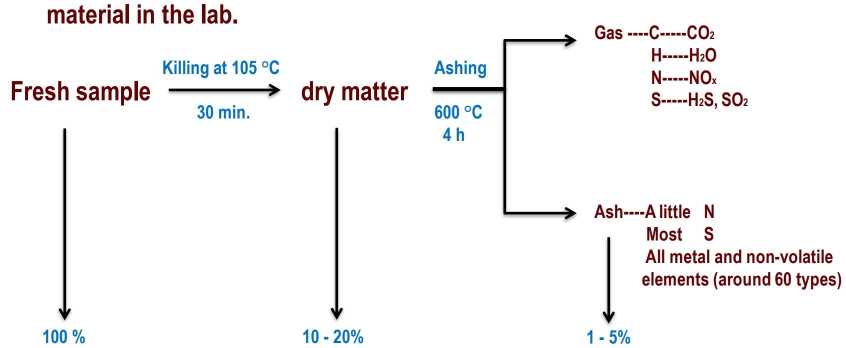
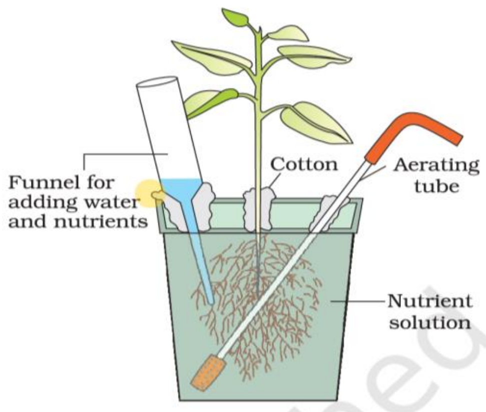
Principles of Plant Physiology

Plant Mineral Nutrition

- Plant require a large number of elements.
- Such elements are either derived from minerals or are mineralized during the biological breakdown of organic matter.
- The mineral nutrients are taken up in the form of ions and incorporated into the plant structure or stored in the cell sap.
- The inorganic components remain as ash after combustion of the dry plant material in the lab.



Essential and non-essential nutrient elements



a typical set-up for nutrient solution culture (
Hydroponic system

Essential and non-essential nutrient elements.

The roots of green plants absorb 30 to 40 elements from the soil. But only a few of them are essential for plant growth and development.

The element is considered essential according to (Epstein 1972) if one of the following cases is presents:-

1. **The plant can not complete its life cycle in a natural way if it is absent.**
   If the plant can not produce viable seeds or seeds at all in the absence of that element , then that element is considered essential like (P)
2. **It is a part of an essential molecule of plant or its metabolites.**
   if the element is a part of the structure of an essential molecule, it will be considered as essential like (Mg) because is a part of the chlorophyll molecule.
3. **The element role in plant metabolism should be direct.**
   if the element is needed at any times during the metabolic process like (Mg) which is work as cofactor for many enzymes involve in respiratory process.

Arnon and stout 1939 gave the following criteria for essentiality of an element:-

1. The element must be absolutely necessary for supporting normal growth of the plant and its reproduction.
2. The requirement of the element must be specific and not replaceable by an other element.
3. The element must play a direct role in the metabolism of the plant.

For example Mg is an important constituent of chlorophyll molecule essential for photosynthesis. No other element can replace it for the same function. Mg is also needed as a cofactor by several enzymes involved in cellular respiration and many other metabolic pathways. And Fe is important for building the cytochromes.

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

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

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

3. Essential elements that activate or inhibit enzymes, for example Mg2+ is an activator for both ribulose bisphosphate carboxylase oxygenase and phosphoenol- pyruvate carboxylase, both of which are critical enzymes in photosynthetic carbon fixation; Zn2+ is an activator of alcohol dehydrogenase and Mo of nitrogenase during nitrogen metabolism.

4. 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.

So, if the element satisfies all the above three criteria, it is considered to be an essential element. If it fails to satisfy any of these , it is called non-essential element.

Of the 30 to 40 elements universally present in all plants, 16 are essential and the rest are non-essential.

- **Essential elements :- Carbon(C), Oxygen(O), Hydrogen (H), Sulphur(S), Nitrogen(N), Phosphate(P), Potassium(K), Magnesium(Mg), Calcium(Ca), Iron(Fe), Copper(Cu), Boron(B), Zinc(Zn), Manganese(Mn), Molybdenum(MoO), and Chlorine(Cl).**

- **Non – essential elements:- Aluminum(Al), Nickel(Ni), Sodium(Na), Cobalt(Cu), *etc.***

Macroelements and microelements.

Essential elements are divided into two categories based on quantity in which they are required by the plants: macroelements or macronutrients and microelements or micronutrients.

1. **Macroelements or macronutrients :- these are required by the plant in large quantities. Like carbon, hydrogen, oxygen, nitrogen , phosphorus, sulphur, potassium, calcium, magnesium and iron.**

2. **Microelements or micronutrients or Trace Elements:- these are required by the plant in traces amount i.e., often less than 1 ppm. These are often called as trace elements. There are manganese, copper, molybdenum, zinc, boron and chlorine.**

Beneficial elements:- these are unessential elements for growth of green plants, but they can help the growth and improve it if they are present.

Note:- the beneficial elements can not considered as essential elements because the plant can complete its life cycle normally in their absence and dose not effect its biological activities.

❖ Some of beneficial elements include:-

1. Sodium(Na) -------- tolerant plants ----------- Halophytes.
2. Cobalt(Co) --------- (N_2 Fixation bacteria) under N deficiency in legumes.
3. Silicon(Si) --------- protect plant from infection with fungi through accumulation in their cells wall.

❖ Some elements are beneficial in the absence of some other element that has similar characteristics e.g. Rubidium(Rb) may substitute(K) and Strontium(Sr) for Ca.

Principles of Plant Physiology *Plant Mineral Nutrition*

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

The nutrient elements in the soil.

Excluding 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.

- Soils are greatly different in their composition, structure and amount 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.

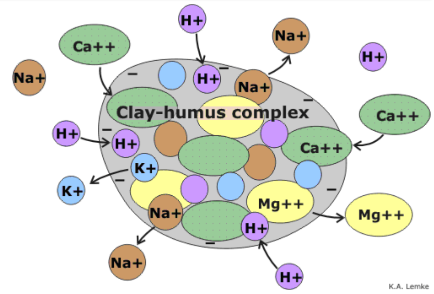
The principle of cation exchange on the surface of a soil particle.

- The clay colloidal particles are highly negatively charged, and have 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 is low, and the anions dose not catch up by soil particles, but drained down to the underground water↓.

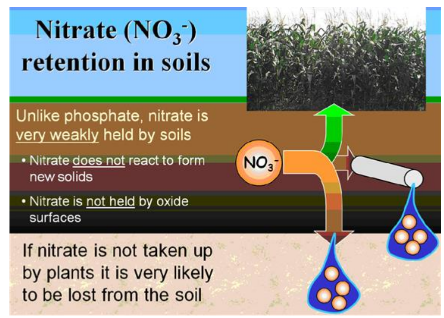
So does the above mentioned explains the reason of adding big amounts of anions fertilizers to the soil ?!

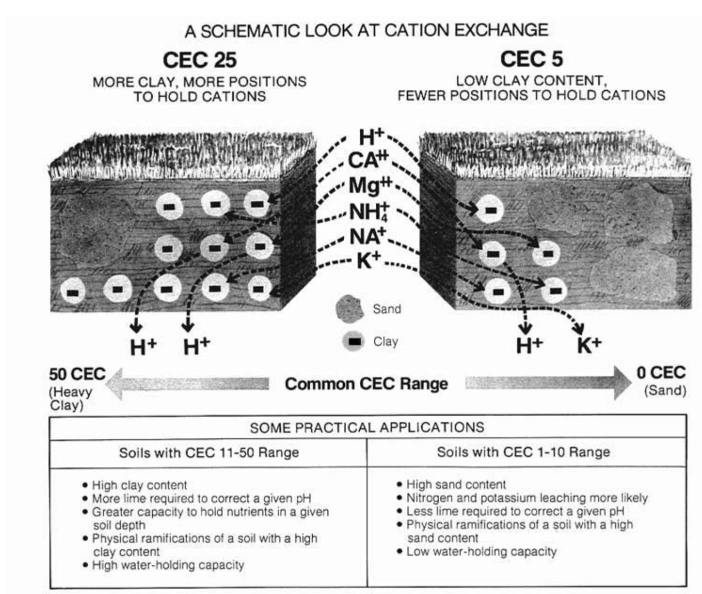
Yes indeed, the mentioned above explains the reason of adding the negatively charged nutrients such as nitrates($NO^-{}_3$) in large quantities.

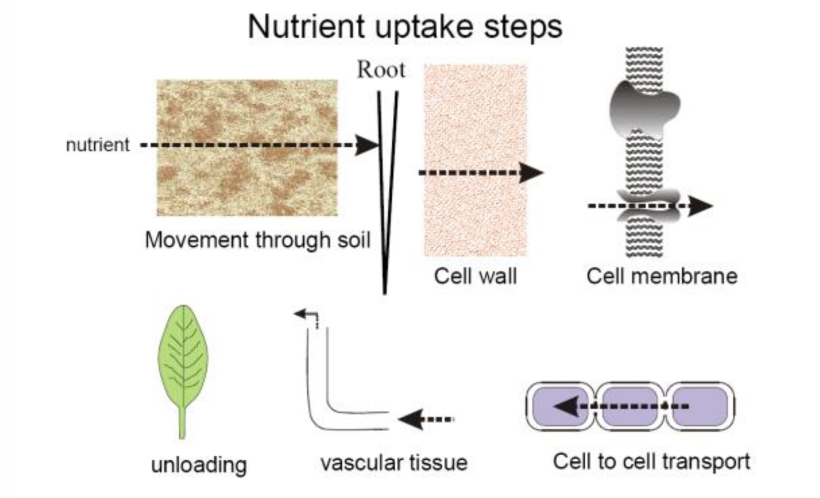
- Figure shows clay particle holds some cations, like K+, Ca++, Mg++ and Na+.

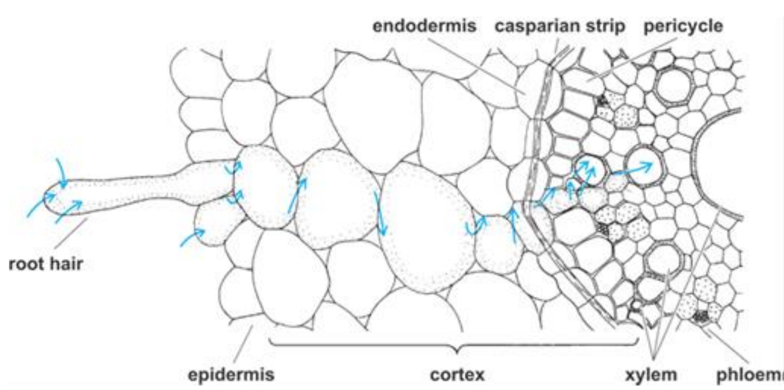


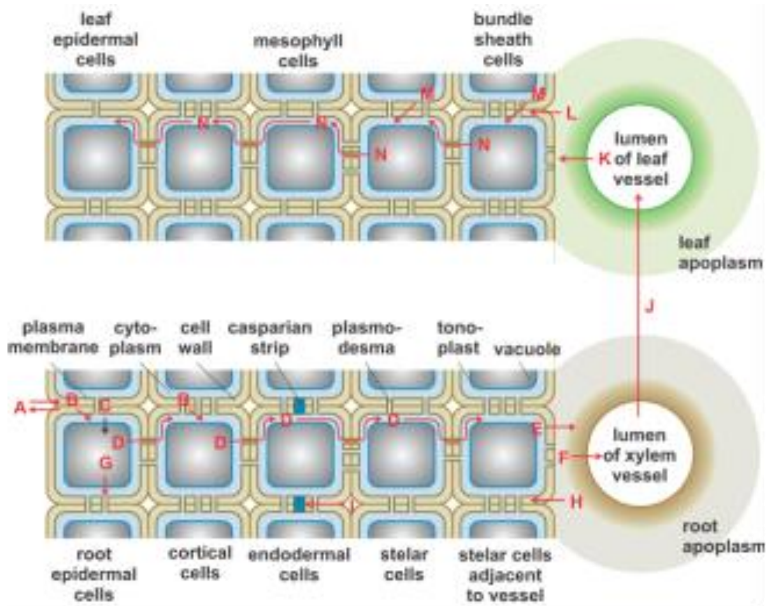
- Figure shows how the soil loses anions like NO_3^-

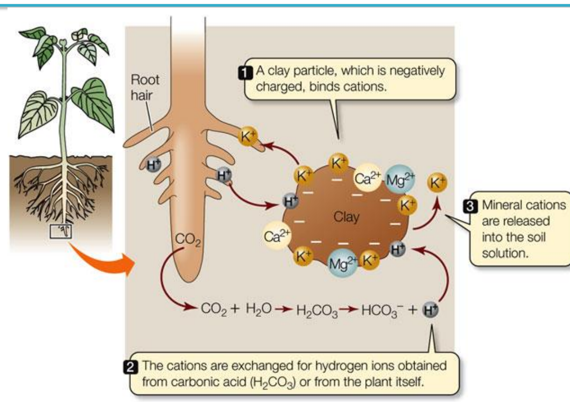





Nutrient uptake steps
Root
nutrient
Movement through soil
Cell wall
Cell membrane
unloading
vascular tissue
Cell to cell transport


endodermis
casparian strip
pericycle
root hair
epidermis
cortex
xylem
phloem





Figures shows the ion exchange in soil rhizosphere.

The rhizosphere is a layer of soil surrounding the growing root that is affected by the root directly. Usually a few mm wide, up to say 1cm.

The ion uptake (absorption).

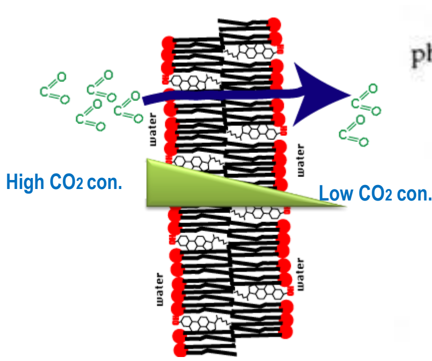
Absorption of mineral elements by plant includes the movement of such elements through the plasmalemma (the main barrier between the cell and the out side medium).

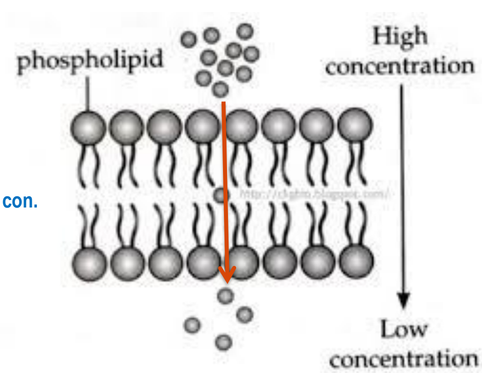
How does this movement (ion absorption) occur?!

Three major concepts were developed to explain how the ion absorbed across the plasmalemma.

1. Simple diffusion.
2. Facilitated diffusion.
3. Active transport (uptake).

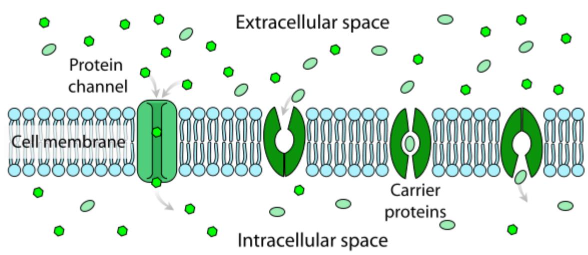
1. Simple diffusion:- the rate of diffusion of molecules in a solution from one region to another depends on the difference in concentration. Non-polar molecules like O_2,CO_2 and NH_3 pass the bio-membranes by this way.



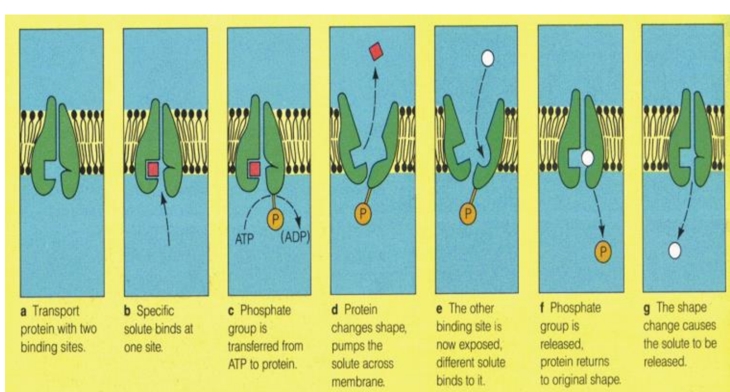


2. Facilitated diffusion:- also known as facilitated transport or passive-mediated transport) is the process of spontaneous passive transport of molecules or ions across a bio-membranes via specific transmembrane integral proteins.

That means the particles that need to go into or come out of the cell cannot do so by themselves. This type of transport requires the use of a carrier that facilitates this process - thus the name facilitated diffusion.



3. Active transport (uptake):- is the movement of ions or molecules across a cell membrane in the direction against their concentration gradient, assisted by enzymes and requiring energy.



Notes:-

- The direction of facilitated diffusion is determined by the concentration gradient for non-polar molecules, or by electrochemical gradient for polar molecules or ions.

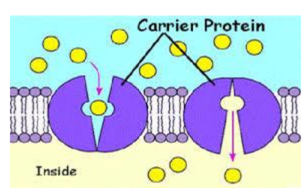
- The transport by diffusion both (simple and facilitated) is a negative or passive process and does not need metabolic energy. So the diffusion energy comes from the concentration or electrochemical gradient of the transported substances.

- The elements transport by diffusion does not lead to accumulation of substances or ions against the electrochemical gradient.

The major characteristics of the passive transport are:-

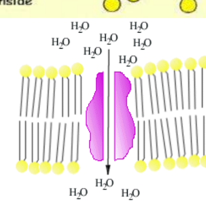
1. Does not need energy.
2. Reversible.
3. Not selective.

Transport protein: carriers and channels.



1. Carriers proteins: also called transporters, they combine specific ion in a way similar of that of the enzyme – substrate conjugation.

2. Channel proteins: these are protein that form channels. These channels are usually recognized by specific ions that can go through them, and this depends on the hydrated size and the ion charge.



Diffusion through a protein channel

The carriers:- is a protein bind the molecule or ion on one side, carry it to the other side.

The carriers should be :-

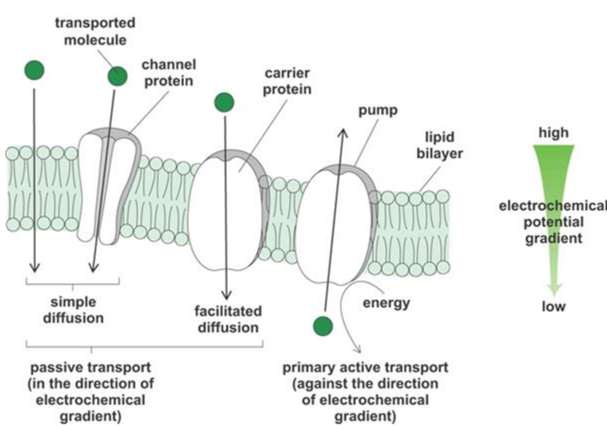
- Binding side confers specificity.

A. Can act to transport a single molecule or ion each time through passive diffusion or active transport → Uniport

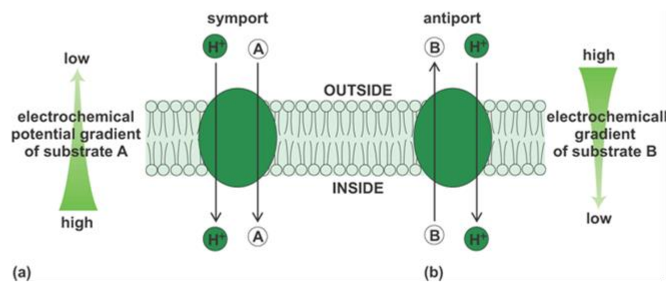
- Or can transport two different molecules or ions each time → cotransport.

1. Can carry those elements in the same direction → symports.
2. Or in opposite directions → antiports.

Important:- cotransport often utilizes the H+ electrochemical gradient established by the H+_ATPase (increases the H+ concentration outside the cell) to drive the transport of another molecule against its electrochemical gradient.

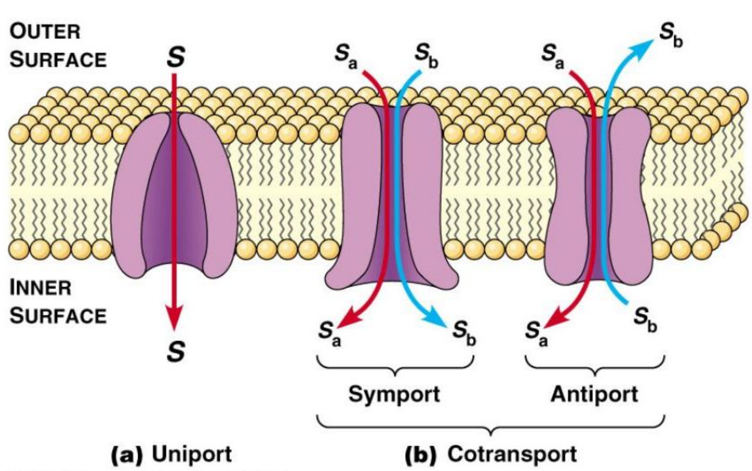


A. Can act to transport a single molecule or ion each time through passive diffusion or active transport Uniport



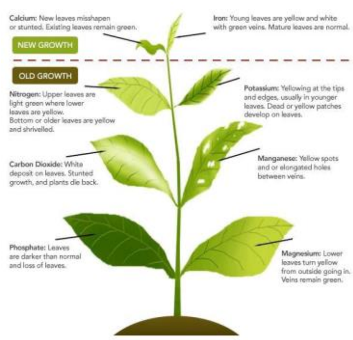
B. Transport two different molecules or ions each time cotransport.
1. Can carry those elements in the same direction symports.
2. Or in opposite directions antiports.

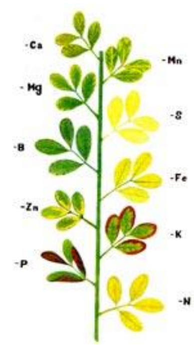
Active transport :- net movement of uncharged molecules from a low concentration to a higher concentration. Uses ATP



Nutrient deficiencies.

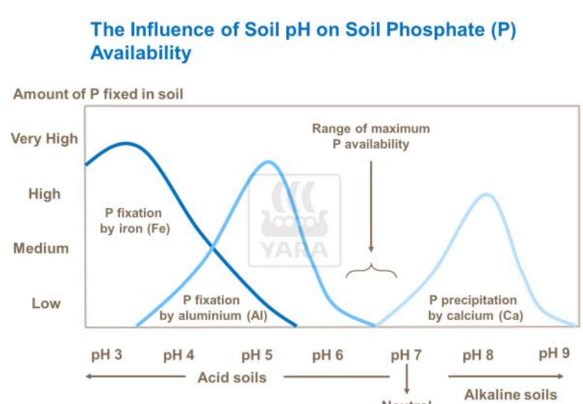
- ❖ Mineral nutrient deficiency occur when the concentration of a nutrient decreases below the typical range.
- ❖ Deficiency of specific nutrient lead to specific visual, often characteristic, symptoms reflective of the role of that nutrient in plant metabolism.



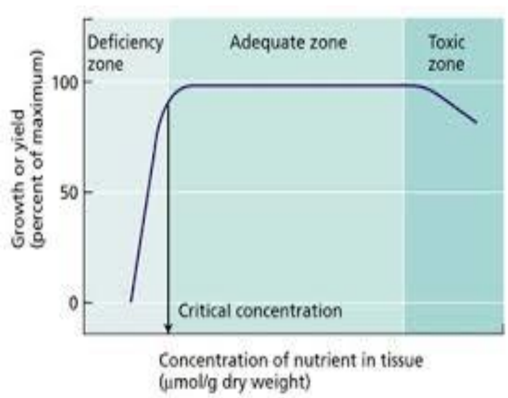


Mineral deficiency can occur when the minerals are inaccessible to the plant due to alkaline or acid pH.

- ❖ Most minerals form soluble carbonates at low pH, these can be taken up by the plant.
- ❖ At alkaline pH or acid pH , some minerals become inaccessible.

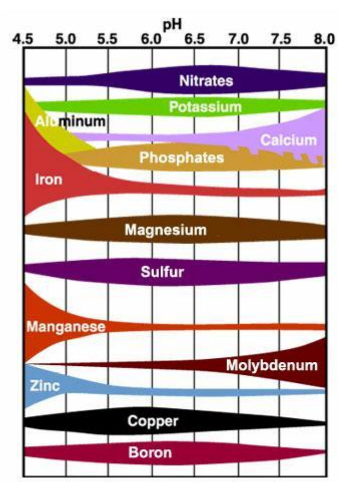


The mineral nutrients can effect the yield of plant.



The soil pH affects nutrient absorption.

- pH affects the growth of plant roots and soil microbes.
- Root growth favors a pH of 5.5-7.5.
- Acidic and alkaline soil conditions make some nutrient elements unavailable for plant roots uptake, like Ca-p and Mg-p complexes in alkaline soil, Al-p and Fe-p in acidic soil. In both cases P become unavailable for root uptake (P deficiency).



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 excess**

The elimination of minerals

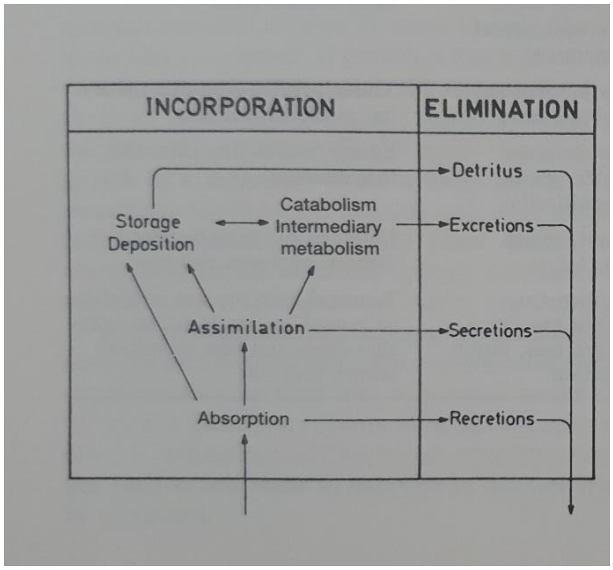
The ascending sap carries minerals into shoot were they gradually accumulated. Most of the deposited mineral substances are eliminated in the course of shedding of various parts of plant like inn leaves and bark thus provide a necessary process of elimination in perennial plants. Minerals also are removed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


INCORPORATION
ELIMINATION
Detritus
Storage
Deposition
Catabolism
Intermediary
metabolism
Excretions
Assimilation
Secretions
Absorption
Recretions