

Nitrogen cycle

Plants need **ammonium** (NH_4^+) or sometimes **nitrate** (NO_3^-) as the usable form of nitrogen. But most nitrogen exists as N_2 **gas**, which plants cannot use directly. The cycle has microbial partners at almost every step.

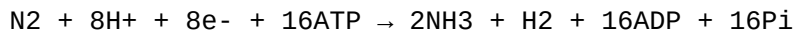
Big picture flow

1. N_2 (0) \rightarrow $\text{NH}_3/\text{NH}_4^+$ (-3) by fixation.
 2. NH_4^+ taken up OR oxidized to nitrate (nitrification).
 3. NO_3^- absorbed \rightarrow reduced back to NH_4^+ (assimilation).
 4. NH_4^+ \rightarrow organic nitrogen (amino acids, proteins).
 5. Denitrification returns N_2 to atmosphere.
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1. Nitrogen fixation (symbiosis with bacteria)

- Atmosphere: ~78% N_2 , but it's very stable (triple bond, oxidation state 0).
- Certain bacteria (*Rhizobium* in legumes, cyanobacteria, etc.) convert $\text{N}_2 \rightarrow \text{NH}_3/\text{NH}_4^+$ using **nitrogenase**, powered by ATP + reductants.

Equation:

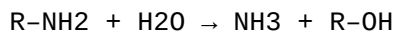


Goal: introduce reduced nitrogen (-3 oxidation state) into ecosystems.

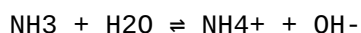
For plants: NH_3 immediately protonates to NH_4^+ in soil solution \rightarrow taken up.

2. Ammonification (decomposition / mineralization)

- Organic nitrogen (proteins, nucleic acids) \rightarrow $\text{NH}_3/\text{NH}_4^+$ via microbial breakdown.
- Example reaction (generic):



Free ammonia (NH_3) in soil solution usually exists as ammonium (NH_4^+), which plants can absorb:

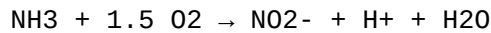


3. Nitrification (microbial oxidation, aerobic)

- Carried out by *Nitrosomonas* and *Nitrobacter*.

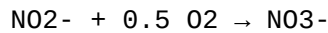
- Converts NH_4^+ into NO_3^- , which is more mobile in soils (but also more prone to leaching).

Step 1: ammonia \rightarrow nitrite



(N: $-3 \rightarrow +3$, oxidation, energy released)

Step 2: nitrite \rightarrow nitrate



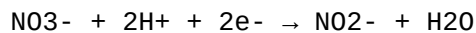
(N: $+3 \rightarrow +5$, oxidation, energy released)

Goal: microbes harvest energy; product NO_3^- can be taken up by plants.

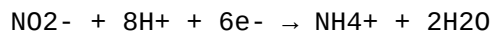
4. Assimilation (in plants)

- Plants absorb both NH_4^+ and NO_3^- .
- If NO_3^- is taken up, it must be reduced back to NH_4^+ inside the plant (because amino acids/proteins require N at -3).

Step A: $\text{NO}_3^- \rightarrow \text{NO}_2^-$ (via nitrate reductase, NADH donor)



Step B: $\text{NO}_2^- \rightarrow \text{NH}_4^+$ (via nitrite reductase, ferredoxin donor)

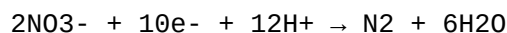


Goal: make reduced nitrogen available for incorporation into glutamine, glutamate, and eventually all amino acids.

5. Denitrification (microbial, anaerobic)

- NO_3^- or $\text{NO}_2^- \rightarrow \text{N}_2$ gas, returning nitrogen to atmosphere.
- Carried out by bacteria in low-oxygen soils (e.g. waterlogged).

Simplified:



Goal: close the cycle, but from agriculture view \rightarrow loss of available nitrogen.
