which only the element under investigation is absent.

- Such conditions are extremely difficult to achieve with plants grown in a complex medium such as soil.

- In the nineteenth century, several researchers, approached this problem by growing plants with their roots immersed in a **nutrient solution** containing only inorganic salts.

- Their demonstration that plants could grow normally with no soil or organic matter proved unequivocally that plants can fulfill all their needs from only inorganic elements, water, and sunlight



- Using the technique of "**solution" or "water" culture**, it was established by Sachs, Knop and other late nineteenth-century investigators, that, in addition to **carbon**, **hydrogen** and **oxygen**, seven elements are universally essential for plant growth. These are nitrogen, phosphorus, sulphur, potassium, calcium, magnesium and iron.
- Acid soils where the amount of calcium is low.

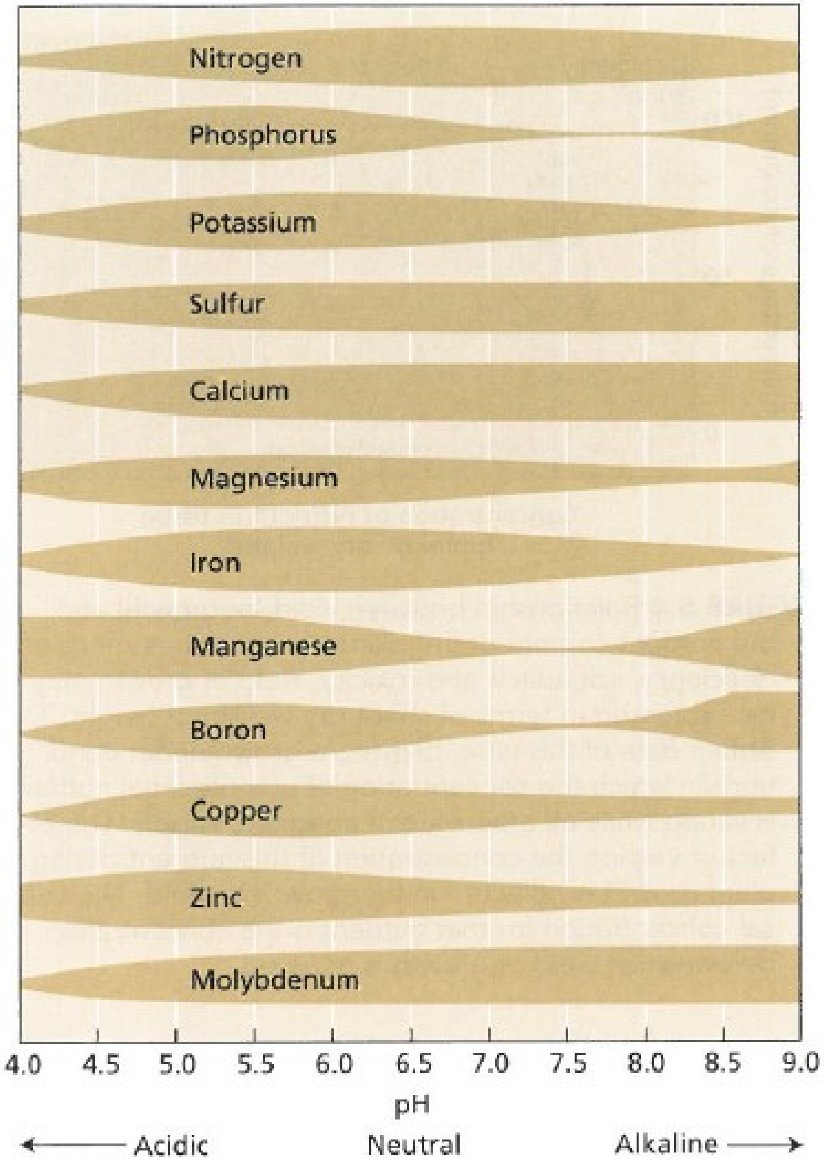


FIGURE 5.5 Influence of soil pH on the availability of nutrient elements in organic soils. The width of the shaded areas indicates the degree of nutrient availability to plant roots. All of these nutrients are available in the pH range of 5.5 to 6.5. (After Lucas and Davis 1961.)

- Many traditional and subsistence farming practices promote the recycling of mineral elements.
- Crop plants absorb nutrients from the soil, humans and animals consume locally grown crops, and crop residues and manure from humans and animals return the nutrients to the soil.

- The main losses of nutrients from such agricultural systems ensue from leaching that carries dissolved ions, especially nitrate, away with drainage water.

- **In acidic soils, leaching may be decreased by the addition of lime**—a mix of CaO, $CaCO_3$, and $Ca(OH)_2$—to make the **soil more alkaline because many mineral elements form less soluble compounds when the pH is higher than 6.**

- **This decrease in leaching, however, may be gained at the expense of decreased availability of some nutrients**, especially iron.

- Most chemical fertilizers contain inorganic salts of the macronutrients nitrogen, phosphorus, and potassium (e.g. NPK).

- Fertilizers that contain only one of these three nutrients are termed *straight fertilizers*.

- Some examples of straight fertilizers are superphosphate, ammonium nitrate, and muriate of potash (a source of potassium).

- Fertilizers that contain two or more mineral nutrients are called *compound fertilizers* or *mixed fertilizers*
- E.g. NPK

Some mineral nutrients can be absorbed by leaves

- In addition to absorbing nutrients added to the soil as fertilizers, **most plants can absorb mineral nutrients applied to their leaves as sprays, a process known as foliar application**.

- In some cases this method has agronomic advantages over the application of nutrients to the soil.

- Foliar application can reduce the lag time between application and uptake by the plant, which could be important during a phase of rapid growth.

- It can also circumvent the problem of restricted uptake of a nutrient from the soil.

- For example, foliar application of mineral nutrients such as iron, manganese, and copper may be more efficient than application through the soil, where these ions are adsorbed on soil particles and hence are less available to the root system.

- **Nutrient uptake by leaves is most effective when the nutrient solution remains on the leaf as a thin film**.

- Production of a thin film often requires that the **nutrient solutions be supplemented with surfactant chemicals**, such as the detergent **Tween 80.**

Soil

- Soil is a complex physically, chemically, and biologically.
- It is a heterogeneous substance containing solid, liquid, and gaseous phases.
- All of these phases interact with mineral elements.

- The liquid phase of soil constitutes the soil solution, which contains dissolved mineral ions and serves as the medium for ion movement to the root surface.

- Gases such as oxygen, carbon dioxide, and nitrogen are dissolved in the soil solution, but roots exchange gases with soils predominantly through the air gaps between soil particles.

- Organic soil particles originate from the products of microbial decomposition of dead plants, animals, and microorganisms.

- The negative surface charges of organic particles result from the dissociation of hydrogen ions from the carboxylic acid and phenolic groups present in this component of the soil.

- Most of the world's soil particles, however, are inorganic.

Inorganic soils are categorized by particle size

	Type of soil	Particle size range
1.	Gravel	>**2 mm**
2.	Coarse sand	between **0.2** and **2** mm
3.	Fine sand	between **0.02** and **0.2** mm
4.	Silt	between **0.002** and **0.02** mm
5.	Clay	<**0.002 mm**

Negatively charged soil particles affect the adsorption of mineral nutrients

- Soil particles, both inorganic and organic, have predominantly negative charges on their surfaces.

- In contrast, aluminium is found in relatively small amounts in many plants, although it is an abundant constituent of soil.

- Many inorganic soil particles are crystal lattices that are tetrahedral arrangements of the cationic forms of aluminum (Al^{3+}) and silicon (Si^{4+}) bound to oxygen atoms, thus forming aluminates and silicates.

- **When cations of lesser charge replace Al^{3+} and Si^{4+} within the crystal lattice, these inorganic soil particles become negatively charged.**

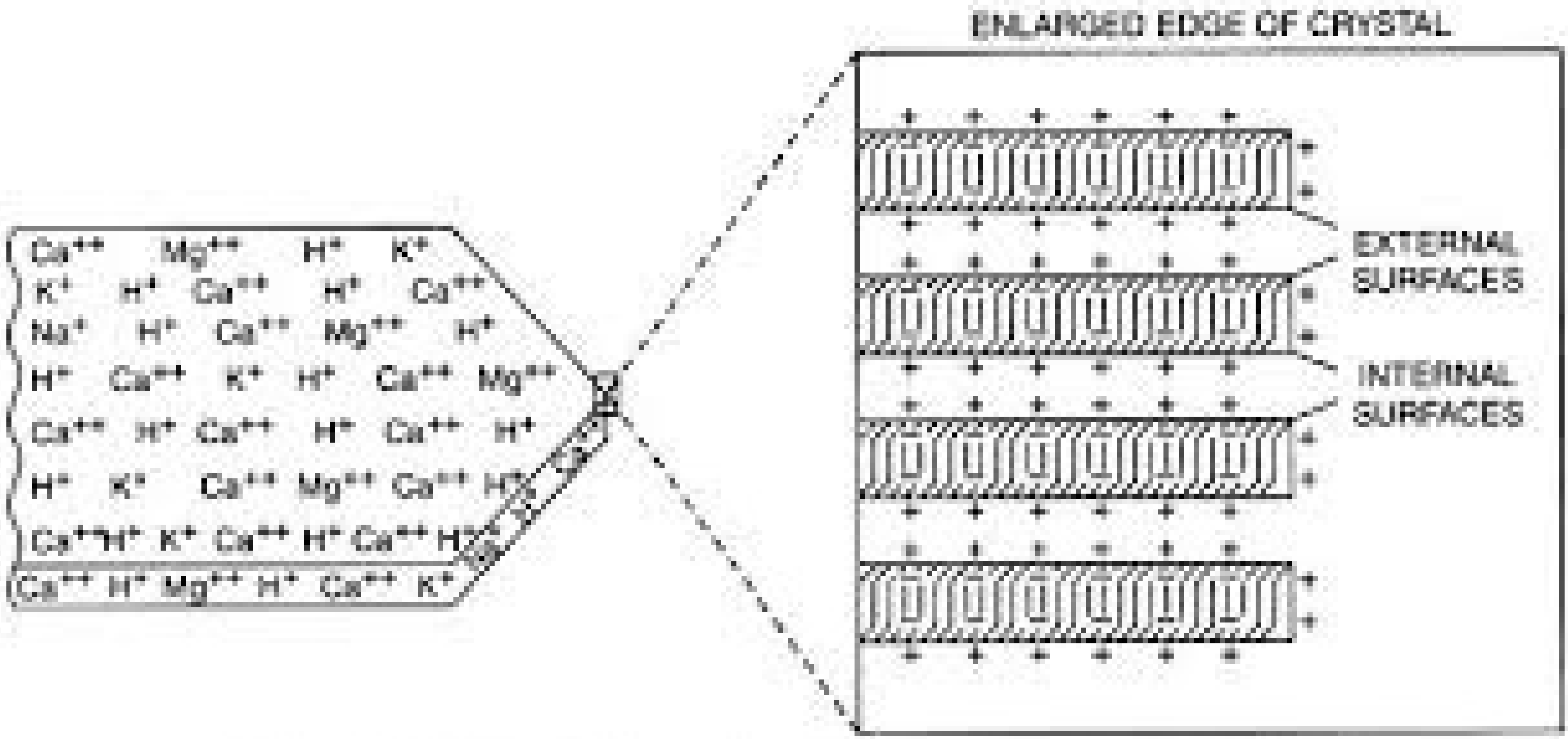
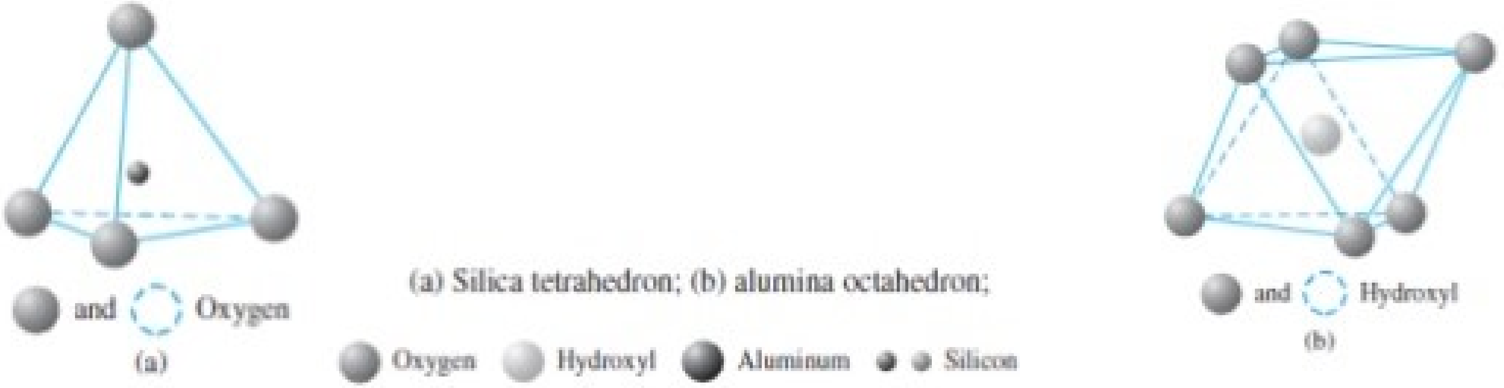


Fig. 9.1. Internal and external surfaces of a plate-like clay crystal unit.

2.3.1.2 Clay minerals

Clay minerals are complex aluminum silicates composed of two basic units:

- (1) *silica tetrahedron*
- (2) *alumina octahedron.*


(a) Silica tetrahedron; (b) alumina octahedron;

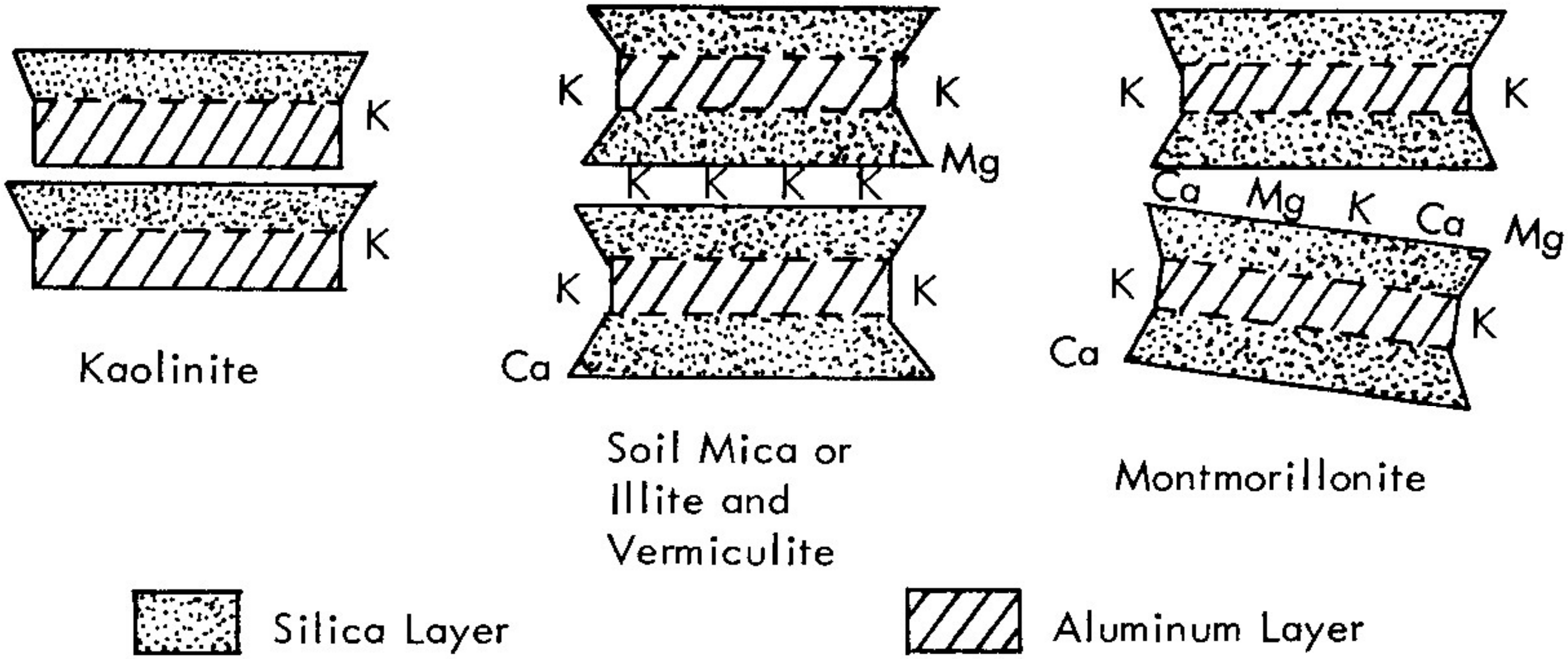
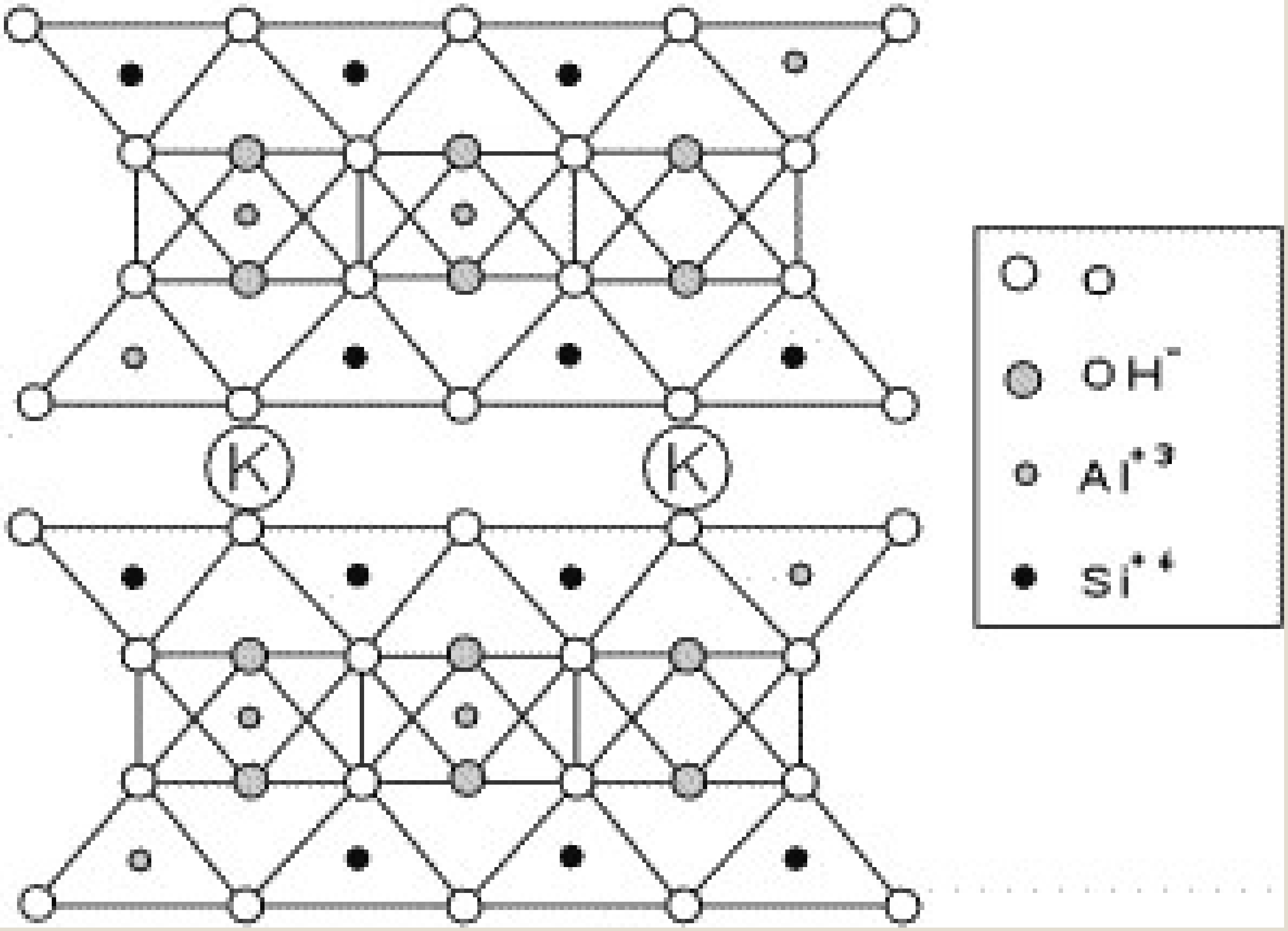
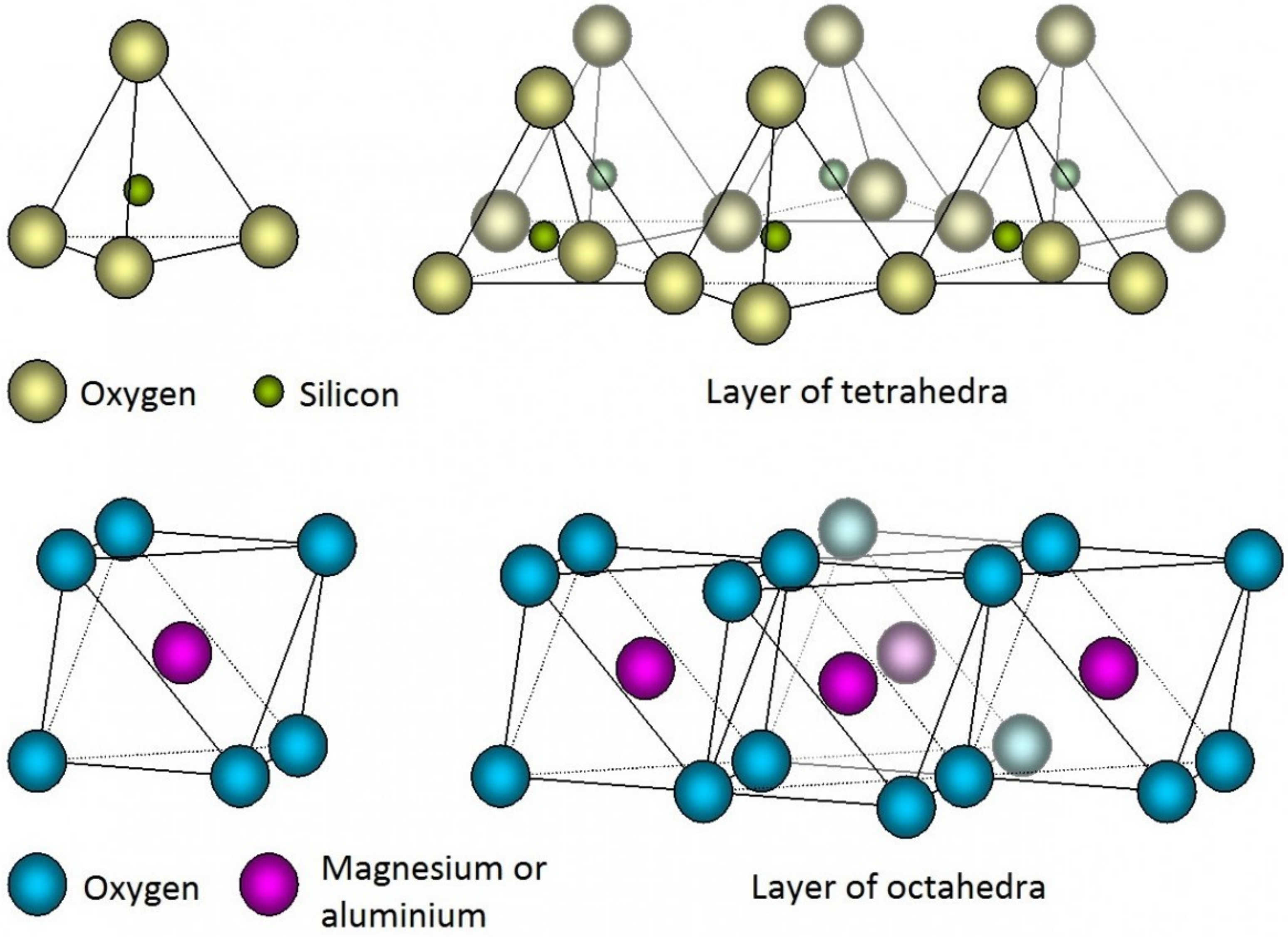
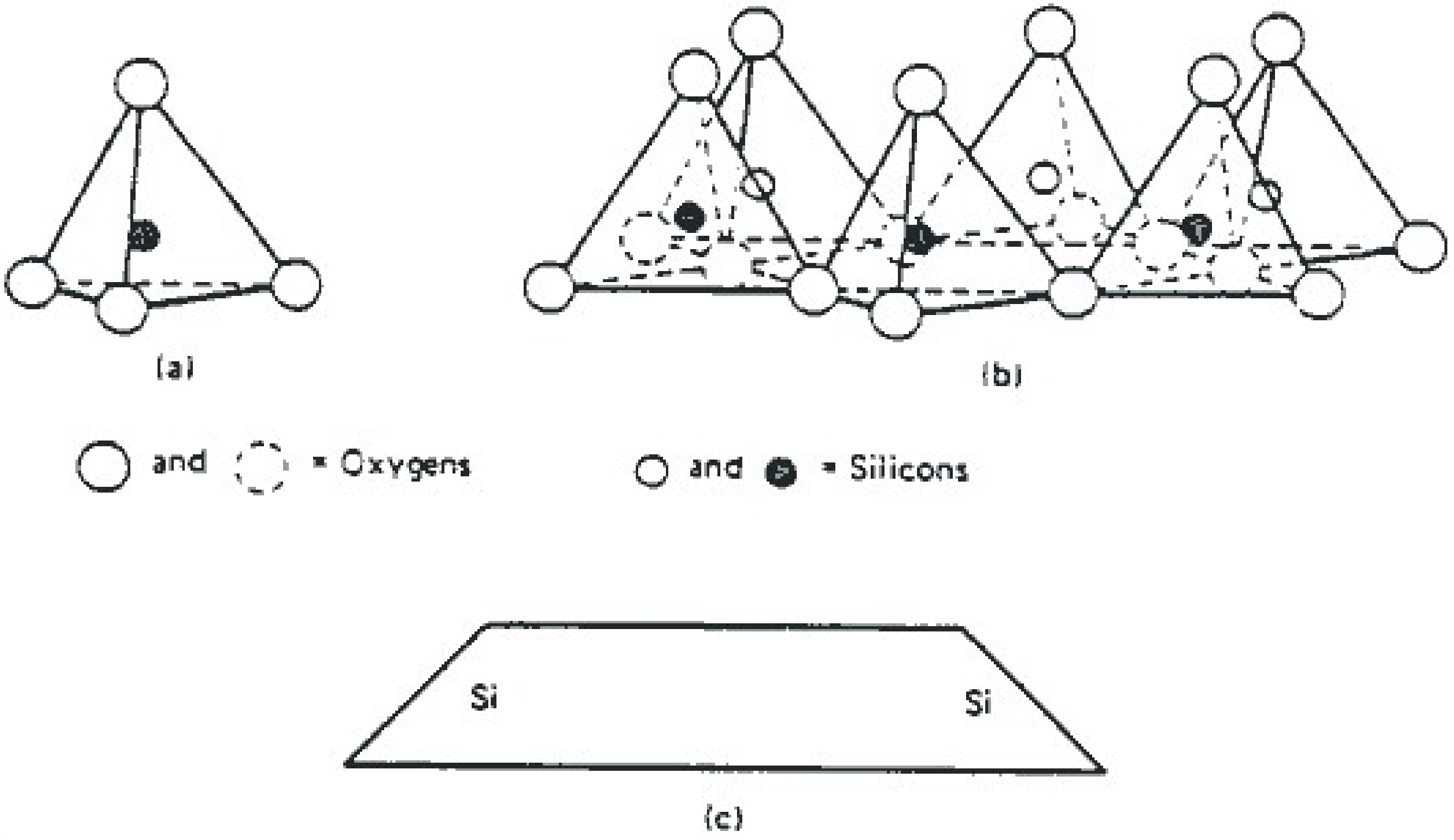


Fig. 3.—The Structure of Four Types of Clay Minerals Found in Kentucky Soils.

Muscovite $KAl_2AlSi_3O_{10}(OH)_2$




Oxygen
Silicon
Layer of tetrahedra
Oxygen
Magnesium or aluminium
Layer of octahedra



(a) Silica tetrahedron.
(b) Silica tetrahedral sheet.
(c) Schematic of silica sheet. See Table 2-1.

Source: Lambe, 1958; Grim, 1968

Figure 2-1. Clay mineral tetrahedral sheet structure.

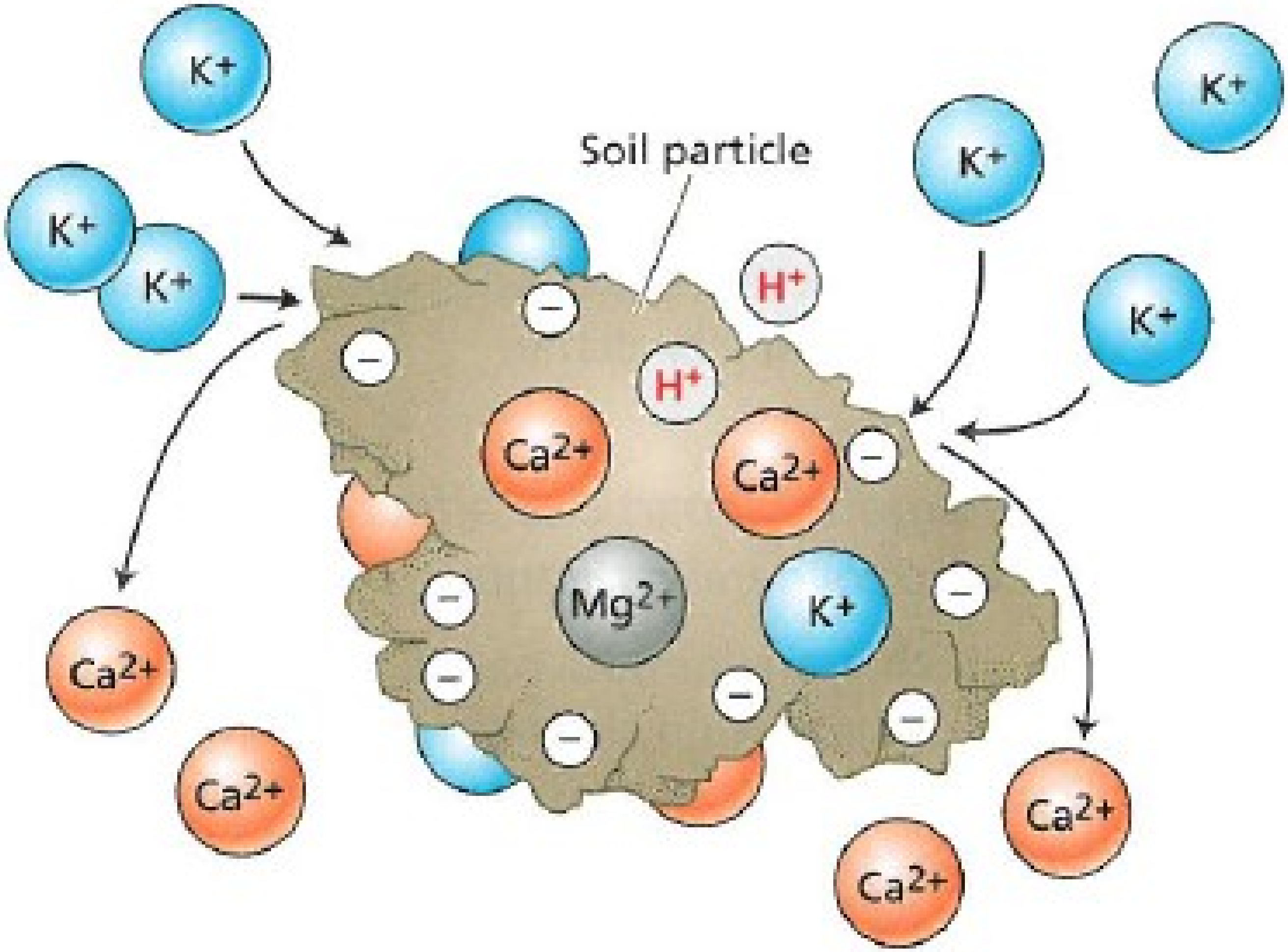


FIGURE 5.6 The principle of cation exchange on the surface of a soil particle. Cations are adsorbed on the surface of a soil particle because that surface is negatively charged. Addition of one cation, such as potassium (K^+), to the soil can displace other cations, such as calcium (Ca^{2+}), from the surface of the soil particle and make it available for uptake by roots.

- Mineral cations such as ammonium (NH_4^+) and potassium (K^+) adsorb to the negative surface charges of inorganic and organic soil particles.

- This cation adsorption is an important factor in soil fertility.

- Mineral cations adsorbed on the surface of soil particles, which are not easily lost when the soil is leached by water, provide a nutrient reserve available to plant roots.

- Mineral nutrients adsorbed in this way can be replaced by other cations in a process known as **cation exchange.**

- The degree to which a soil can adsorb and exchange ions is termed its *cation exchange capacity* (CEC) and is highly dependent on the soil type.

- **A soil with higher cation exchange capacity generally has a larger reserve of mineral nutrients**.

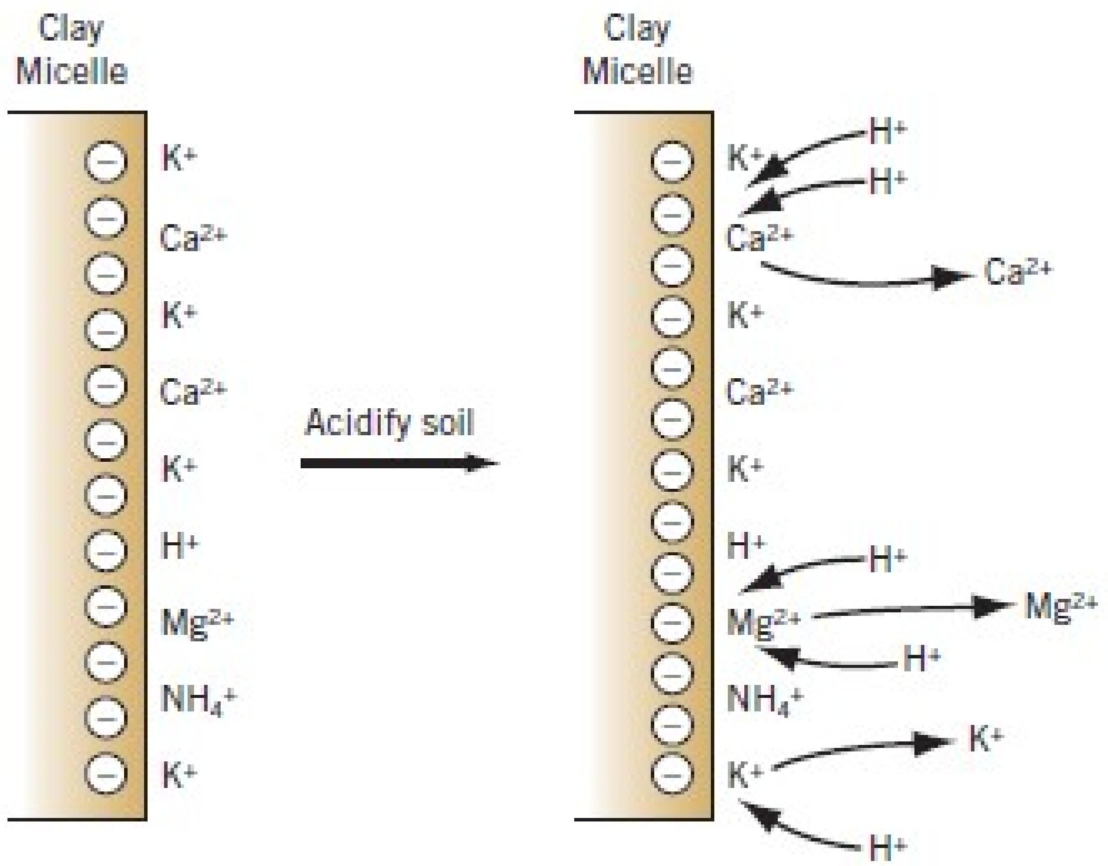


FIGURE 3.2 Ion exchange in the soil. (*A*) Cations are adsorbed to the negatively charged soil particles by electrostatic attraction. (*B*) Acidifying the soil increases the concentration of hydrogen ions in the soil. The additional hydrogen ions have a stronger attraction for the colloidal surface charges and so displace other cations into the soil solution.

- Mineral anions such as nitrate (NO_3^-) and chloride (Cl^-) tend to be repelled by the negative charge on the surface of soil particles and remain dissolved in the soil solution.

- Thus the anion exchange capacity of most agricultural soils is small compared with the cation exchange capacity.

- **Nitrate, in particular, remains mobile in the soil solution, where it is susceptible to leaching by water** moving through the soil.

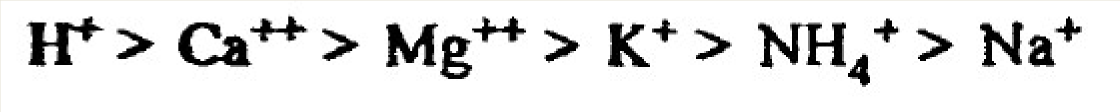
- The available minerals of soil occur in ionic forms.

- The common catonic forms are K, Mg, Ca, Fe, Mn, Cu, Zn, Co while anionic forms are P, B, S and Cl.

- These ions are found either in the form of loosely absorbed ions or firmly absorbed ions.

- loosely absorbed ions can be easily displaced on decreasing their own concentration in the soil solution while the firmly absorbed ions can be replaced by other ions which have more affinity for the colloid or ion exchange.

- Though not fixed; for some of the cations the order for cation retentive capacity of colloids is as follows:



$$H^{+} > Ca^{++} > Mg^{++} > K^{+} > NH_4^{+} > Na^{+}$$

Availability of Mineral Salts

- Mineral salts are found either as soluble fractions of soil solution or as adsorbed ions on the surface of colloidal particles.

- Many physiologists believe in the uninterrupted supply of mineral nutrients from the adsorbed fractions possibly by ionic exchange.

- 1st step in the absorption of mineral salts is the process of ion-exchange which does not require metabolical energy but greatly facilitates mineral salt absorption.

Ion exchange

- The ions adsorbed on the surface of the walls or membranes of root cells may be exchanged with the ions of same charge from external solution.

- E.g. the cation K^+ of the external soil solution may be exchanged with H^+ ion adsorbed on the surface of the root cells.

- Similarly, an anion may be exchanged with OH^- ion.

- So far two theories have been put forward to explain the ionic exchange:

  (1) Carbonic acid exchange theory and

  (ii) Cation/contact exchange theory

(ii) Cation/contact exchange theory

- This theory postulates that ions adsorbed on the surface of root cells and clay particles (or clay micelles) are not completely static.

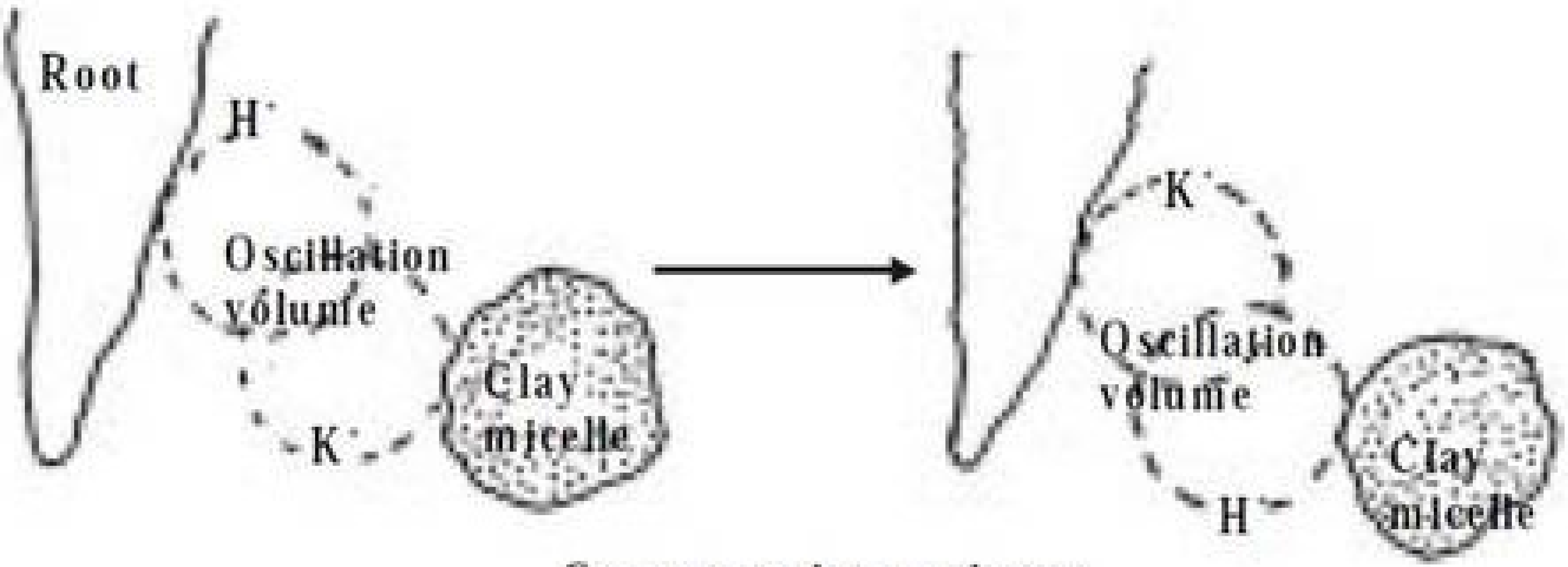
- Ions adsorbed on solid particles are not held tightly but always oscillating within a small volume of space around their adsorption surface.

- If the roots and clay particles are in close contact with each other, the oscillation space/volumes of an ion adsorbed to root surface overlaps the oscillation space of an ion adsorbed to soil micelle. Thus exchange of ions may takes place.

- According to this theory, the ions adsorbed on the clay micelles get adsorbed to the root in exchange for hydrogen ions, previously adsorbed on the root.

- Here the ions are exchanged directly without first being dissolved in soil solution.

- An equilibrium is, however, always maintained between the dissolved fractions as any depletion in the soil solution is immediately covered by movement of ions.



Contact exchange theory

Process of absorption of mineral salts

1. Passive absorption

- When the concentration of mineral salts is higher in the outer solution than in the cell sap of the root cells, the mineral salts are absorbed according to the concentration gradient by simple process of diffusion.
- It does not require expenditure of metabolic energy.

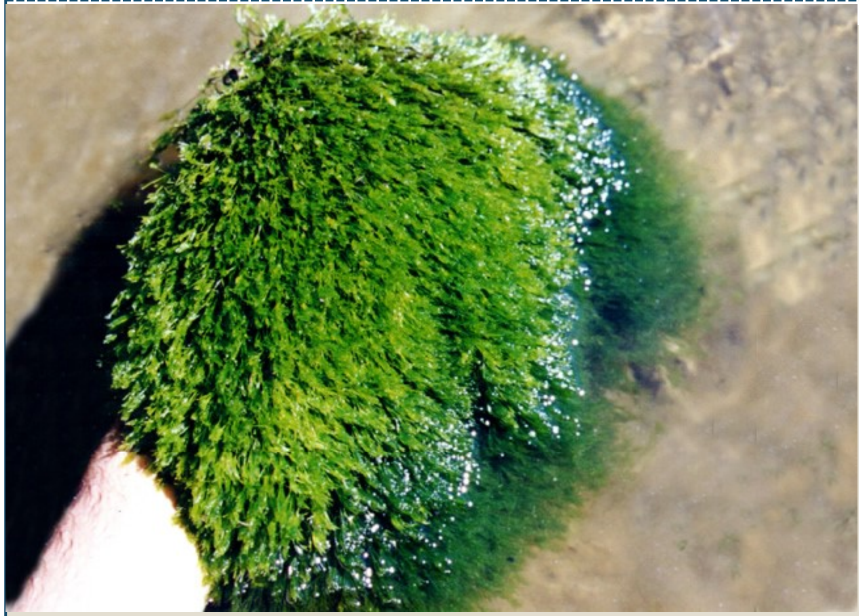
2. Active absorption

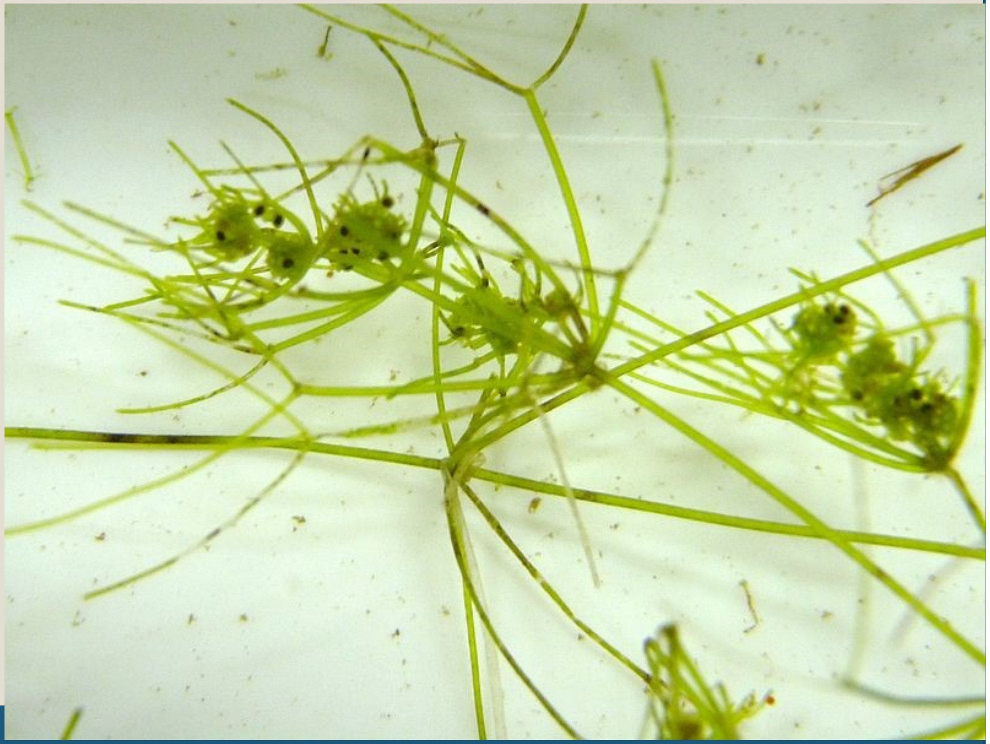
- It has often been observed that the cell sap in plants accumulates large quantities of mineral salts ions against the concentration gradient.

e.g. in alga *Nitella* the cell sap accumulated K+ and phosphate ions to such an extent that their concentrations were thousands and hundreds times greater than in the pond water in which the plant was growing.

- This can not be explained by simple diffusion and has led people to believe that absorption and accumulation of mineral salts against the concentration gradient is an active process.
- It involves the expenditure of metabolic energy through respiration.

Nitella





Mechanism of Mineral Salt Absorption

- Various theories proposed to explain the mechanism of mineral salt absorption can be placed under two broad categories:

(1) **Passive absorption**. It includes

The theories of diffusion

Ion exchange ⇦

Donnan equilibrium and

Mass flow.

(2) **Active absorption**. It includes theories related to carrier concepts such as

The carrier concept theory ⇦

Cytochrome pump theory

Protein lecithin theory etc.

PASSIVE ABSORPTION

- Passive absorption may also be called physical absorption.

- It may be defined as the absorption of solute by cells according to ordinary laws of diffusion.

- **Briggs and Roberston** (1957) demonstrated the passive absorption of ions by root system in contact with soil colloids and root solution.

- They showed that the process is not affected by temperature and metabolic inhibitors and also that when a plant cell or tissues are transferred from a medium of low concentration to a medium of high concentration, there is a rapid uptake of ions.

- The direction of the initial uptake gets reversed if the tissues are transferred back to a medium of low concentration.
- Based on these findings various theories have been proposed to explain the mechanism of salt uptake.

2. Ion Exchange Theory

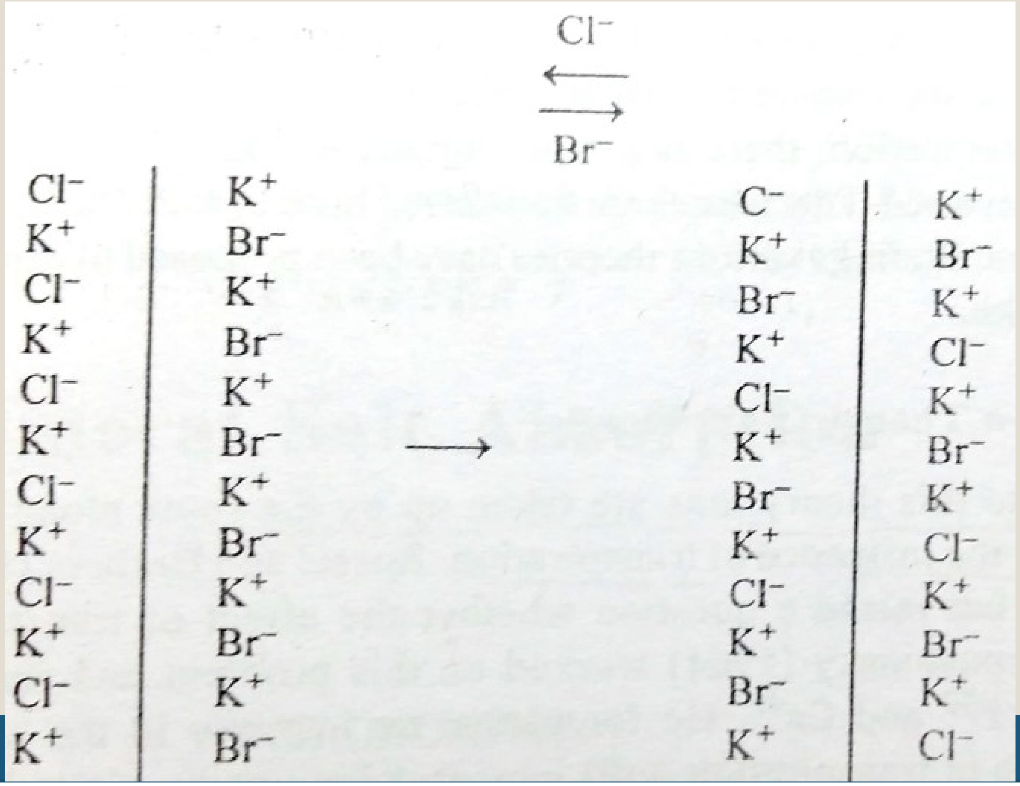
- According to this theory ions from the external solution in which the tissue is immersed may exchange with the ions absorbed *on the surface of the cell wall or membranes* of the tissue.

- Just like ions exchanged between soil colloids and soil solution the cations may exchange with hydrogen ions and anions with hydroxyl ions adsorbed on the surface of the tissue and this ion exchange may allow greater absorption of ions from the external medium than could normally be accounted for by free diffusion.

- As hydrogen ions and hydroxyl ions are both readily available (adsorbed on the surface of the cell membrane), the cations and anions are exchanged freely.
- This process **does not involve** participation of the **metabolic energy.**
- Ionic exchange phenomenon has been experimentally shown in excised barley roots with the use of radioactive K^+ in which case K^+ ions exchange place with non-radioactive K^+ ions.

- Likewise negatively charged Cl^- and Br^- are also exchanged without disturbing the electrical neutrality.

- It is believed that a similar mechanism operates between soil solution and clay micelle which would allow for a greater absorption of ions from the external medium than could normally be accepted by free diffusion.



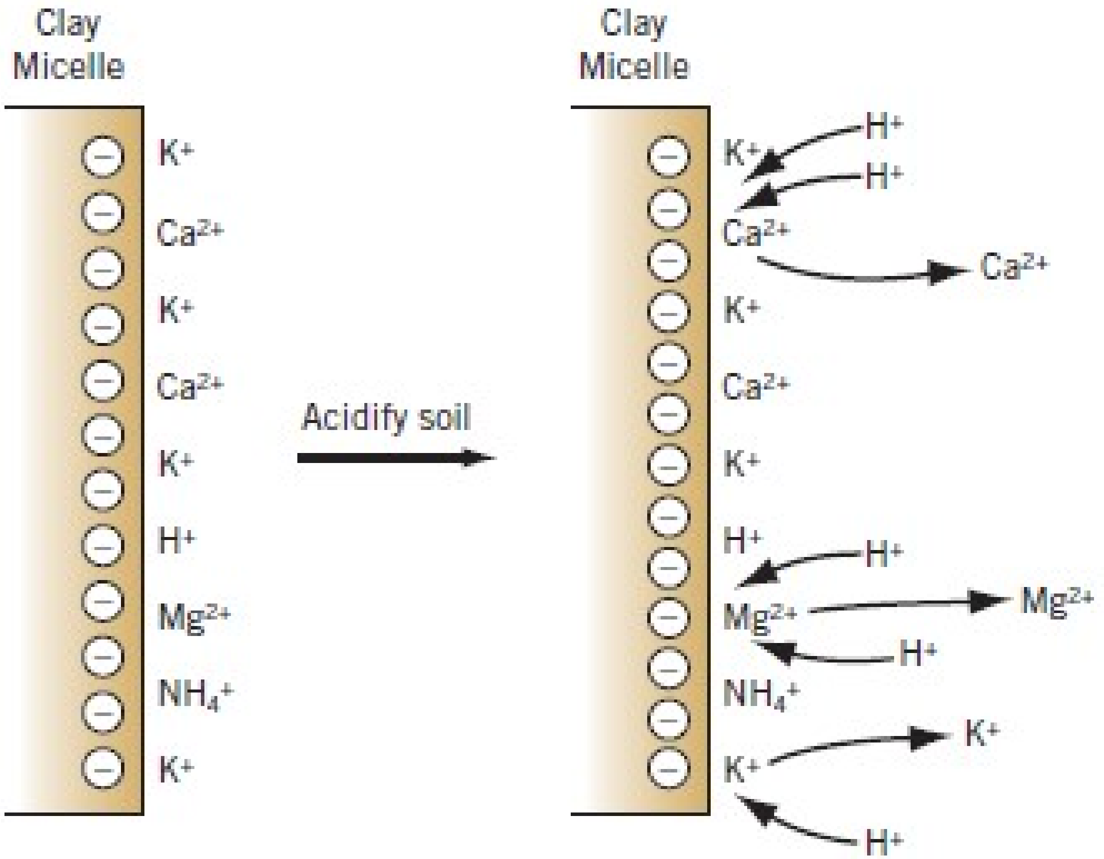


FIGURE 3.2 Ion exchange in the soil. (*A*) Cations are adsorbed to the negatively charged soil particles by electrostatic attraction. (*B*) Acidifying the soil increases the concentration of hydrogen ions in the soil. The additional hydrogen ions have a stronger attraction for the colloidal surface charges and so displace other cations into the soil solution.

Objections to Passive Absorption Concept

- Certain strong objections have been raised against passive absorption concept of salt uptake.

A few of them are:

- **(1)** In actual process, the rate of absorption of minerals is too rapid to be explained by passive absorption.

- **(2)** No theory of passive absorption adequately explains absorption and accumulation of salts or ions against the osmotic gradients (or against the laws of diffusion).

- However, cases of extra accumulation of K^+ ions within the cells (like lOOO times as against the surrounding medium) are now frequently known in *Nitella translucens*, *Chara australis* and *Hydrodictyon africanum*.

- (**3**) It has been experimentally demonstrated that there is at close relationship between salt uptake and metabolic activities. This may be supported by the following examples:

(a) A quantitative relationship has been found between anion absorption and respiration.

(b) A close relationship between salt accumulation and respiration is found in all cases. Hopkins (I956) observed that salt accumulation is slowed, and even prevented completely, with the decrease in the oxygen content of the nutrient medium.

(c) The active phase of salt absorption is inhibited by the absence of oxygen, i.e. oxygen is required during salt uptake.

(d) There is a close relationship between metabolic activities and ability to absorb and accumulate solutes.

(e) The metabolic inhibitors influence the salt absorption. Lundegardh (1955) reported that salt uptake is inhibited by oxidase inhibitors, azides, carbon monoxides and cyanides (all metabolic inhibitors).

(f) Salt uptake has been found to stimulate and increase the rate of respiration. This increased respiration has been termed as **salt induced respiration.**

(g) Factors like pH, light, oxygen tension and growth affect the salt absorption suggesting that there is some essential role of metabolic activities in salt uptake.

- These objections to passive absorption led scientists like Street, Lundegardh, Clark, Epstein etc. to support the active absorption concept of salt uptake.

- So various theories have been proposed.

ACTIVE ABSORPI ION

- According to active absorption concept of salt uptake, it is believed that this process is supported by metabolic energy.

- There have been modifications from time to time to discuss the nature of participation of metabolic energy and that is why several theories have been proposed.

1. The Carrier Concept Theory

- Observations of phenomena like selectivity, antagonism and synergism during salt uptake led Honert (1937) to propose the carrier concept theory of mineral salt absorption.

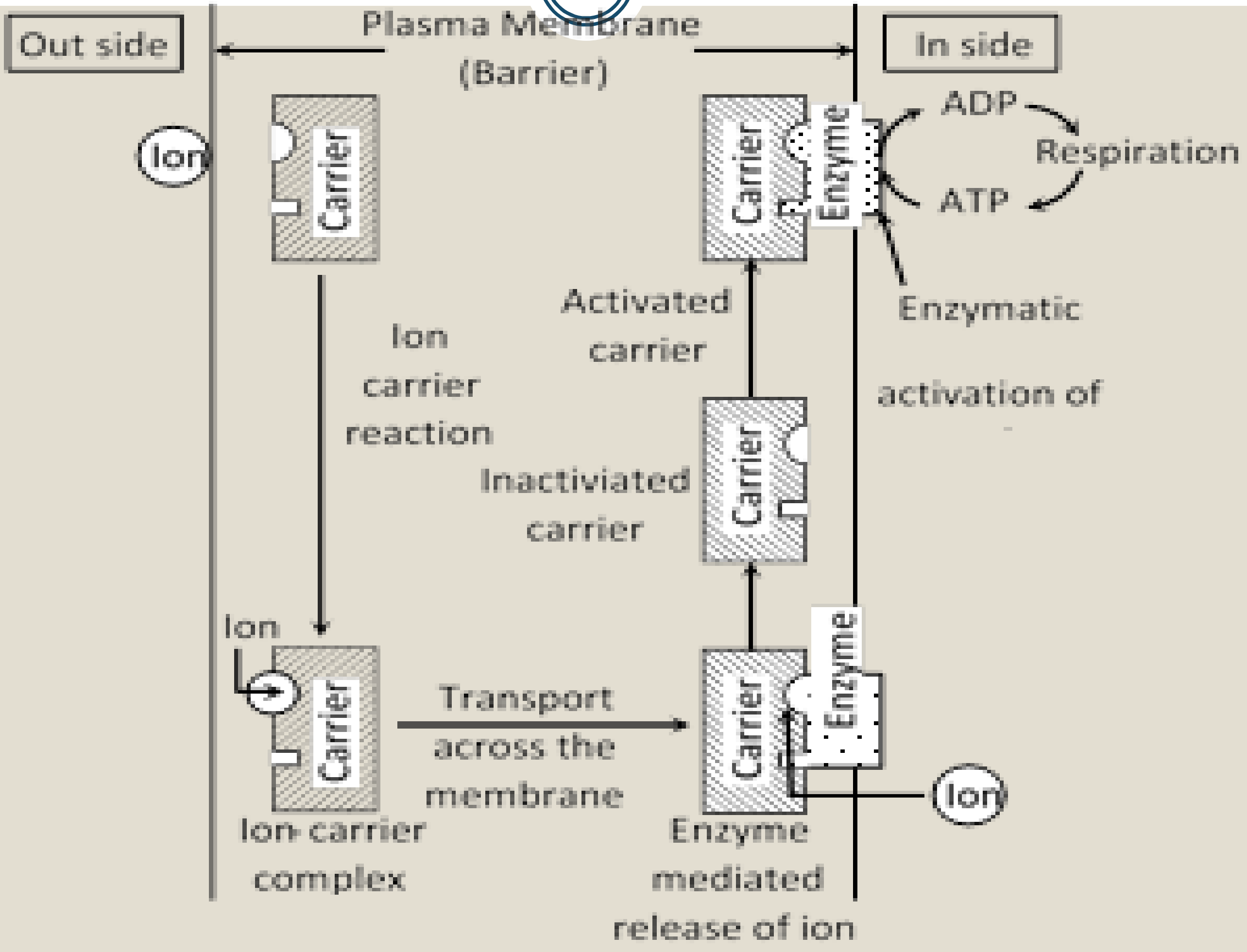
- According to this theory the plasma membrane is impermeable to free ions. But some compound present in it acts as carrier and combines with ions to form carrier –ion-complex which can move across the membrane.

- Here the ion transport process is carried out by means of carriers which may be organic molecules or vesicles.

- It is believed that ions undergo reversible binding with some constituents of outer space designated as carriers and pass through the impermeable boundary between outer space and inner **space in the form of ion carrier complexes.**

- on reaching the inner space ions are again separated from carrier molecules and the carrier goes back to the outer surface to pick up fresh ions.

- The direction of the movement of ion carrier complexes is from outer space to inner space only and ions released in the inner space cannot move out and thus are accumulated there.



The ion-carrier hypothesis

- This theory explains selectivity, abundance of selected ions in the membrane and their chemical affinities with the carrier molecules.

- Following observations strongly support the carrier concept of active absorption of mineral salts:

1. Isotopic exchange

- Several times, it has been found that actively absorbed radio active ions (such as $^{35}SO_4$) can not diffuse back or be exchanges with other ions in the outer solution indicating thereby that the plasma membrane is not permeable to free ions.

2. Saturation effects

- Beyond a certain limit, increased concentration of salts in outer solution does not bring about an increase in the rate of mineral salt absorption. It is because the active sites on the carrier compound become saturated with ions.

3. Specificity

- Active sites on carrier compound may be specific which can bind only some specific ions. This also explains the selective and unequal absorption of ions by the plants.

- There are 2 common theories based on the carrier concept to explain the mechanism of active salt absorption, although they are not universally accepted.

  i) **Lundegardh's cytochrome pump theory**

  ii) **Bennet –Clark's Protein –Lecithin theory**

Mineral deficiencies disrupt plant metabolism and function

- An inadequate supply of an essential element results in a nutritional disorder manifested by characteristic **deficiency symptoms.**

- In hydroponic culture, withholding of an essential element can be readily correlated with a given set of symptoms.

- For example, a particular deficiency might elicit a specific pattern of leaf discoloration.

- **Diagnosis of soil-grown plants can be more complex for the following reasons:**

- Deficiencies of several elements may occur simultaneously in different plant tissues.
- Deficiencies or excessive amounts of one element may induce deficiencies or excessive accumulations of another.
- Some virus-induced plant diseases may produce symptoms similar to those of nutrient deficiencies.

- Nutrient deficiency symptoms in a plant are the expression of metabolic disorders resulting from the insufficient supply of an essential element.

- These disorders are related to the roles played by essential elements in normal plant metabolism and function.

- Although each essential element participates in many different metabolic reactions, some general statements about the functions of essential elements in plant metabolism are possible.

- In general, the essential elements function in plant structure, metabolism, and cellular osmoregulation.

Deficiency symptoms

Mineral sufficient
(control)

Potassium deficient
(–K)

Phosphorous deficient
(–P)

Dark to blue green colour of leaves

Mineral sufficient
(control)

Iron deficient
(–Fe)

Zinc deficient
(–Zn)

Calcium deficient
(–Ca)

Mineral sufficient
(control)

Magnesium deficient
(–Mg)

Copper deficient
(–Cu)

Manganese deficient
(–Mn)

Chlorosis

- **Magnesium Deficiency Symptoms:** Magnesium deficiency symptoms show green banding around the margin and next to the midrib. Leaves turn yellowish with brown goods on the leaf margin. Plant height reduced marginal yellowing of leaf margin extends towards the midrib. Purplish mottling of leaf petiole and malformation of leaves. Fruits do not ripen well and become tasteless.
- **Correction Measure:** Spraying MgSO4 5% or application of dolomite lime stone 3t/ha effectively corrects the deficiency.

Inter veinal chlorosis

"Iron deficiency in Petunia."

Necrosis


Necrotic leaf edges

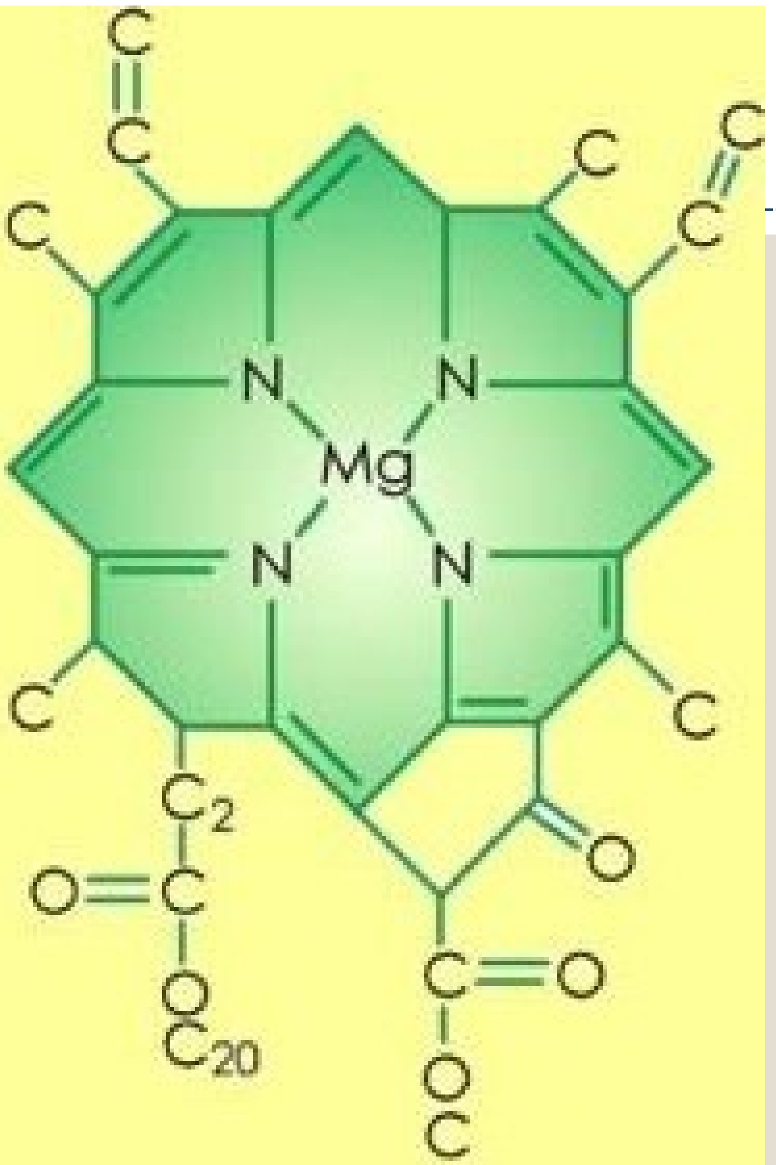
Whip tail disease – Molybdenum deficiency

Great Basin Whiptail

Die back disease – Cu

Mottle leaf – Zn deficiency

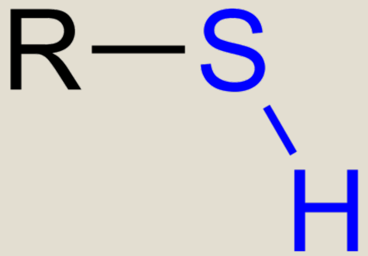
Mineral element (Macronutrients)	Major role
1. Nitrogen	Constituent – **Proteins, nucleic acids, porphyrins, alkaloids, some vitamins, coenzymes.** **Porphyrins –** part of **Chlorophyll and cytochrome** **Growth, metabolism, heredity and reproduction**
2. Phosphorus	Constituent – **nucleic acids, phospholipids, coenzyme – NAD, NADP and ATP** **Protein synthesis** **Oxidation –reduction, energy transfer reactions- photosynthesis, respiration fat metabolism**

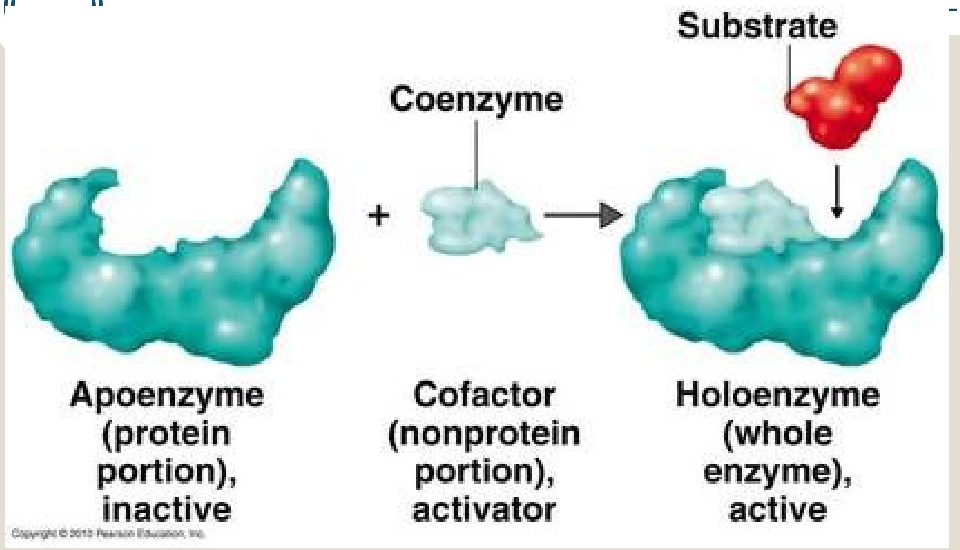


Plant Chlorophyll

Mineral element (Macronutrients)	Major role
3. Sulphur	**Amino acids- Cystine, cysteine and methionine** **Disulphide linkages** **Vitamins- biotin, thiamine, co-enzyme A** **Enzyme activator – sulfhydryl groups**
4. Potassium	Essential for the process of **respiration and photosynthesis** **Activator of many enzymes** – carbohydrate metabolism and protein synthesis

Sulfhydryl groups





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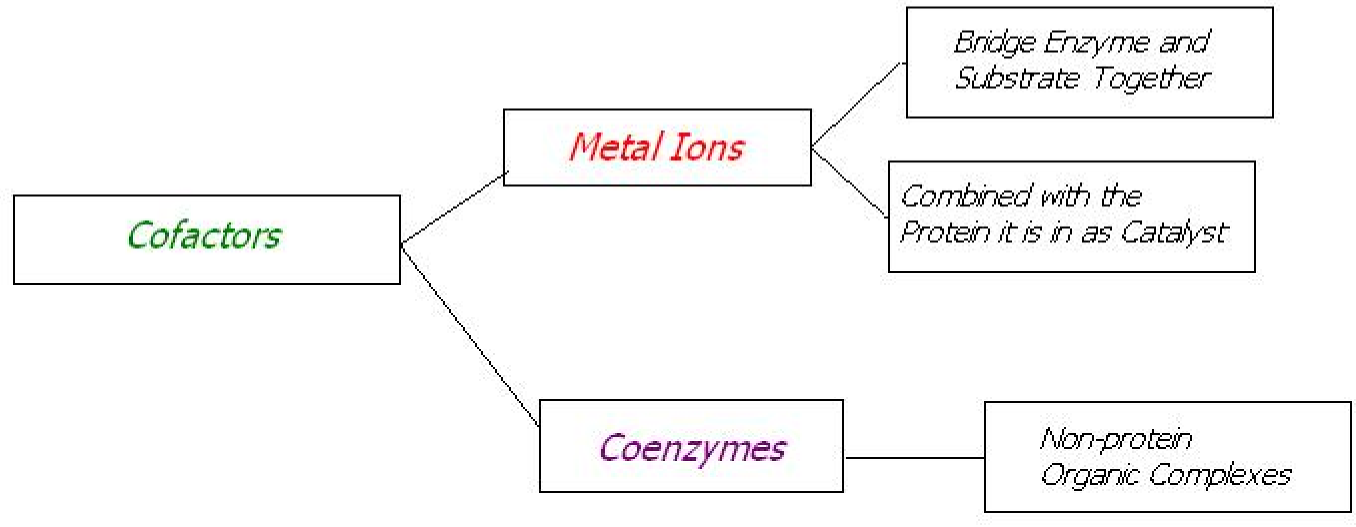

Cofactors

- *Metal Ions*
  - *Bridge Enzyme and Substrate Together*
  - *Combined with the Protein it is in as Catalyst*
- *Coenzymes*
  - *Non-protein Organic Complexes*

Mineral element (Macronutrients)	**Major role**
5. Magnesium	Constituent – **chlorophyll** **Enzyme activator in phosphate transfer reactions** Role in **binding ribosomal particles during protein synthesis.**
6. Calcium	**Middle lamella in cell wall** **Formation of cell membranes** **Enzyme activator** **Stabilize chromosome structure**

Mineral element (Macronutrients)	**Major role**
7. Iron	**Synthesis of chlorophyll** Constituent **– iron – porphyrin proteins –** **cytochrome peroxidases, catalases** **Ferredoxin –** **biological nitrogen fixation,** **light reaction of photosynthesis**

Mineral element (Micronutrients)	**Major role**
1. Mn	**Enzyme activator – nitrite reductase, hydroxylamine reductase** **Evolution of oxygen - photosynthesis**
2. Cu	Constituent – **oxidizing enzymes** **Cu toxicity**
3. Zn	**Auxin biosynthesis – IAA** **Enzyme activator – carbonic anhydrase, alcohol dehydrogenase**
4. B	**Role note clear. But translocation of sugars**

Mineral element (Micronutrients)	Major role
5. Mo	**Enzyme activator – nitrate reductase – nitrogen metabolism**
6. Cl	**Water splitting reaction of photosynthesis** **Cell division in leaves and roots**

Deficiency symptoms	Mineral element (Macronutrients)
Chlorosis	N, S, Ca, Mg, Fe
Inter veinal chlorosis	Fe, Mg
Necrosis	P, Ca, Mg, K
Stunted growth	N, Ca, K
Premature leaf fall	P
Dark to blue green	P
Mottle	K

Deficiency symptoms	**Mineral element (Micronutrients)**
Chlorosis	Cl, Mn, Zn, Mo
Necrosis	Cl, Mn, Cu, B
Stunted growth	Cl, B, Mo
Mottle	Zn
Die back	Cu
Leaves coppery	B
Whip tail disease	Mo

Thank you