Nitrogen – Transformation, factors affecting nitrogen availability ,deficiency and toxicity symptoms

Learning objectives

a. To understand the transformation of nitrogen
b. To know the factors affecting the availability of nitrogen
c. To understand the deficiency symptoms of Nitrogen and corrective measures

Nitrogen

The cheap source of N is the crop residues in temperate region. In tropical soils, the total N content is 0.03 - 0.1 %. Rainfall is also source of N at 4.6 kg of N / ha is received ha^{-1} yr^{-1}. It is converted to NO_3 during lighting addition of organic matter and fertilizer is other major sources. Nitrogen is an essential constituent of protein and also other non protein compounds of great physiological importance in plant metabolism. It is an integral part of chlorophyll, which is primary observer of light energy needed for photosynthesis. Nitrogen also imparts vigorous vegetative growth and governs the utilization of P,K and other elements

Forms of soil nitrogen

Inorganic forms N	**Organic forms of soil**
1. Ammonium NH_4^+	Amide form (NH_2)
2. Nitrite NO_2^-	Plant absorbs N as both
3. Nitrate NO_3^-	NH_4^-, NO_3^-.
4. Elemental N (No)	

Losses of Nitrogen

1. Crop removal
2. Leaching (or) drainage (11-18% loss)
3. Gaseous losses as NH_4 or elemental N_2
4. Volatilization.
5. Erosion (8 – 15 kg $ha^{-1}yr^{-1}$).
6. Ammonia fixation by clays
7. Immobilization in organic materials.

N transformations in soils

a. **N -** Mineralisation
b. Aminisation
c. Conversation of urea

d. N Immobilization.
e. N factor
f. Ammonification.
g. Nitrification
h. Denitrification
i. Organic fixation
j. Elemental N loss.
k. Nitrogen cycle.

N transformations in soils

Nitrogen mineralization

Mineralization is the conversation of organic N to NH_4^+ as a result of microbial decomposition. Mineralization increases with a rise in temperature and is enhanced by adequate, although not excessive, soil moisture and a good supply of O_2. Mineralization of organic N involves in two reactions.

i.e 1) Aminization 2) Ammonification.

Aminisation

Aminisation is the decomposition of proteins and the release of amines, amino acids and urea is called aminisation.

Bacteria NH_2 NH_2

| |

Proteins $\longrightarrow$ $R – C – COOH + R\ NH_2 + C = O + CO_2$ + Energy

Fungi H_2O | |

H amines NH_2

Amino acid Urea.

The initial step in the decomposition of organic matter by the enzymatic digestion of proteins into amino acids like, peptones and amino acid. **Under aerobic** protolysis the major end products are CO_2 $(NH_4)_2\ SO_4$ and H_2O. Under anaerobic conditions the end products are ammonia, amides, CO_2 and H_2S.

The organic compounds and proteins are mainly decomposed by various species of Pseudomonas,

Bacilli, clostridium, serrotia, Micrococcus

Generally in the neutral and sodic soils, bacteria are active and in acidic soils fungi are active.

Conversion of urea

Urea is a product of ammonization. The hydrolysis of urea by the action of increases enzyme is effected by Bacilli micrococcus, Pseudomonas, clostridium, Aeromobactor and coryne bactor.

$$Co\ (NH_2)\ + H^+ + 2H_2O \longrightarrow 2NH_4^+ + HCO_3^-$$

$$NH_4^+ \longrightarrow NH_3 + H^+$$

$$2NH_3 + H_2\,CO_3 \longrightarrow (NH_4)_2\,CO_3 \longrightarrow NH_4^+ + CO_3^{2-}.$$

The optimum H_2O holding capacity for these reactions is 50 – 75 and optimum temperature is 30 – 50°C.

The NH_4 can be utilized by microorganisams and root of higher plants. Some of the released NH_3 is fixed by clay especially illite. A major portion is oxidized to nitrate form. In the second reaction NO_2^- is further oxidized to NO_3^- by nitrobactor

$$2\,NO_2^- + O_2 \longrightarrow 2\,NO_3^-.$$

Nitrogen immobilization

"Immobilisation is the process of conversion of inorganic N (NH_4^+ or NO_3^-) to organic N and it is basically the reverse of N mineralization".

The Microorganisms accumulate NH_4 N and NO_3 – N in the form of protein, nucleic acid and other complexes. If C:N ratio is wider than 30, it favours immobilization and lesser C:N ratio encourage mineralization.

N factor

N factor is the No of units of in organic nitrogen immobilized for each 100 units of materials under going decomposition". The average values for the nitrogen factor vary from 0.1 or < to 1.3.

Ammonification

"Amines and Aminoacids produced during aminisation of organic N are decomposed by other heterotrophs with release of NH_4^+ is termed **Ammonifcation**

$$\longrightarrow$$

$R - NH_2 + H_2O$ $\quad\quad$ $NH_3 + R - OH + energy$

$$H_2O \searrow NH_4^+ + OH^-$$

Nitrification

Nitrification is the process of biological oxidation by which the NH_4- Cal form of N converts to nitrate form of N. There are two steps. (a) NH_4 is converted first to NO_2^- and then to NO_3^-.

$$2NH_4 + 3O_2 \xrightarrow{\text{Nitrosomonas}} 2\,NO_2^- + 2\,H_2O + 4\,H^+$$

Nitrosomonas are obligate autotropic bacteria that obtain their energy from the oxidations of N and their C from CO_2.

Others autotrophic bacteria *Nitrosolobus, Nitrospira* and *nitroso vibrio* and to some extend heterotrophic bacteria also can oxidize NH_4^+ and other N reduces, compounds to NO_3^-.

Losses of Nitrogen

The major losses of N from the soil are due to (1) crop removal and leaching, however under certain conditions inorganic N ions can be converted to gases and lost to the atmosphere. The primary pathway of gaseous N losses are

1. Denitrification
2. NH_3 volatilization.

Denitrification

Denitrification is the biochemical reduction of NO_3N or NO_2N to gaseous N, either as molecular Nitrogen or an oxide of Nitrogen. The most probable bio chemical pathway is

$$\mathbf{NO_3} \longrightarrow \mathbf{NO_2} \longrightarrow \mathbf{NO} \longrightarrow \mathbf{N_2O} \longrightarrow \mathbf{N_2}$$

Nitrate $\quad$ Nitrite $\quad$ Nitric oxide $\quad$ Nitrous oxide $\quad$ Nitrogen

Nitrogen fixation

The conversation of elemental nitrogen to organic forms readily use able in biological process. Vermicullite and illite are capable of fixing NH_4^+ by a replacement of K^- or Na^+ for interlayer cations in the expended lattice of clay minerals. The radius of NH_4 ion 0.143° A. K^+ ion 0.133°A.

Because of NH_4 and K have more or less same charge, they easily replace each other in the exchange sites.

Organic fixation

It the soil has more organic matter the NH_4 will lockup as a complex. There complex are called **Chelates**. It release the nutrients only after its molecular break down. The facultative aerobic bacteria tiles pseudomonas, bacillus, porococcus are responsible for denitrification. It also depends upon the texture of soil. In heavy clay soils loss is upto 50% of added fertilizer.

Elemental N loss

It is due to chemical reduction. If chemical fertilizer containing amide (or) NH_4 form of N, it may be oxidized to elemental N and lost.

$$2NHO_2 + CO(NH_2)_2 \longrightarrow CO_2 + 3H_2O + 2\ NH_2$$

Sources of N leading to N and NO_2 gaseous loss

1. Denitrification
   $NO_3^- \longrightarrow NO_2^- \longrightarrow NO \longrightarrow N_2O \longrightarrow N_2$

2. Nitrification
   $NH_4^- \longrightarrow NH_2OH \longrightarrow NO_2 \longrightarrow NO_3^-$

3. Nitrates and Ammonium
   $NH_4^+ + NO_2^- \longrightarrow N_2 + 2H_2O$

4. Nitriates and aminoacids.
   $HNO_2 + RNH_2 \longrightarrow N_2\ ROH + H_2O$

5. Lignin : HNO_2 + lignin $\longrightarrow N_2 + N_2O + CH_3O\ NO$

6. Phenols : Phenol $\longrightarrow N_2 + N_2O$ + Organic residue

7.Decomposition of nitrous acid / reaction with metal cations.

$$3\ HNO_2 \longrightarrow 2NO + 2\ HNO_3 + H_2O$$

$$Mn^{2+} + HNO_2 + H^+ \longrightarrow Mn^{3+} + NO + H_2O$$

$$Fe^{2+} + HNO_2 + H \longrightarrow Fe^{3+} + NO + H_2O$$

8. NH_3 Gas

9. Urea : $(NH_4)_2CO + H_2O \longrightarrow 2NH_3 + CO_2$

10. NH_4 Salts : $NH_4 + OH \rightarrow NH_3 + H_2O$

11. Decomposition of residues and manures

Release and volatilization of NH_3

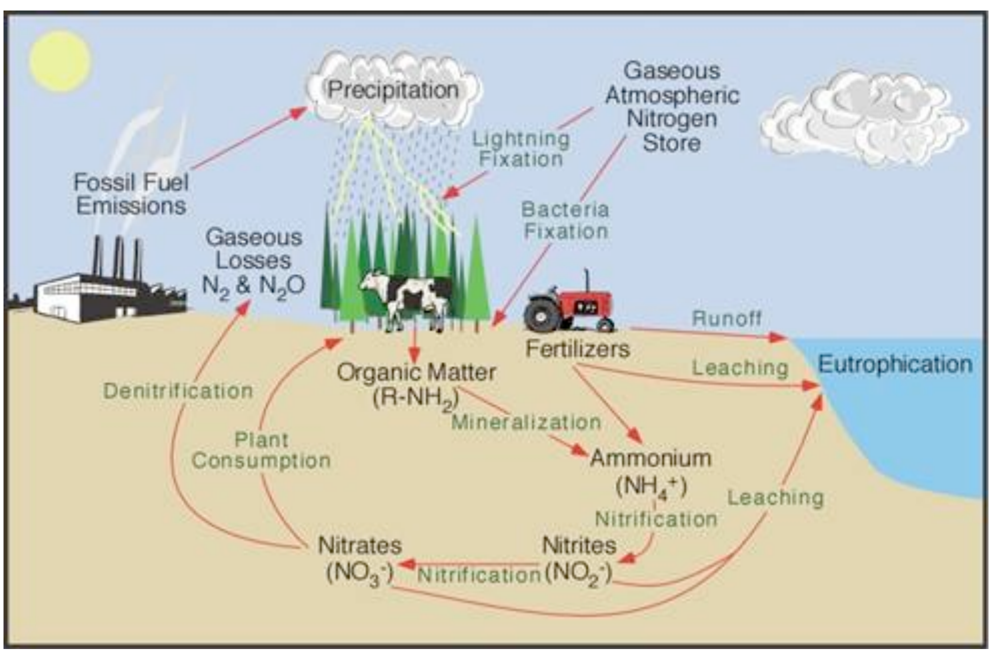
Nitrogen cycle

The cycling of N in the soil – plant – atmosphere system involves many transformations of N between inorganic and organic forms.

The N cycle can be divided into

1. N inputs or gains.
2. N outputs of losses
3. N cycling with in the soil.

1. N in plant and animal residues and N derived from the atmosphere through electrical, combustion, biological and industrial process is added to the soil.
2. N in the residues is mobilized as NH_4 by soil organisms as an end product of residue decomposition, plant roots absorb a portion of the NH_4.
3. Much of the NH_4 is converted to No_3^- by nitrifying bacteria in a process called nitrifications.
4. NO_3 is taken up by the plant roots and is used to produce the protein in crops that are eaten by humans or fed to live stocks.
5. Some NO_3 is lost to ground H_2O or drainage systems as a results of downward movement through the soil in perculating H_2O.
6. Some NO_3 is consorted by denitrifying bacteria in to N_2 and N_2O that escape into the atmosphere, completely the cycle.



The nitrogen cycle

Source: http://www.physicalgeography.net

Important microorganisms in BNF

Organisms	Properties	Active location
Azotobacter	Aerobic, free living	Soil, water, rhizosphere, leaf surface
Azospirillum	Micro aerobic rhizobacteria; free fixers	Free living in Rhizosphere; Colonize roots of cereals and also gives phytotonic effect
Rhizobium	Symbiotic	Root nodules of legumes
Actinomycetes, Frankia, Beijerinckia	Symbiotic	Non leguminous forest tree roots, leaf surfaces
Cyanobacteria	Photo autotrophic Anabaena - symbiotic	In wetland flood water; Anabaena associate with Azolla

Symbiotic N fixation

The symbiosis is the mutually beneficial relationship between host plant and bacteria. The location of association is in root or stem nodules, inside cavities, or by colonizing and penetrating plant tissue.

Legume (nodule forming)

Legumes and bacteria of the genera **Rhizobium** and **Bradyrhizobium** provide the major biological source of fixed N (40-60%) in agricultural soils. These organisms infect the root hairs and the cortical cells, ultimately inducing the formation root nodules that serve as the site of N fixation. The host plant supplies the bacteria with carbohydrates for energy and the bacteria reciprocate by supplying the plant with fixed N compound.

Effective nodules cluster on primary roots and have pink to red centers. The red colour of the nodule is attributed to the occurrence of **leghemoglobin**. The quantity of N fixed by properly nodulated legume averages about 75% of the total N used for the plant growth. The amount of BNF varies with Rhizobium strain, host plant, and environment.

Yield of non-legume crops often increase when they are grown following legumes (e.g. maize after soybean). Maximum N fixation occurs only when available soil N is at a minimum. When optimum conditions for N fixation is not prevailing, a legume crop can deplete soil N greatly, more than a cereal, if the legume grown is not incorporated into the same soil.

Fixer	Host plant
Rhizobium	Alfalfa, clover, peas, bean, soybean
	Gliricidia, Leuceana, Sesbania, Mimosa, Acacia
Bradyrhizobium	Cowpea, groundnut, red gram

Non-legume (nodule forming)

Roots of many species of angiosperm trees like casuarina in forests and wetlands form distinct nodules when infected with Actinomycetes of the genus **Frankia**.

Non-legume (non-nodule forming)

Azospirillum, **Azotobacter**, and **Azorhizobium**, dominant N fixers in cereals like rice, wheat, corn, sorghum, millets can grow on root surfaces and penetrate root tissues. The organisms use carbohydrates of root exudates as source of energy. They also induce crop growth by hormonal action. The organism **Beijerinckia** fixes N on leaf surfaces of tropical plants.

The **Anabaena** blue green algae (Cyanobacteria) inhabit cavities in the leaves of the floating water fern **Azolla** and fix quantities of N comparable to those of the better Rhizobium-legume complex. It could fix about 30-105 kg N/ season taking care of 75% N requirement of rice.

Nonsymbiotic N fixation

In wetland floodwater photoautotrophic **Cyanobacteria** independently do photosynthesis and fix N up to 20–30 kg N/ ha/ year. The excess ammonia is excreted in floodwater, which is beneficially absorbed by rice plants.

Free-living heterotroph bacteria like **Azotobacter** and **Beijerinckia** in aerobic upland soils and **Clostridium** in anaerobic wetland soils effectively fix N in pockets where O_2 supply is limited. Fixation depends upon the pH, soil N level, and source of organic matter.

Industrial fixation of N

Commercially produced N is the most important source of plant nutrient in agriculture. Industrial N fixation is by Haber-Bosch process, in which H_2 and N_2 gases react to form NH_3 under high temperature (1200^{O} C) and pressure (500 atm). Anhydrous NH_3 can directly be used as fertilizer or combined to other ions as solid forms.

N additions from atmosphere

Ammonia escapes in to atmosphere from soils, manures, and industries because of volatilization. Organic N compounds remain in fine dust of air lifted from earth surface. Rainfall brings down to soil NH_3, NO_3^-, NO_2^-, N_2O, and organic N. About 10 to 20% of the NO_3^- in the rainfall is due to fixation of N_2 by energy of lightning.

Deficiency and toxicity symptoms of Nitrogen in plants

Deficiency of N:

1. Plants are stunted and yellow in appearance.
2. The loss of protein N from chloroplasts. In older leaves produces the yellowing or chlorosis. It appears first on the lower leaves, the upper leaves remain green, while under severe N deficiency lower leaves will turn brown and die.
3. The necrosis begins at the leaf tip and progress along the midrib until the leaf is dead. In cauliflower - young leaves turn pale yellow and old leaves become orange.

   In coffee - Veins becomes yellow and new leaves are very small.

   Tomato - Stem become purple and hard. Flower buds become yellow and flower dropping rate also increases

Excess of Nitrogen (Toxicity of nitrogen)

a. Causes excess vegetative growth, dark green leaves, lodging, maturity is delayed with increases susceptibility to pest and disease.

b. In cotton, weak fibre are resulted. In rice, lodging is common.

c. Lengthening of crop duration and narrow leaf.

d. Slender shoot, profuse vegetation, thick peel and skin will be rough and leathery in the case of citrus.

e. Excess N in coffee plant, interferes the K uptake causing imbalance between N and K.

References

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Questions to ponder

1) How does the soil pH affect the nitrogen availability?
2) What climatic factors influence nitrogen availability to crops?
3) What is nitrogen fixation?
4) What is C: N ratio?
5) How does salinity affect nitrogen availability?