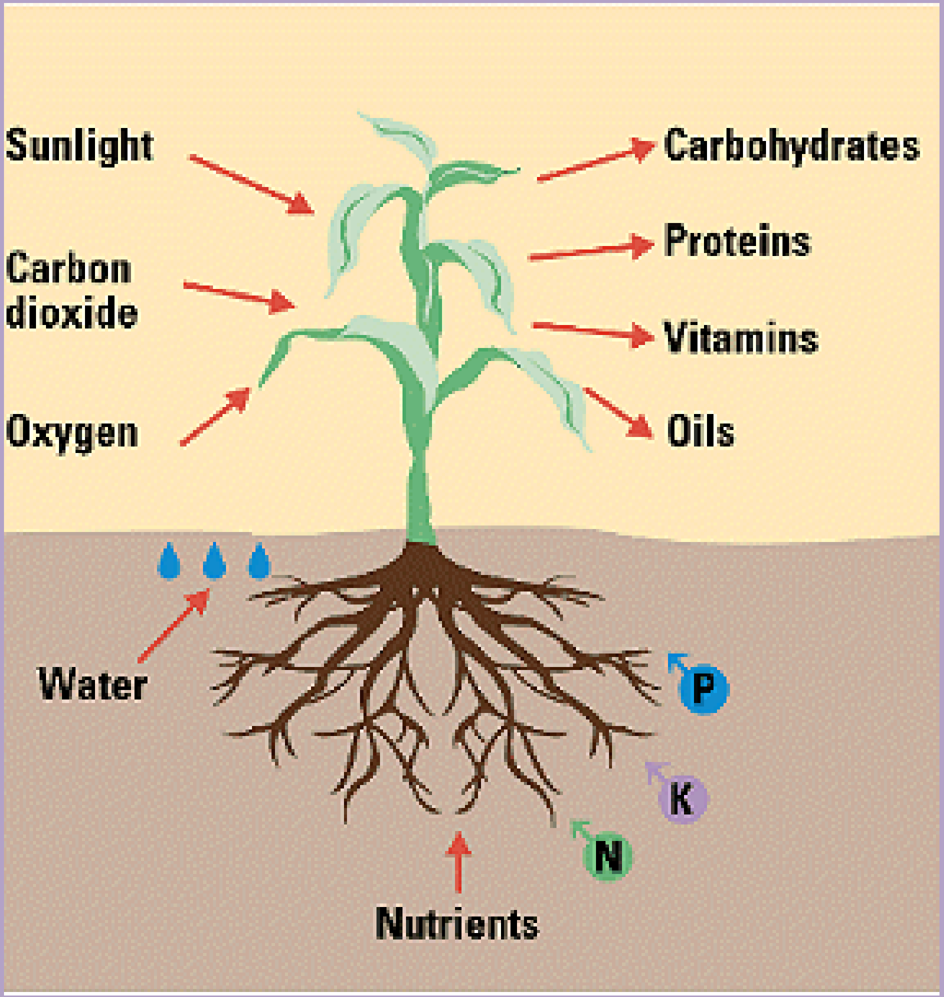
Role of Nitrogen in Soils

One of the 3 Plant Essential Macronutrients: Nitrogen, Potassium, & Phosphorous

Nitrogen Nutrient Functions

- **plant and microbial growth and development**
- **needed for enzymatic reactions**
- **photosynthesis**
- **quality and quantity of dry matter in leafy vegetables and protein in grain crops**
- **primary production of most ecosystems is limited by N availability**

(Silva and Uchida, 2000)



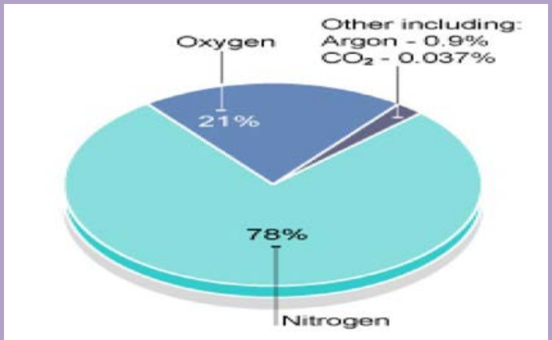
Found online @: is.lrs.uoguelph.ca/.../gp/bmp/nutrbmp.html

Outline:

1) Inputs
2) Biological Nitrogen Fixation
3) Mineralization
4) Nitrification
5) Denitrification
6) Other Losses

Inputs:

Atmospheric: Mostly N_2, traces of NO_2, N_2O, NH_3

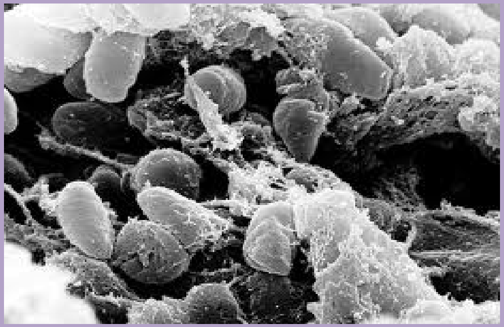


Lightning: HNO_3 (Nitric Acid) Oxidation of N:

$$N_2 + 3O_2 \rightarrow 2NO_3^-$$

Animal Waste: $(NH_2)_2CO$ (Urea)

Microbial Residue: OM → amino and nucleic acids



Animal & Plant Residue: OM → largely $R\text{-}NH_2$ (amine groups) in proteins

Industrial Fertilizers:
NH_3, NO_3, NH_2
Haber-Bosch
(1200°C, 500 ATM)
$3CH_4 + 3O_2 + 2N_2 \rightarrow 4NH_3 + 3CO_2$

http://www.google.com/search?q=image

Soil Nitrogen Cycle

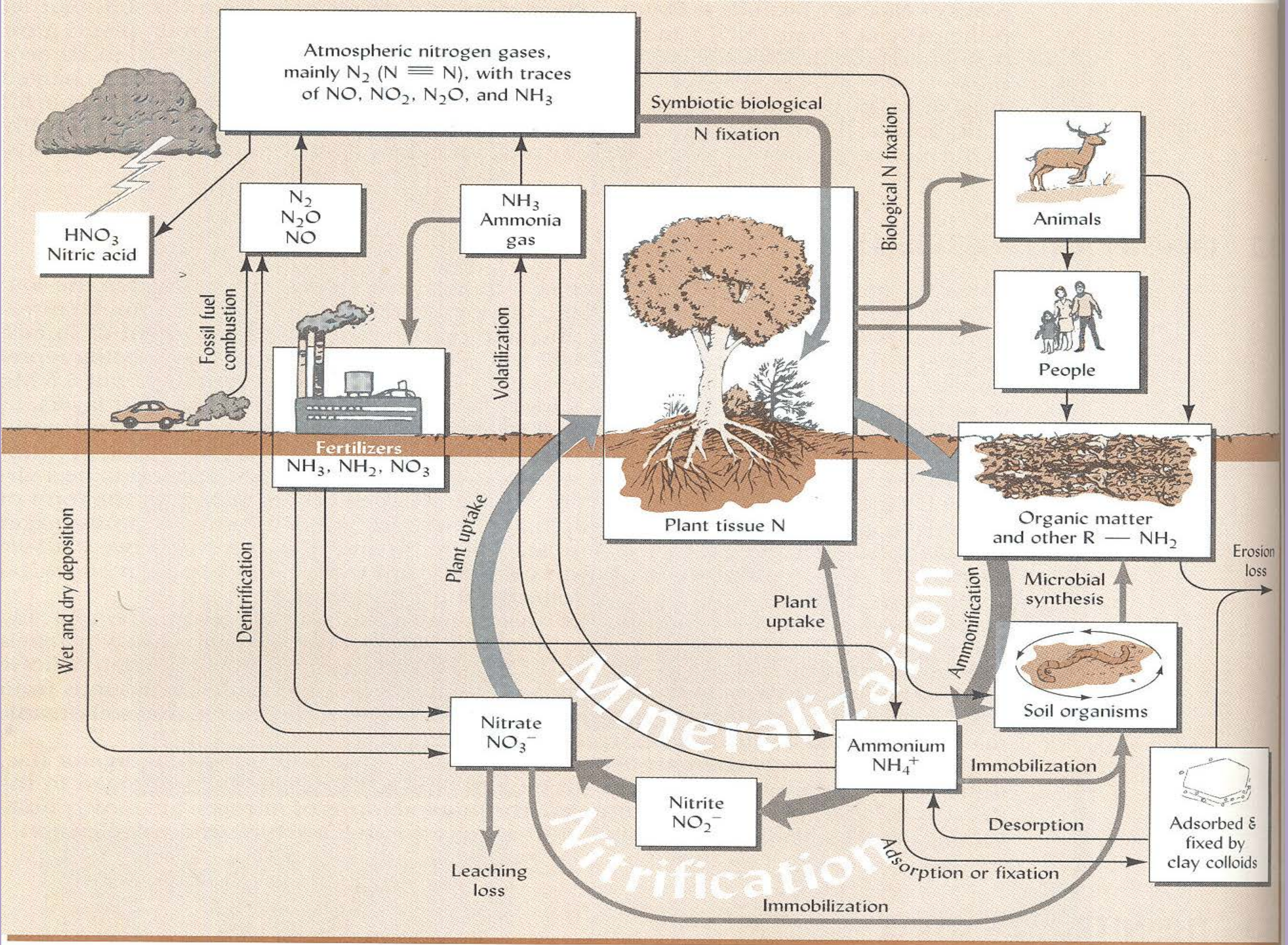


FIGURE 13.2 The nitrogen cycle, emphasizing the primary cycle (heavy, dark arrows) in which organic nitrogen is mineralized, plants take up the mineral nitrogen, and eventually organic nitrogen is returned to the soil as plant residues. Note also the pathways by which nitrogen is lost from the soil and the means by which it is replenished. The compartments represent various forms of nitrogen; the arrows represent processes by which one form is transformed into another.

Ammonium nitrogen is subject to five possible fates in the nitrogen cycle: (1) *immobilization* by microorganisms; (2) removal by *plant uptake;* (3) ammonium ions may be *fixed* in the interlayers of certain 2:1 clay minerals; (4) ammonium ions may be transformed into ammonia gas and lost to the atmosphere by *volatilization;* (5) ammonium ions may be oxidized to nitrite and subsequently to nitrate by a microbial process called *nitrification.*

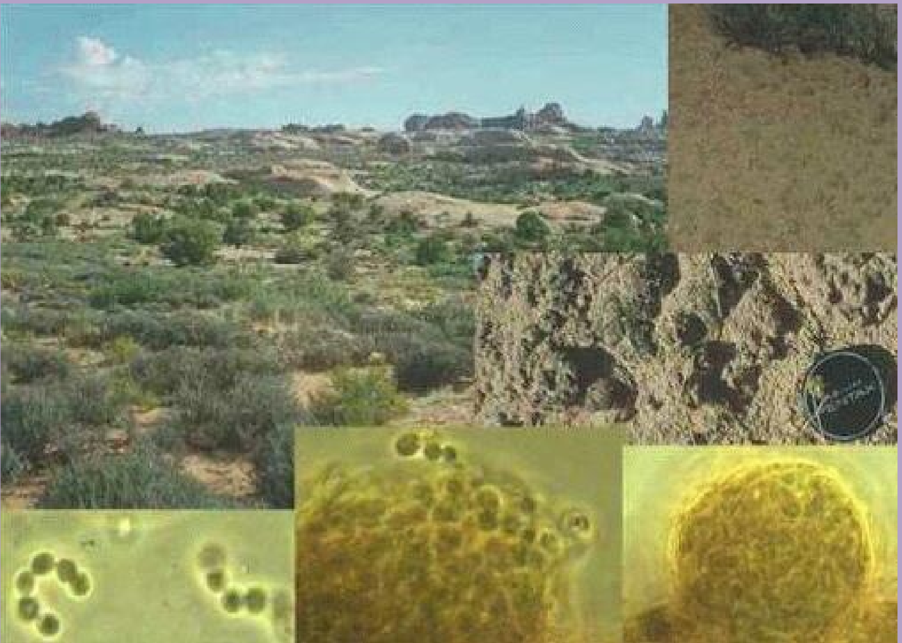
Nitrogen in the nitrate form is highly mobile in the soil and in the environment. Whether added as fertilizer or produced in the soil by nitrification, nitrate may take any of four paths in the nitrogen cycle: (1) *immobilization* by microorganisms; (2) removal by *plant uptake;* (3) nitrate ions may be lost by *leaching* in drainage water; or (4) by *volatilization* to the atmosphere as several nitrogen-containing gases.

(Brady and Weil, 1996)

Conversions & Players in the Cycle

- **Biological nitrogen fixation** (BNF) occurs when atmospheric nitrogen is converted to ammonia by an enzyme called nitrogenase. The formula for BNF is: $N_2 + 8\ H^+ + 16ATP + 8\ e^- \rightarrow 2\ NH_3 + H_2 + 16ADP + 16Pi$

1) free-living bacteria: cyanobacteria and azotobacteraceae The image below shows a pure culture of the cyanobacterium *Nostoc*, a common photosynthetic partner of lichens. Nitrogen fixation occurs in special cells termed **heterocysts** or **heterocytes** (H) which occur at intervals along the cyanobacterial filaments. This separation of cellular functions is necessary because cyanobacteria have oxygen-evolving photosynthesis but the nitrogen-fixing enzyme, **nitrogenase**, is unstable in the presence of oxygen. This problem is overcome because the heterocysts contain only part of the photosynthetic apparatus, termed photosystem I, which can be used to generate energy (as ATP). But the heterocysts do not contain photosystem II, which is used to split water into hydrogen (for combination with CO_2 to produce organic products) and oxygen



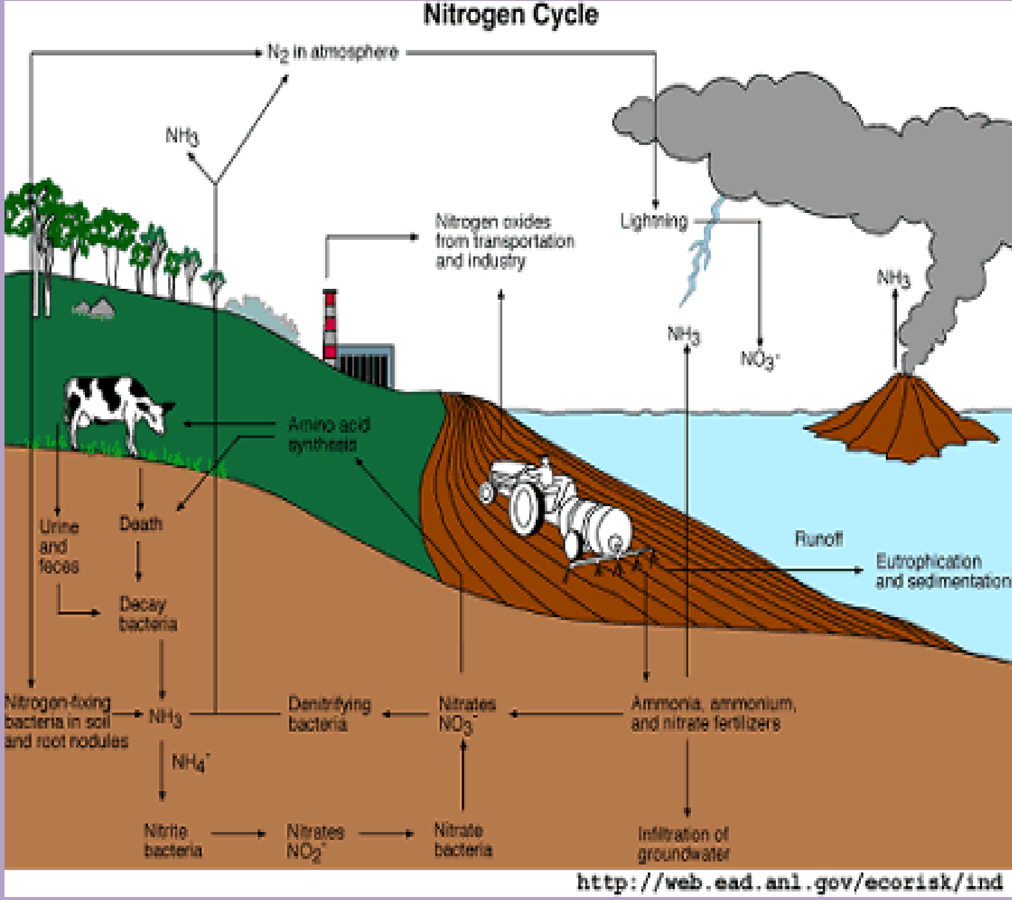
2) symbiotic bacteria: rhizobia and frankia
Clover root nodules at higher magnification, showing two partly crushed nodules (arrowheads) with pink-coloured contents. This colour is caused by the presence of the pigment **leghaemoglobin** - a unique metabolite of this type of symbiosis. Leghaemoglobin is found only in the nodules and is not produced by either the bacterium or the plant when grown alone.

http://www.biology.ed.ac.uk/research/groups/jdeacon/microbes/nitrogen.htm

❖Mineralization

Organic N → R-NH_2 → NH3 → NH4

In nitrogen mineralization, organic nitrogen from decaying plant and animal residues (proteins, nucleic acids, amino sugars, urea) is converted to ammonia (NH_3) and ammonium (NH_4^+) by the mechanisms listed below. This process is also called ammonification. The resultant ammonia can be converted back to organic N (immobilization) where it is taken up by microbes and plants (assimilated), or nitrified to nitrate.



1) *Aminization & Proteolysis*: break down of proteins and allied compounds into amino acids

<u>A. Direct Removal</u>

- R-CH_2 CH-NH_2-COOH --------> R-CH=CH-COOH + NH_3

<u>B. Deamination (oxidative - aerobic, reductive - anaerobic)</u>

- Oxidative: R-CH_2CH-NH_2COOH + 1/2 O_2 -------> R-CH_2-CO-COOH + NH_3
- Reductive: R-CH_2CH-NH_2COOH + 2H^+ -------> R-CH_2CH-COOH + NH_3

<u>C. Decarboxylation</u>

- Reductive: R-CH_2CH-NH_2COOH + H_2 -------> RCH_3 + CO_2 + NH_3
- Oxidative: R-CH_2CH-NH_2COOH + O_2 -------> R-COOH + CO_2 + NH_3

2) *Ammonification*: amino compounds converted into ammonia and ammonium

R-NH_2 + H_2O → R-OH + Energy + 2NH_3

Urea Hydrolysis - Ammonification

- $CO(NH_2)_2$ + HOH + UREASE ---->
- $H_2NCOOHNH_4$ -----> 2NH_3 + CO_2
- 2NH_3 + HOH ------> 2NH_4OH

http://filebox.vt.edu/users/chagedor/biol_4684/Cycles/Mineralization.html

Fates of NH4:

1.It can be assimilated (or immobilized) by microbes and plants.

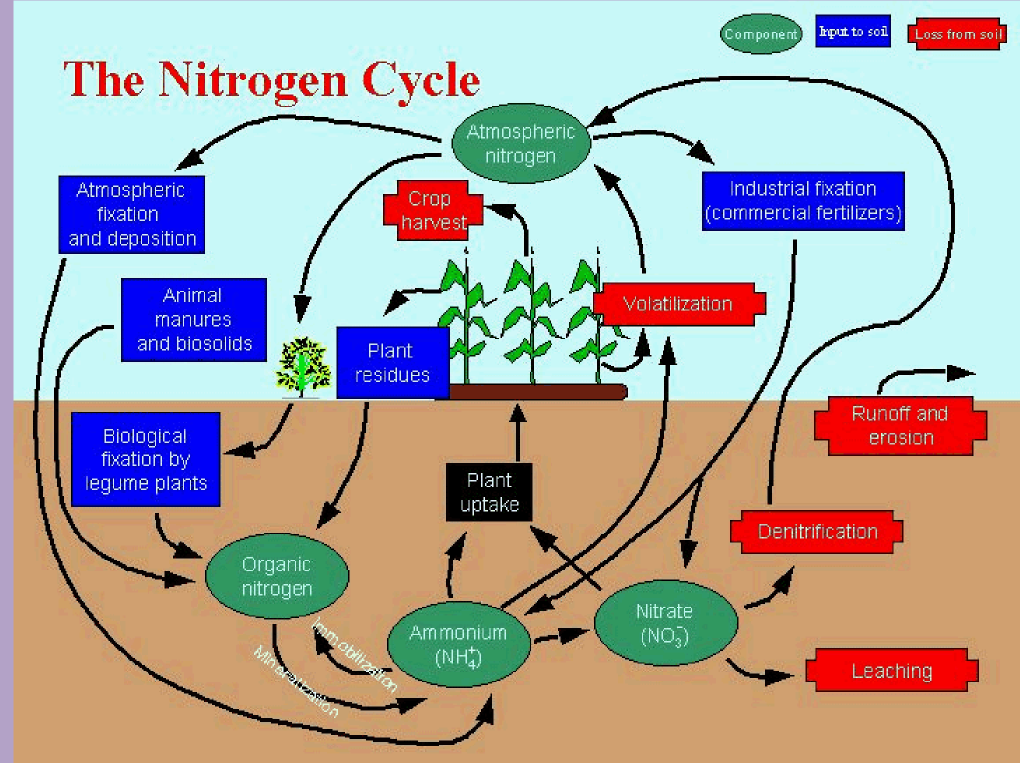
2.It can be held on exchange complexes in soil.

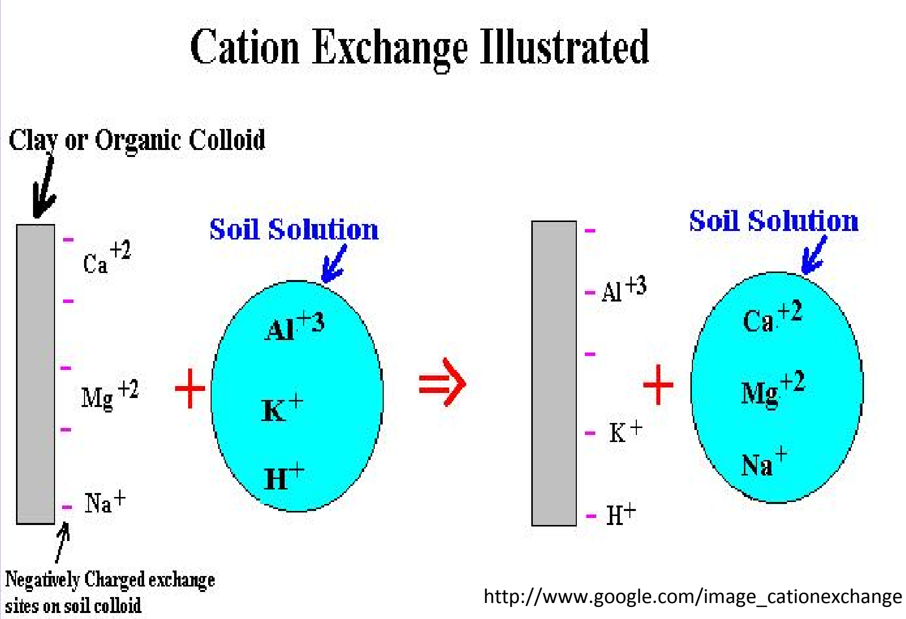
3.It can be fixed in the inner layer portions of clays.

6.It can be nitrified by the autotrophic nitrifying bacteria

4.It can react with SOM to form quinone-NH_2 complexes.

5.It can be volatilized as NH_3 in decaying vegetation or manure.





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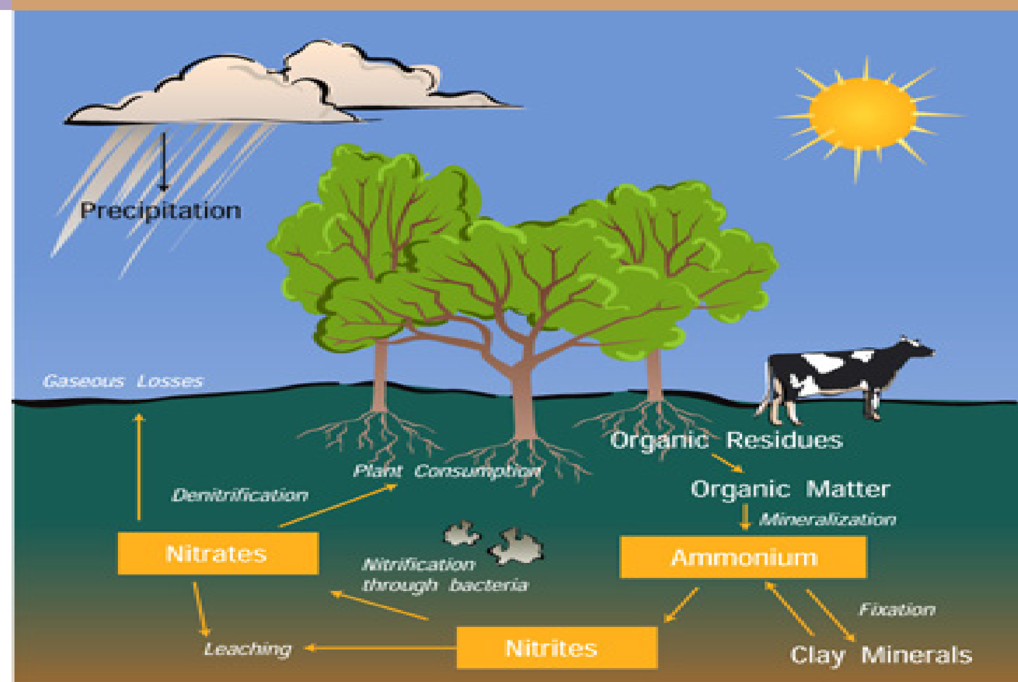
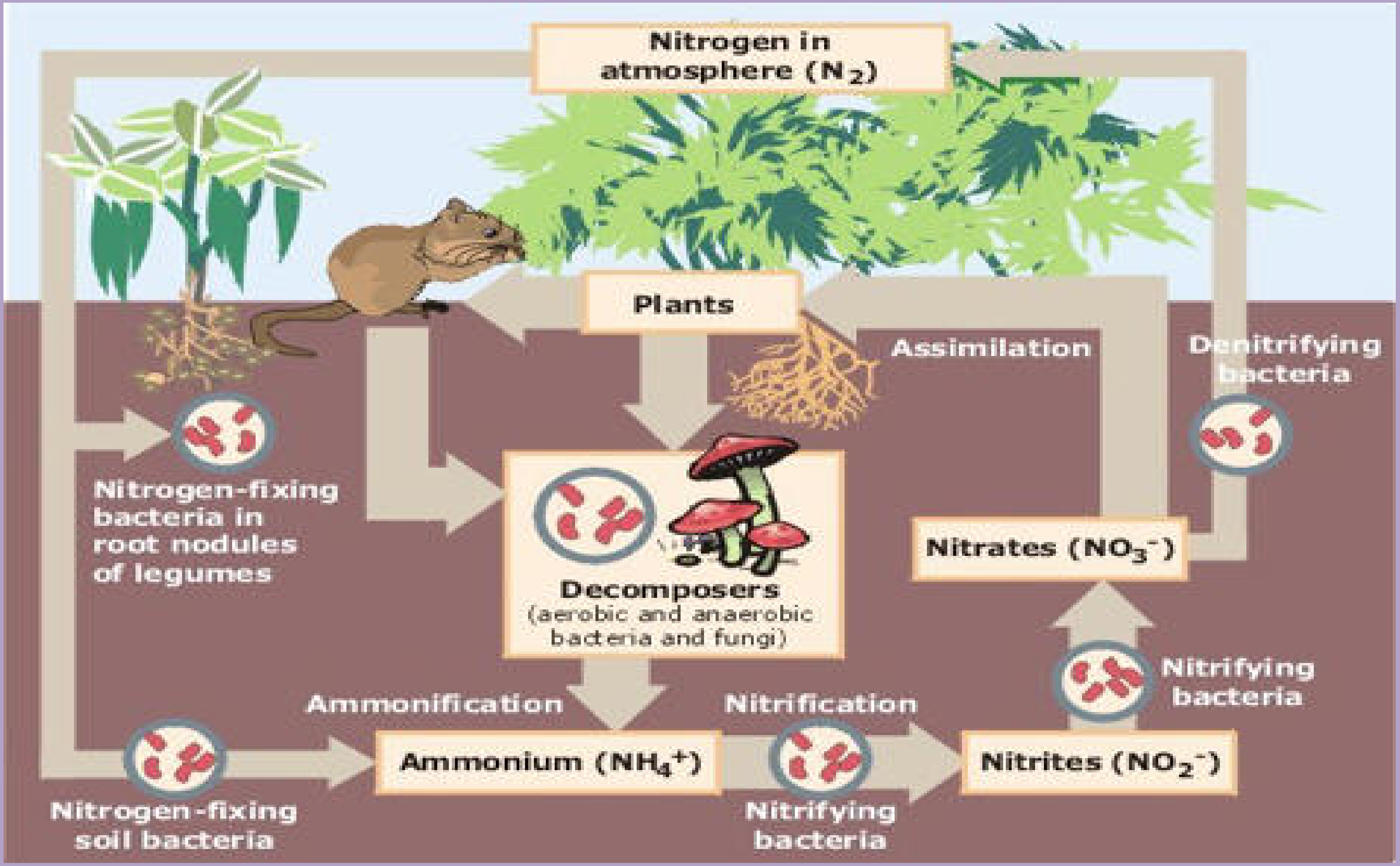


❖Nitrification: Oxidation of ammonium

1) $2NH_4 + 3O_2 \rightarrow 2NO_2 + 2H_2O + 4H + E$ nitrosomonas

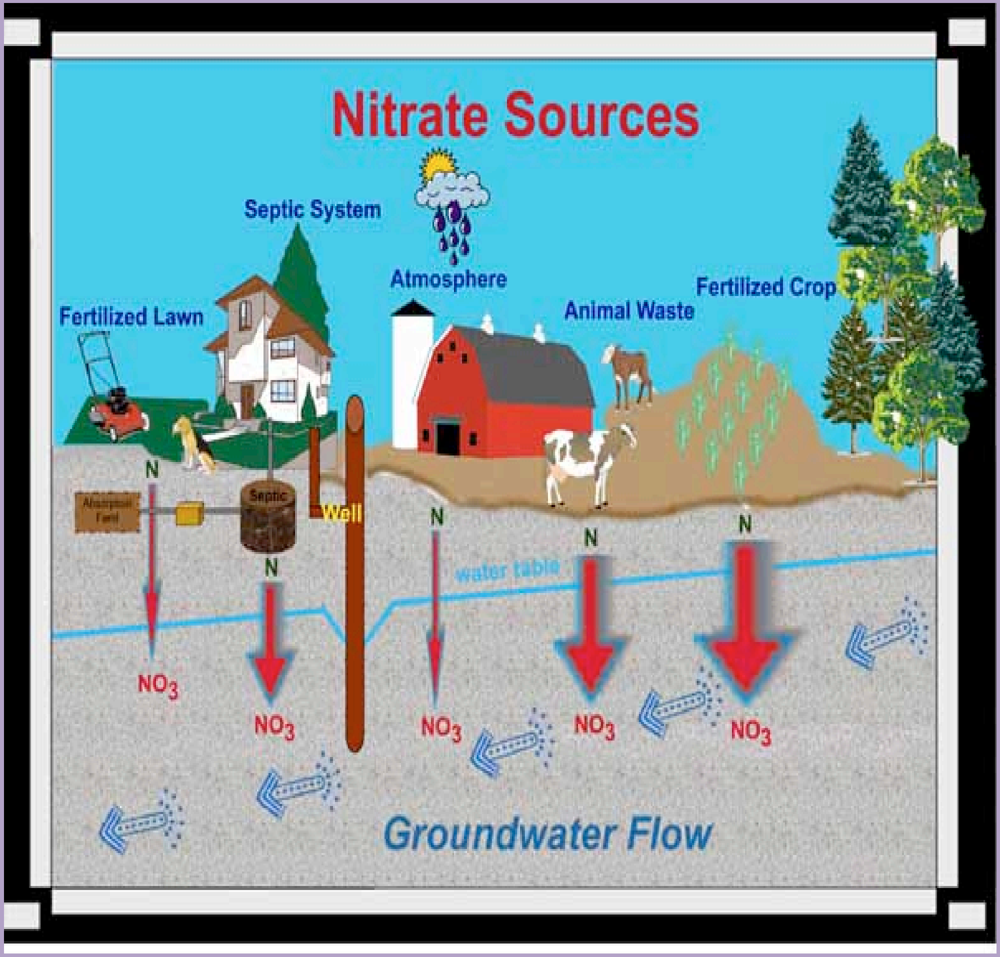
2) $2NO_2 + O_2 \rightarrow 2NO_3 + E$ nitrobacter



http://www.uwsp.edu/geo/faculty/ritter/geog101/textbook/earth_system/nitrogen_cycle_EPA.jpg

Other Fates of Nitrogen

❖Leaching



http://www.google.com/imgres?q=nitrogen+leaching

❖Erosion

http://www.google.com/imgres?imgurl=http://plantandsoil.unl.edu/croptechnology 2005/UserFiles/Image/siteImages/GullyErosionPasture-NRCS-LG.jpg

Eutrophication or more precisely hypertrophication, is the ecosystem response to the addition of artificial or natural substances, such as nitrates and phosphates, through fertilizers or sewage, to an aquatic system.[1] One example is the "bloom" or great increase of phytoplankton in a water body as a response to increased levels of nutrients. Negative environmental effects include hypoxia, the depletion of oxygen in the water, which induces reductions in specific fish and other animal populations. Ecosystems receiving more nitrogen than the plants require are called nitrogen-saturated. Saturated terrestrial ecosystems then can contribute both inorganic and organic nitrogen to freshwater, coastal, and marine eutrophication, where nitrogen is also typically a limiting nutrient (Wikipedia, February 2012).

The eutrophication of the Potomac River is evident from its bright green water, caused by a dense bloom of cyanobacteria

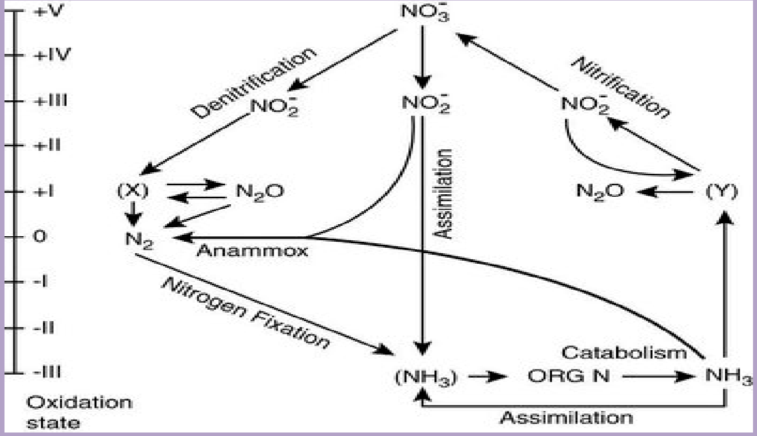
Eutrophication is apparent as increased turbidity in the northern part of the Caspian Sea, imaged from orbit.

❖Denitrification:

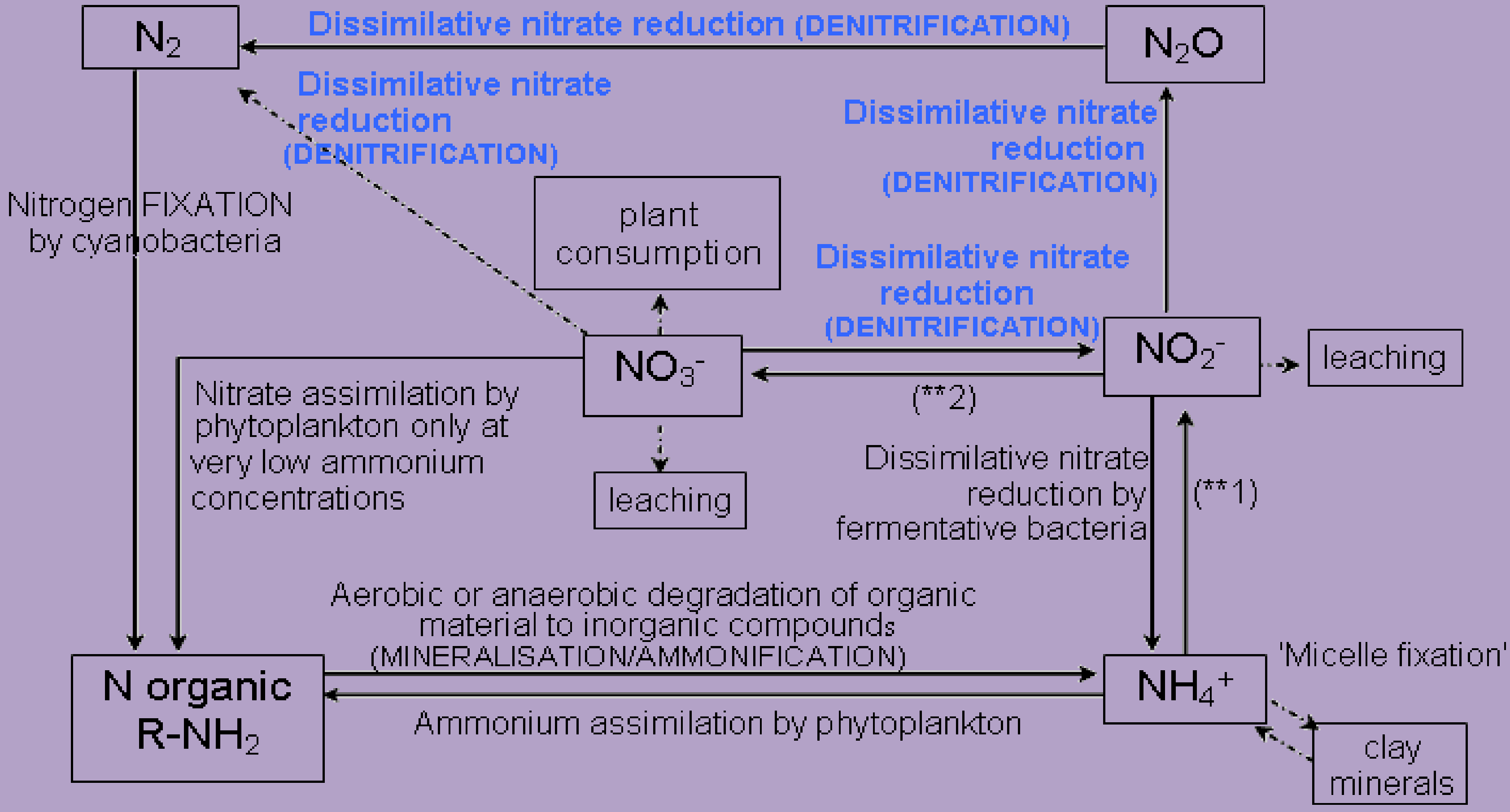
Reduction of nitrate

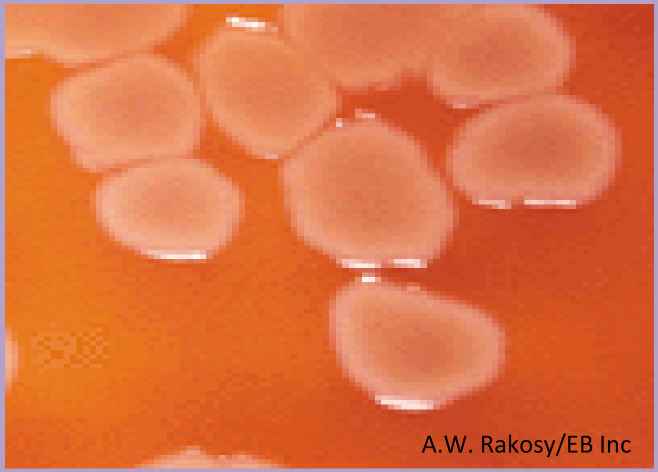
$NO_3 \rightarrow NO_2 \rightarrow NO \rightarrow N_2O \rightarrow N_2$

In anaerobic conditions N is reduced, denitrifying bacteria ie Baciullus and Pseudomonas



http://www.eoearth.org/files/120101_120200/120160/350px-Marine_N_cycle.JPG





Pseudomonas aeruginosa
Bacteria in urine

Bacillus species are Gram-positive and rod-shaped. They are capable of growing in the presence of oxygen. Each bacterial cell can form a capsule (called an endospore) to help it survive hostile conditions. These bacteria are found in almost all environments.

Methods for Inorganic N Measurements in Our Lab

❖50 ml of 0.5 M K_2SO_4 is added to a 10 g soil sample, shaken for one hour and then extracted and frozen at To = t

❖A separate 22 g sample is brought to field capacity moisture (23% for our soils) and placed in a sealed jar for a 14 day incubation which is hoped to represent the organic N mineralized under optimal conditions: PMN = t+1

❖ On the two week incubation date, a 10 g subsample undergoes the same extraction procedure as the To sample

❖ To and PMN extractions are analyzed for nitrate and ammonium

Ammonium: 40 uL sample; 80 uL sodium salicylate; 80 uL bleach NaOH

Nitrate: 10 uL sample; 190 vanadium chloride solution

Plates run on a microplate spectrophotometer (Biotek) which reports a wavelength absorbance in nm

A set of 8 standards of varying concentrations of nutrient are used to convert absorbance to concentration (ppm)


OPTIPLEX GX620
BioTek
PowerWave HT
DELL
250ml PLASTIC ERLENMEYERS

Calculations:

- ppm= mg N/ L solution

  Normalize → (mg N/ L solution)*(L solution / kg soil) = mg N/ kg soil

- Net N mineralization= $(NH_4^+\text{-}N + NO_3^-\text{-}N)_{t+1}$ - $(NH_4^+\text{-}N + NO_3^-\text{-}N)_t$

  A negative value here indicates net immobilization

- Net nitrification= $(NO_3^-\text{-}N)_{t+1}$ - $(NO_3^-\text{-}N)_t$

(Hart et. al, 1994)