I. Essential Nutrients—Elements That Are Absolutely Required for Normal Growth and Development
   A. Macronutrients are those elements that are required in large quantities.
   B. Micronutrients are required in smaller amounts.
   C. Deficiency of an essential element results in abnormal growth.

Figure 33.1a-c

II. Essential Elements—Obtained from Soil in Form of Positively or Negatively Charged Ions
   A. Texture and composition of soil depend on parent rock.

   Figure 33.3
   1. Texture affects oxygen availability and root penetration.
   2. Composition affects nutrient availability.

   Figure 33.4 + charged ions tend to bind to organic matter as well as clay. – charged phosphates also bind to organic matter. Soils without organic matter and clay lose nutrients fast.

   B. Nutrient uptake occurs through root hairs in most plants, by passive or active means.

   Figure 33.5
   2. Active transport of ions can occur against an electrochemical gradient if proton pumps and specific co-transporters are present within the root-hair cell membrane.

   Figures 33.6 (left) & 33.7b

   C. Nutrients that are poisonous or essential elements that become toxic at high concentration are excluded from plants by passive and active mechanisms.

   Figure 33.9 Copper Tolerance related to ability to produce copper-binding proteins
III. Plant Adaptations for Increasing Nutrient Uptake

A. Mycorrhizae are fungi that live in a mutualistic association with plant roots.
   1. Fungus absorbs nitrogen and phosphorus from soil and provides them to plant.
   2. Plant provides sugar to the fungus.
Figure 33.8 Mutualism: An association wherein both participants benefit

B. Nitrogen-fixing bacteria and pea-family plants form mutualistic association.
   1. Bacteria living in root nodules of plant provide nitrogen in the form of ammonia to plants.
   Figures (not in text) showing clover & Wisteria root nodules, nitrogen-fixing bacteria attached to root hairs, and diagrams depicting the enzyme nitrogenase that is used by nitrogen-fixing bacteria to split the N₂ molecule.
   2. Bacteria fixation is not sufficient for modern agricultural needs.
   3. The chemical manufacture of nitrogen fertilizers consumes more energy than any other aspect of US crop production.
   4. Plant provides protection in root nodules and sugars for bacterial growth.
   Figure 33.10
   5. Association is species-specific and requires reciprocal recognition between rhizobia and specific legume for colonization to occur.

C. Epiphytes grow on branches and leaves of trees and obtain nutrients from rain water that collects on plants they grow upon.
Figure 33.13

D. Parasitic plants obtain essential nutrients and water from the root systems of plants they parasitize.
   Figures (not in text) Parasitic Plants: Mistletoe contains chlorophyll and gets mainly water from host plant; dodder does not manufacture chlorophyll & has lost ability to photosynthesize as it gets all its nutrients from host plant.

E. Carnivorous plants grow in areas with low nitrogen, where they trap and digest insect prey.
   Figures (not in text) Pitcher plants, Venus fly trap, sundew