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) → **NH_3/NH_4^+ (–3)** by fixation.
2. NH_4^+ taken up OR oxidized to nitrate (nitrification).
3. NO_3^- absorbed → reduced back to NH_4^+ (assimilation).
4. NH_4^+ → 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 N_2 → NH_3/NH_4^+ using **nitrogenase**, powered by ATP + reductants.

Equation:

```
N2 + 8H+ + 8e- + 16ATP → 2NH3 + H2 + 16ADP + 16Pi
```

Goal: introduce reduced nitrogen (–3 oxidation state) into ecosystems.
For plants: NH_3 immediately protonates to NH_4^+ in soil solution → taken up.

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2. Ammonification (decomposition / mineralization)

- Organic nitrogen (proteins, nucleic acids) → NH_3/NH_4^+ via microbial breakdown.
- Example reaction (generic):

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R–NH2 + H2O → NH3 + R–OH
```

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

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NH3 + H2O ⇌ NH4+ + OH-
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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 → nitrite

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NH3 + 1.5 O2 → NO2- + H+ + H2O
```

(N: –3 → +3, oxidation, energy released)

Step 2: nitrite → nitrate

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NO2- + 0.5 O2 → NO3-
```

(N: +3 → +5, oxidation, energy released)

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

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4. Assimilation (in plants)

- Plants absorb both $\mathbf{NH_4^+}$ and $\mathbf{NO_3^-}$.
- 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: $NO_3^- \rightarrow NO_2^-$ (via nitrate reductase, NADH donor)

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NO3- + 2H+ + 2e- → NO2- + H2O
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Step B: $NO_2^- \rightarrow NH_4^+$ (via nitrite reductase, ferredoxin donor)

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NO2- + 8H+ + 6e- → NH4+ + 2H2O
```

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

5. Denitrification (microbial, anaerobic)

- NO_3^- or $NO_2^- \rightarrow N_2$ gas, returning nitrogen to atmosphere.
- Carried out by bacteria in low-oxygen soils (e.g. waterlogged).

Simplified:

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2NO3- + 10e- + 12H+ → N2 + 6H2O
```

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