Chapter 38 Plant Nutrition

I. Nutritional Requirements for Growth and Reproduction

A. Where does a plant get its mass?
1. Van Helmont researched this question through an experiment using willow trees. (**Fig. 38.1**)
   a. Planted a willow tree sapling in 200 lb. of soil
   b. Allowed it to grow for 5 years; then weighed the plant and the soil
   c. The plant gained over 164 lb., but the soil lost less than 1 lb.
   d. Erroneously concluded that the plant gained its mass from water
2. Further experiments demonstrated that a plant gains its mass from carbon dioxide and some from the soil.

B. Essential nutrients are absolutely required for normal growth and development. (**Table 38.1**)
1. Three criteria are used to define an essential nutrient:
   a. Required for growth and reproduction
   b. No other element can substitute
   c. Necessary for specific structure or metabolic function
2. Micronutrients are required in small quantities and are usually enzyme cofactors.
3. Macronutrients
   a. They are required in large quantities.
   b. They are needed for the formation of cell macromolecules.
   c. Some are obtained from atmosphere and water.
   d. Others are extracted from soil.

C. Deficiency in an essential nutrient results in abnormal growth.
1. A study on the effect of copper deficiency on tomato plants. (**Fig. 38.3**)
   a. Grew one set of tomato seedlings in hydroponic culture with all essential nutrients
   b. Grew other set with all nutrients except copper
   c. Tomatoes lacking copper had stunted roots and shoots, curled leaves, no flowers, dark foliage.
2. Nutrient deficiency results in severe effects on all plant tissues.
3. Small amount of nutrient will cure deficiency.
4. Effects of all essential nutrients have been studied.

II. Soil Is the Source of Nutrients for Plants

A. Soil Constituents
1. Breakdown (weathering) of rock yields particles of different size and composition. (**Fig. 38.4**)
2. Decomposed organic matter is humus.
3. Soil eventually becomes a mixture of inorganic and organic particles and living organisms. (**Fig. 38.5**)
4. Texture and chemical composition of soil depend on parent rock.
   a. Texture affects oxygen availability and root penetration.
   b. Chemical composition affects nutrient availability.
5. Soil composition will determine plant species capable of growth.

B. Soil Conservation
1. Soil erosion occurs when soil is carried away from a site by wind or water.
2. Erosion can become a problem when an area has become devegetated.
   a. The "Dust Bowl" of the 1930s resulted from drought and poor farming practices. (**Fig. 38.6a**)
   b. Deforestation in Dominican Republic and Haiti has resulted in mudslides and flooding. (**Fig. 38.6b**)
3. Sustainable agriculture techniques can prevent or reduce unnecessary erosion:
   a. Planting rows of trees as windbreaks
   b. Minimizing tilling and plowing
   c. Adding organic matter such as manure; planting over plowed-in crops

C. Elements are found as ions in soil.
1. Negatively charged ions (**Fig. 38.7**)
   a. Dissolve in soil water via hydrogen bonds, except phosphate ions

b. Absorbed by plants
c. Leach out of soil with rainwater

2. Positively charged ions (**Fig. 38.8**)
   a. Bind to negatively charged organic matter and clay
   b. Resist leaching
   c. Are difficult for plants to absorb because of the strong binding to clay
   d. Under the hot, wet weather conditions in tropical rain forests, cations can be leached, leading to decline in nutrient-containing cations.
3. Soil pH affects nutrient availability.
   a. Acidic soil usually has high concentrations of carbonic acid, phosphoric acid, and nitric acid.
      (1) The presence of acids in soils can increase the rate at which elemental ions are released from the soil.
      (2) A higher concentration of protons in the soil speeds the rate of cation exchange and makes cations more available to plants.
   b. Basic or alkaline soils are common where limestone is common.

   See Table 38.2 for summary

III. Mechanisms of Nutrient Uptake

A. Root system is the site of nutrient uptake in most plants.
   1. The zone of maturation is the site of absorption.
   2. Root hairs of epidermal cells increase surface area of roots for absorption. (**Fig. 38.9**)
   3. Roots hairs contain many membrane proteins, which selectively facilitate ion passage into cells.

B. Establishing and Using a Proton Gradient
   1. Plants need to take up diffuse nutrients and concentrate them inside the cell.
   2. Uptake against a concentration gradient requires expenditure of energy.
   3. Proton pumps (H^+-ATPases) use the energy in ATP to accumulate protons outside of the cell. (**Fig. 38.10**)
      a. Leads to concentration gradient that favors proton movement into the cell
      b. Also leads to voltage, or charge difference across the membrane; the exterior is more positive.
         (1) Causes plant cells to have a membrane potential of about –200 mV
         (2) Thus, proton pumps create an electrical gradient as well as a concentration gradient, known as an electrochemical gradient.
      c. The electrical gradient produced by the proton pumps is enough to attract cations into the cell despite their concentration gradients.
   4. Evidence of active uptake occurred in experiments with radioactive K^+.
      a. When K^+ concentration outside cell was lower than inside, uptake into cell continued. (**Fig. 38.109b**)
      b. Further research isolated the sequence for the gene that encodes for a protein that is responsible for the uptake of K^+.
   5. Anions enter the cell via cotransporters. (**Fig. 38.10c**)
      a. Cotransporters are proteins that facilitate diffusion of protons into the cell.
      b. These proteins use the energy released by the diffusion of protons to transport anions into the cell up their concentration gradients.

C. Mycorrhizal fungi aid in nutrient uptake.
   1. Mycorrhizae are fungi that live in association with plant roots.
      a. Ectomycorhizzal fungi (EMF) wrap around root exterior and radiate into soil. (**Fig 38.11a**)
      b. Arbuscular mycorrhizal fungi (AMF) penetrate into root cells.
   2. Relationship between mycorrhizae and plant is mutually beneficial.
      a. Carbon dioxide fixed by plants is transferred to fungi as sugar.
      b. Nitrogen and phosphorus taken up fungi are transferred to plant tissues.

IV. Mechanisms of Ion Exclusion

A. Two systems exist for excluding poisonous metal ions and potentially toxic essential nutrients.

B. Passive Exclusion (**Fig. 38.12)**

1. The presence of the Casparian strip stops the movement of substances into the vascular tissue via the apoplastic pathway, forcing all substances to pass through endodermal cells to reach the vascular tissue.
    a. These cells have specific types of channels and transporters.
    b. This limits the substances allowed into the vascular tissue of the roots.
2. Root hairs also participate in passive exclusion.
    a. A comparison of salt-tolerant corn and salt-intolerant rice suggested that the salt-tolerant species have more sodium channels.
    b. This hypothesis has yet to be confirmed.

C. Active Exclusion

1. Many ions, such as copper, are toxic or dangerous to plants.
2. One mechanism of neutralizing dangerous ions in plants involves metallothionein proteins that bind to and sequester metal ions.
    a. Natural populations of *A. thaliana* vary in their ability to tolerate high concentrations of copper.
    b. Copper-tolerant *A. thaliana* individuals produce more metal-binding protein than copper-intolerant individuals do.
3. Another mechanism for neutralizing toxins involves transport proteins in the tonoplast. (**Fig. 38.13a**)
    a. The tonoplast is the membrane that surrounds the vacuole.
    b. These transport proteins function as antiporters.
        (1) They send protons out of the vacuole, and bring sodium in.
        (2) This may allow plants to survive in salty soil. (**Fig. 38.13b**)
        (3) This mechanism may also be useful in cleaning up contaminated soil via phytoremediation.

V. Nitrogen Fixation

A. Importance of Nitrogen

1. Nitrogen is required in large quantities by all living organisms for production of amino acids and nucleic acids.
2. Molecular nitrogen, N_2, is most abundant component in the atmosphere; very stable and rarely participates in chemical reactions.
3. Almost no living organisms are able to directly utilize N_2 from the atmosphere.
4. Only several species of bacteria can convert atmospheric N_2 to ammonia, NH_3.
5. Conversion is known as nitrogen fixation.

B. Nitrogen-fixing bacteria in genus *Rhizobium* form mutualistic relationship with pea-family plants.

1. Bacteria provide plant with ammonia.
2. Plant provides protection in root nodules and sugars to support bacterial growth. (**Fig. 38.15**)
3. The relationship is symbiotic because two species are living in close association.

C. Colonization of roots by bacteria requires recognition.

1. Roots cells produce flavenoids.
2. When rhizobia contact flavenoids, they synthesize sugar-containing Nod factors.
3. Nod factors bind to membrane proteins on the root hairs. (**Fig. 38.15**)
4. Root hair curls and colonization of root by bacterium proceeds.

D. Host Plant Response

1. Binding of bacterial Nod factors to roots initiates rapid division in cortex cells, forming nodules.
2. Host-plant cells also begin making leghemoglobin.
    a. The nitrogen-fixing bacteria need ATP to fix nitrogen, but their nitrogen-fixing enzyme, nitrogenase, is poisoned by oxygen (a by-product of cellular respiration that makes ATP).
    b. Leghemoglobin binds oxygen, delivering it directly to the enzymes of the electron transport chain. **(Fig. 38.16)**

VI. Adaptations for Nutrient Uptake

A. Epiphytic Plants

1. Grow on the leaves or branches of trees and never make contact with soil
2. Absorb nutrients from rainwater that collects on plants upon which they grow
3. Found mostly in tropics and subtropics; include many orchids, bromeliads, staghorn ferns, and mosses (**Fig. 38.17**)

B. Parasitic Plants

1. Represent less than 1% of total number plant species described thus far
2. Mistletoe taps into its host vascular tissue (**Fig. 38.19**); most are photosynthetic but obtain nutrients and water from the host plant's root system.
3. Is root parasitism more detrimental than competition from same-species plants?
   a. Two alfalfa seeds are grown in pots with one of two different root parasites, an additional alfalfa seed, or left alone.
   b. Plants are grown to maturity, and dry weight of plants grown under each condition is calculated.
   c. Biomass was smaller in pots with parasites than in pots with only host plants.
   d. Conclusion: Parasitism is more damaging than competition, and parasitism reduces the total productivity of organisms involved.

C. Carnivorous Plants

1. Venus flytrap is a photosynthetic plant that grows in bogs with low levels of nitrogen.
2. Through natural selection, Venus flytrap leaf has been modified to form a trap.
   a. Insects land on the trap and touch small hairs that trigger trap closure.
   b. Glands near trap release enzymes that digest the prey.
   c. Plant obtains nitrogen from the digested prey.