Section A: Nutritional Requirements of Plants

1. The chemical composition of plants provides clues to their nutritional requirements
2. Plants require nine macronutrients and at least eight micronutrients
3. The symptoms of a mineral deficiency depend on the function and mobility of the element
Introduction

• Every organism is an open system connected to its environment by a continuous exchange of energy and materials.

• In the energy flow and chemical cycling that keep an ecosystem alive, plants and other photosynthetic autotrophs perform the key step of transforming inorganic compounds into organic ones.

• At the same time, a plant needs sunlight as its energy source for photosynthesis and raw materials, such as CO₂ and inorganic ions, to synthesize organic molecules.

• The root and shoot systems extensively network a plant with its environment.
1. The chemical composition of plants provides clues to their nutritional requirements

- Early ideas about plant nutrition were not entirely correct and included:
  - Aristotle’s hypothesis that soil provided the substance for plant growth
  - van Helmont’s conclusion from his experiments that plants grow mainly from water
  - Hale’s postulate that plants are nourished mostly by air.
- Plants *do* extract minerals from the soil.
• **Mineral nutrients** are essential chemical elements absorbed from soil in the form of inorganic ions.
  
  • For example, plants acquire nitrogen mainly in the form of nitrate ions ($\text{NO}_3^-$).

• Yet, as indicated by van Helmont’s data, mineral nutrients from the soil make only a small contribution to the overall mass of a plant.
  
  • About 80 - 85% of a herbaceous plant is water.
  
  • Because water contributes most of the hydrogen ions and some of the oxygen atoms incorporated into organic atoms, one can consider water a nutrient too.
However, only a small fraction of the water entering a plant contributes to organic molecules. Over 90% is lost by transpiration. Most of the water retained by a plant functions as a solvent, provides most of the mass for cell elongation, and helps maintain the form of soft tissues by keeping cells turgid. By weight, the bulk of the organic material of a plant is derived not from water or soil minerals, but from the CO₂ assimilated from the atmosphere.
• The uptake of nutrients occurs at both the roots and the leaves.

• Roots, through mycorrhizae and root hairs, absorb water and minerals from the soil.

• Carbon dioxide diffuses into leaves from the surrounding air through stomata.
• Of the 15-20% of a herbaceous plant that is not water, about 95% of the dry weight is organic substances and the remaining 5% is inorganic substances.

• Most of the organic material is carbohydrate, including cellulose in cell walls.

• Thus, carbon, hydrogen, and oxygen are the most abundant elements in the dry weight of a plant.

• Because some organic molecules contain nitrogen, sulfur, and phosphorus, these elements are also relatively abundant in plants.
• More than 50 chemical elements have been identified among the inorganic substances present in plants.
  • However, it is unlikely that all are essential.

• Roots are able to absorb minerals somewhat selectively, enabling the plant to accumulate essential elements that may be present in low concentrations in the soil.
  • However, the minerals in a plant reflect the composition of the soil in which the plant is growing.
  • Therefore, some of the elements in a plant are merely present, while others are essential.
2. Plants require nine macronutrients and at least eight micronutrients

• A particular chemical element is considered an **essential nutrient** if it is required for a plant to grow from a seed and complete the life cycle.

• Hydroponic cultures have identified 17 elements that are essential nutrients in all plants and a few other elements that are essential to certain groups of plants.
Hydroponic culture can determine which mineral elements are actually essential nutrients.

Plants are grown in solutions of various minerals dissolved in known concentrations.

If the absence of a particular mineral, such as potassium, causes a plant to become abnormal in appearance when compared to controls grown in a complete mineral medium, then that element is essential.

Fig. 37.2
• Elements required by plants in relatively large quantities are macronutrients.

• There are nine macronutrients in all, including the six major ingredients in organic compounds: carbon, oxygen, hydrogen, nitrogen, sulfur, and phosphorus.

• The other three are potassium, calcium, and magnesium.
• Elements that plants need in very small amounts are **micronutrients**.

  • The eight micronutrients are iron, chlorine, copper, zinc, magnanese, molybdenum, boron, and nickel.

  • Most of these function as cofactors of enzymatic reactions.

  • For example, iron is a metallic component in cytochromes, proteins that function in the electron transfer chains of chloroplasts and mitochondria.

  • While the requirement for these micronutrients is so modest (only one atom of molybdenum for every 16 million hydrogen atoms in dry materials), a deficiency of a micronutrient can weaken or kill a plant.
<table>
<thead>
<tr>
<th>Element</th>
<th>Form Available to Plants</th>
<th>Major Functions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Macronutrients</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon</td>
<td>CO₂</td>
<td>Major component of plant’s organic compounds</td>
</tr>
<tr>
<td>Oxygen</td>
<td>CO₂</td>
<td>Major component of plant’s organic compounds</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>H₂O</td>
<td>Major component of plant’s organic compounds</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>NO₃⁻, NH₄⁺</td>
<td>Component of nucleic acids, proteins, hormones, and coenzymes</td>
</tr>
<tr>
<td>Sulfur</td>
<td>SO₄²⁻</td>
<td>Component of proteins, coenzymes</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>H₂PO₄⁻, HPO₄²⁻</td>
<td>Component of nucleic acids, phospholipids, ATP, several coenzymes</td>
</tr>
<tr>
<td>Potassium</td>
<td>K⁺</td>
<td>Cofactor that functions in protein synthesis; major solute functioning in water balance; operation of stomata</td>
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<tr>
<td>Calcium</td>
<td>Ca²⁺</td>
<td>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</td>
</tr>
<tr>
<td>Magnesium</td>
<td>Mg²⁺</td>
<td>Component of chlorophyll; activates many enzymes</td>
</tr>
<tr>
<td><strong>Micronutrients</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chlorine</td>
<td>Cl⁻</td>
<td>Required for water-splitting step of photosynthesis; functions in water balance</td>
</tr>
<tr>
<td>Iron</td>
<td>Fe³⁺, Fe²⁺</td>
<td>Component of cytochromes; activates some enzymes</td>
</tr>
<tr>
<td>Boron</td>
<td>H₂BO₃⁻</td>
<td>Cofactor in chlorophyll synthesis; may be involved in carbohydrate transport and nucleic acid synthesis</td>
</tr>
<tr>
<td>Manganese</td>
<td>Mn²⁺</td>
<td>Active in formation of amino acids; activates some enzymes; required for water-splitting step of photosynthesis</td>
</tr>
<tr>
<td>Zinc</td>
<td>Zn²⁺</td>
<td>Active in formation of chlorophyll; activates some enzymes</td>
</tr>
<tr>
<td>Copper</td>
<td>Cu⁺, Cu²⁺</td>
<td>Component of many redox and lignin-biosynthetic enzymes</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>MoO₄²⁻</td>
<td>Essential for nitrogen fixation; cofactor that functions in nitrate reduction</td>
</tr>
<tr>
<td>Nickel</td>
<td>Ni²⁺</td>
<td>Cofactor for an enzyme functioning in nitrogen metabolism</td>
</tr>
</tbody>
</table>
3. The symptoms of a mineral deficiency depend on the function and mobility of the element

- The symptoms of a mineral deficiency depend partly on the function of that nutrient in the plant.
  - For example, a magnesium deficiency, an ingredient of chlorophyll, causes yellowing of the leaves, or chlorosis.

Fig. 37.3
• The relationship between a mineral deficiency and its symptoms can be less direct.

• For example, chlorosis can also be caused by iron deficiency because iron is a required cofactor in chlorophyll synthesis.
• Mineral deficiency symptoms depend also on the mobility of the nutrient within the plant.
  
• If a nutrient moves about freely from one part of a plant to another, then symptoms of the deficiency will appear first in older organs.
  
• Young, growing tissues have more “drawing power” than old tissues for nutrients in short supply.
  
• For example, a shortage of magnesium will lead to chlorosis first in older leaves.
  
• If a nutrient is relatively immobile, then a deficiency will affect young parts of the plant first.
  
• Older tissue may have adequate supplies which they retain during periods of shortage.
• The symptoms of a mineral deficiency are often distinctive enough for a plant physiologist or farmer to diagnose its cause.

• This can be confirmed by analyzing the mineral content of the plant and the soil.

• Deficiencies of nitrogen, potassium, and phosphorus are the most common problems.

• Shortages of micronutrients are less common and tend to be geographically localized because of differences in soil composition.

• The amount of micronutrient needed to correct a deficiency is usually quite small, but an overdose can be toxic to plants.
• One way to ensure optimal mineral nutrition is to grow plants hydroponically on nutrient solutions that can be precisely regulated.

• This technique is practiced commercially, but the requirements for labor and equipment make it relatively expensive compared with growing crops in soil.
Mineral deficiencies are not limited to terrestrial ecosystems, nor are they unique to plants among photosynthetic organisms.

For example, populations of planktonic algae in the southern oceans are restrained by deficiencies of iron in seawater.

In a limited trial in the relatively unproductive seas between Tasmania and Antarctica, researchers demonstrated that dispersing small amounts of iron produced large algal blooms that pulled carbon dioxide out of the air.

Seeding the oceans with iron may help slow the increase in carbon dioxide levels in the atmosphere, but it may also cause unanticipated environmental effects.