Section C: The Special Case of Nitrogen as a Plant Nutrient

1. The metabolism of soil bacteria makes nitrogen available to plants
2. Improving the protein yield of crops is a major goal of agricultural research
1. The metabolism of soil bacteria makes nitrogen available to plants

- It is ironic that plants sometimes suffer nitrogen deficiencies, for the atmosphere is nearly 80% nitrogen.
  - Plants cannot use nitrogen in the form of N\(_2\).
  - It must first be converted to ammonium (NH\(_4^+\)) or nitrate (NO\(_3^-\)).
  - In the short term, the main source of nitrogen is the decomposition of humus by microbes, including ammonifying bacteria.
• Nitrogen is lost from this local cycle when soil microbes called denitrifying bacteria converts NO$_3^-$ to N$_2$ which diffuses to the atmosphere.

• Other bacteria, **nitrogen-fixing bacteria**, restock nitrogenous minerals in the soil by converting N$_2$ to NH$_3$ (ammonia), via **nitrogen fixation**.
• All life on Earth depends on nitrogen fixation, a process performed only by certain prokaryotes.
  
  • In the soil, these include several species of free-living bacteria and several others that live in symbiotic relationships with plants.
  
  • The reduction of \( \text{N}_2 \) to \( \text{NH}_3 \) is a complicated, multi-step process, catalyzed by one enzyme complex, \textbf{nitrogenase}:

\[
\text{N}_2 + 8\text{e}^- + 8\text{H}^+ + 16\text{ATP} \rightarrow 2\text{NH}_3 + \text{H}_2 + 16\text{ADP} + 16\text{P}_i
\]

• Nitrogen-fixing bacteria are most abundant in soils rich in organic materials, which provide fuels for cellular respiration that supports this expensive metabolic process.
• In the soil solution, ammonia picks up another hydrogen ion to form ammonium (NH$_4^+$), which plants can absorb.

• However, nitrifying bacteria in the soil quickly oxidize ammonium to nitrate (NO$_3^-$) which plants can also absorb.
  
  • After nitrate is absorbed by roots, plant enzymes reduce nitrate back to ammonium, which other enzymes then incorporate into amino acids and other organic compounds.
  
  • Most plant species export nitrogen from roots to shoots, via the xylem, in the form of nitrate or organic compounds that have been synthesized in the roots.
2. Improving the protein yield of crops is a major goal of agricultural research

- The ability of plants to incorporate fixed nitrogen into proteins and other organic substances has a major impact on human welfare.
  - Protein deficiency is the most common form of malnutrition.
  - Either by choice or economic necessity, the majority of the world’s people have a predominately vegetarian diet.
  - Unfortunately, plants are a poor source of protein and may be deficient in one or more of the amino acids that humans need from their diet.
• Plant breeding has resulted in new varieties of corn, wheat, and rice that are enriched in protein.

• However, many of these “super” varieties have an extraordinary demand for nitrogen which is usually supplied by commercial fertilizer produced by energy-intensive industrial production.

• Generally, the countries that most need high-protein crops are the ones least able to afford to pay for the fossil fuels that power the factories.
• Agricultural scientists are pursuing a variety of strategies to overcome this protein deficiency.
  • For example, the use of new catalysts based on those used by nitrogenase to fix nitrogen may make commercial production of nitrogen fertilizers cheaper.
  • Alternatively, improvements of the productivity of symbiotic nitrogen fixation may potentially increase protein yields of crops.