



Chapter 15

Optimizing Food Production

THE MAIN IDEA



Agriculture employs much chemistry.

15.1 [Humans Eat at All Trophic Levels](#)

15.2 **Plants Require Nutrients**

15.3 [Soil Fertility](#)

15.4 [Natural and Synthetic Fertilizers](#)

15.5 [Pesticides Kill Pests](#)

15.6 [Past Agricultural Practices](#)

15.7 [Quality Agricultural Practices](#)



15.2 Plants Require Nutrients

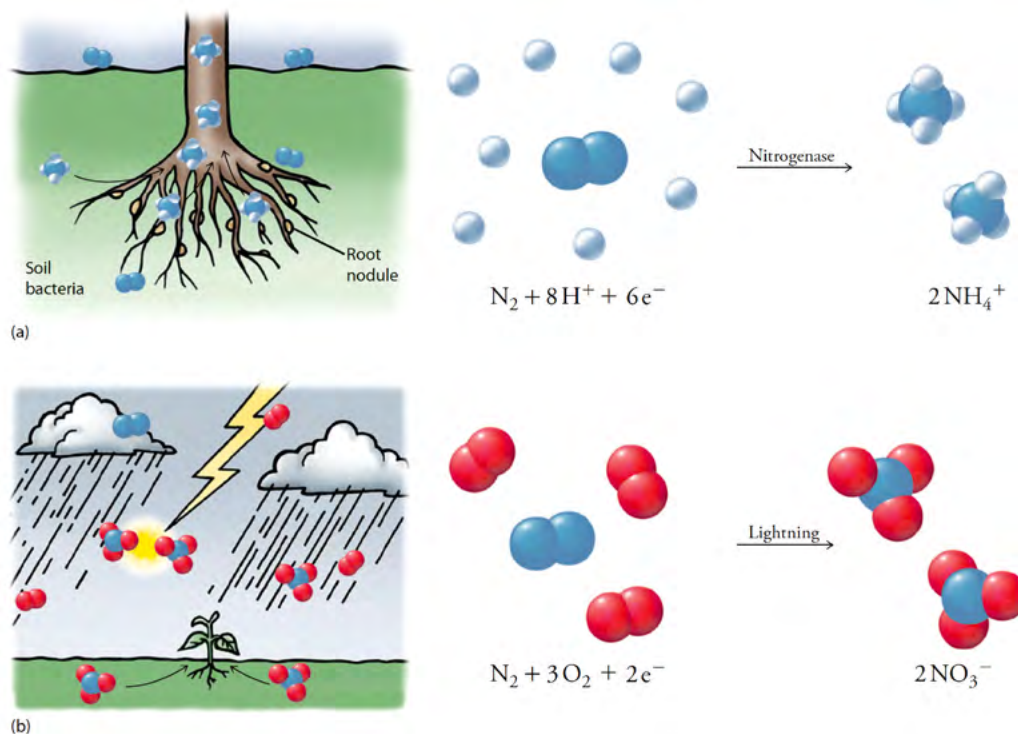
Plant material consists primarily of carbohydrates, which are made of the elements carbon, oxygen, and hydrogen. Plants get these three elements from carbon dioxide and water, but the soil in which the plants live also provides many other elements vital to their survival and good health. **Table 15.1** lists these nutrients as *macronutrients*, those nutrients needed in large quantities, and *micronutrients*, those nutrients needed only in trace quantities. Some micro-nutrients are needed in such trace quantities that a plant's lifetime supply is provided by the seed from which the plant grew.

TABLE 15.1 Essential Elements for Most Plants

ELEMENT	FORM AVAILABLE TO PLANTS
Macronutrients	
Nitrogen, N	NO_3^- , NH_4^+
Potassium, K	K^+
Calcium, Ca	Ca^{2+}
Magnesium, Mg	Mg^{2+}
Phosphorus, P	$\text{H}_2\text{PO}_4^{2-}$, HPO_4^{2-}
Sulfur, S	SO_4^{2-}
Micronutrients	
Chlorine, Cl	Cl^-
Iron, Fe	Fe^{3+} , Fe^{2+}
Boron, B	H_2BO_3^-
Manganese, Mn	Mn^{2+}
Zinc, Zn	Zn^{2+}
Copper, Cu	Cu^+ , Cu^{2+}
Molybdenum, Mo	MoO_4^{2-}

Figure 15.4 >

Two pathways for nitrogen fixation, a source of nitrogen for plants. (a) Both free-living bacteria in the soil and microorganisms in root nodules produce ammonium ions. (b) Lightning provides the energy needed to form nitrate ions from atmospheric nitrogen.



Plants Utilize Nitrogen, Phosphorus, and Potassium

Plants need nitrogen to build proteins and a variety of other biomolecules, such as *chlorophyll*, the green pigment responsible for photosynthesis. As Table 15.1 shows, plants are able to absorb nitrogen from the soil in the form of ammonium ions, NH_4^+ , and nitrate ions, NO_3^- . **Figure 15.4** shows the natural sources of nitrogen for a plant. The two reactions shown there are examples of **nitrogen fixation**, which is defined as any chemical reaction that converts atmospheric nitrogen to a form of nitrogen that plants can use. The two most common forms are ammonium ions and nitrate ions.

Most of the ammonium ions in soil come from nitrogen fixation carried out either by bacteria living in the soil or by microorganisms living in root nodules of certain plants, especially those of the legume family, including clover, alfalfa, beans, and peas (plants generally called *nitrogen fixers*). These microorganisms possess the enzyme *nitrogenase*, which catalyzes the formation of ammonium ions from atmospheric nitrogen and soil-bound hydrogen ions, as **Figure 15.4a** shows.

Nitrogen fixation also results to a lesser extent from the action of lightning on atmospheric nitrogen, as **Figure 15.4b** shows. The high energy of the lightning is sufficient to initiate the oxidization of atmospheric nitrogen to nitrate ions, which are then washed into the soil by rain.

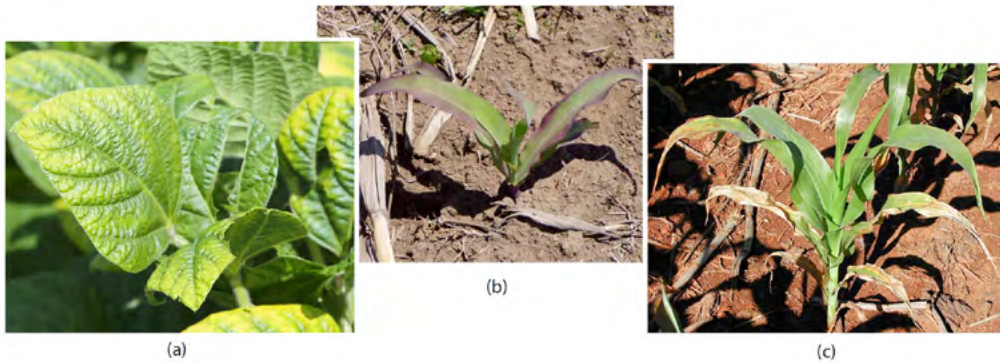
In a natural setting, nitrogen fixation is the original source of ammonium and nitrate ions in the soil. Most of this fixed nitrogen, however, is recycled from one organism to the next. After a plant dies, for example, bacterial decomposition of the plant releases ammonium and nitrate ions back into the soil, where these ions become available to plants that are still living.

Plants deficient in nitrogen have stunted growth. Because nitrogen is needed for making chlorophyll, another symptom of nitrogen deficiency in plants is yellow leaves, as **Figure 15.5a** shows. The yellowing is most pronounced in older leaves—younger ones remain green longer, because soluble forms of nitrogen are transported to them from older dying leaves.



READING CHECK

What macronutrients do plants need for making chlorophyll?



< **Figure 15.5**

(a) The leaves of nitrogen-deficient plants turn yellow prematurely. (b) Phosphorus deficiencies are marked by stunted growth. (c) The leaves of potassium-deficient plants develop dead areas.

Plants need phosphorus to build nucleic acids, phospholipids, and a variety of energy-carrying biomolecules such as ATP. All phosphorus comes to plants in the form of phosphate ions. The major natural source of these ions is eroded phosphate-containing rock. Significant amounts of phosphates are also recycled as organisms die and become incorporated into the soil. After nitrogen, phosphorus is most often the limiting element in soil. Phosphorus-deficient plants are stunted, as **Figure 15.5b** shows.

Potassium ions activate many of the enzymes essential to photosynthesis and respiration. As with phosphates, the major natural sources of potassium ions are eroded rock and the recycling of potassium ions from decomposing plant material. After nitrogen and phosphorus, soils are usually most deficient in potassium. Symptoms of potassium deficiency include small areas of dead tissue, usually along leaf tips or edges, as shown in **Figure 15.5c**. As with nitrogen and phosphorus, potassium ions are easily redistributed from mature to younger parts of the plant, so deficiency symptoms first appear on older leaves. When cereal grains, such as wheat or corn, are potassium-deficient, they develop weak stalks and their roots become more easily infected with root-rotting organisms. These two factors cause potassium-deficient plants to be easily bent to the ground by wind, rain, or snow.

Plants Also Utilize Calcium, Magnesium, and Sulfur

Both calcium and magnesium are absorbed by plants as the positively charged calcium and magnesium ions, Ca^{2+} and Mg^{2+} , respectively, and sulfur is absorbed as the negatively charged sulfate ion, SO_4^{2-} . Most topsoil contains enough of these ions for adequate plant growth.

Calcium ions are essential for building cell walls. Once absorbed by the plant, calcium ions are relatively immobile; that is, they do not travel well from one part of the plant to another. The plant therefore is not very capable of reallocating calcium supplies in times of need. This is why new-growth zones, such as the tips of roots and stems, are most susceptible to calcium deficiencies. The results are twisted and deformed growth patterns.



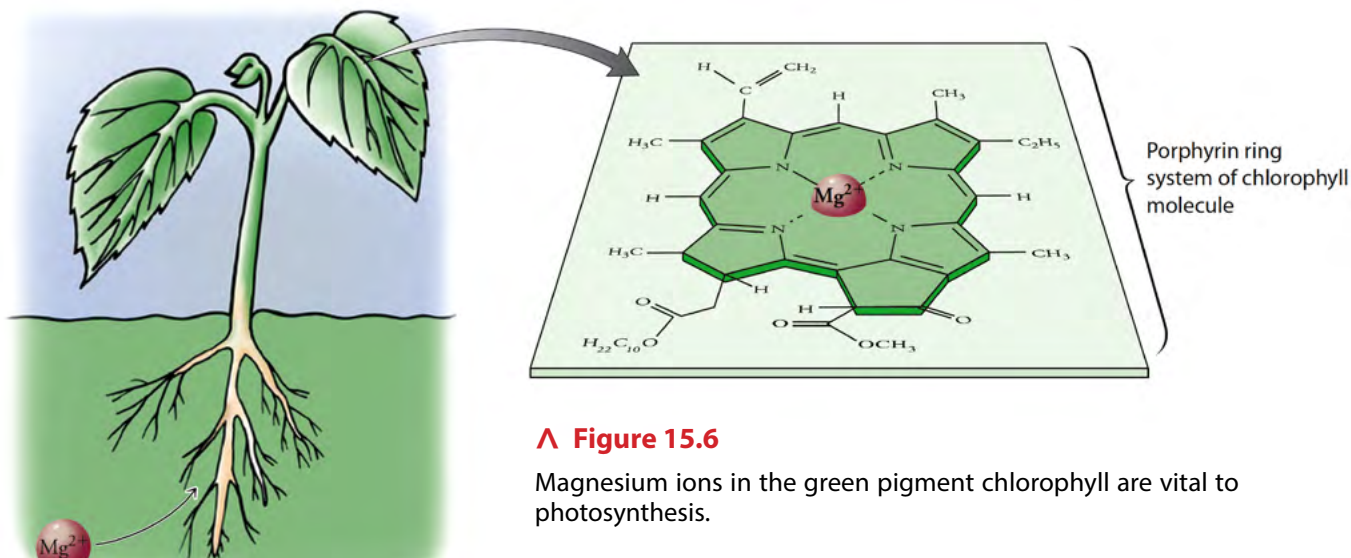
FOR YOUR INFORMATION

Plants readily absorb potassium ions, but they have a low tolerance for sodium ions, which they actively pump out of their systems. Interestingly, all living cells, not just plant cells, have a low tolerance for sodium ions and therefore have evolved mechanisms for pumping them out. As was shown in Figure 14.20, a neuron pumping out sodium ions sets the stage for a nerve impulse. Multiple nerve impulses ultimately lead to conscious thought. From a macroscopic perspective, plants and animals are significantly different. On a deeper submicroscopic level, however, their chemistries are much the same. In other words, plants and animals are more closely related than one might initially think.

CONCEPT CHECK

Why are the seeds of nitrogen-fixing plants such as soybeans and peanuts unusually high in protein?

CHECK YOUR ANSWER Plants use nitrogen to build proteins. Nitrogen-fixing plants assimilate a lot of nitrogen, so they produce proteins in large quantities.



Magnesium ions are essential for the formation of chlorophyll, which is the green-pigmented molecule essential for photosynthesis. Chlorophyll houses a magnesium ion at the center of a structure called a porphyrin ring, as shown in **Figure 15.6**. Besides its presence in chlorophyll, magnesium is essential because it activates many metabolic enzymes. Deficiencies in magnesium, which are rare, result in yellow leaves, because the plant is unable to generate chlorophyll. Most of the sulfur in plants occurs in proteins, especially in the amino acids cysteine and methionine. Another essential compound that contains sulfur is coenzyme A, a compound essential for respiration, for the synthesis and breakdown of fatty acids, and for the vitamins thiamine and biotin. Sulfur can be absorbed by leaves as gaseous sulfur dioxide, SO_2 , an environmental pollutant released from active volcanoes and from the burning of wood or fossil fuels.

CONCEPT CHECK

Plants require more calcium and magnesium than phosphorus and potassium, yet deficiencies of calcium and magnesium are much more infrequent than deficiencies of phosphorus and potassium. How can this be?

CHECK YOUR ANSWER The potential for nutrient deficiency depends not only on the amount of nutrient needed but also on the nutrient's availability. Calcium and magnesium are abundant in most soils, but phosphorus and potassium are not. Deficiencies of phosphorus and potassium therefore tend to be more frequent.