THE NITROGEN CYCLE

NITROGEN:

- Key building block of the protein molecule upon which all life is based
- Indispensable component of the protoplasm of plants animals and microorganisms
- One of the few soil nutrients lost by volatilization and leaching, thus requiring continued conservation and maintenance
- Most frequently deficient nutrient in crop production

Nitrogen Ion/Molecule Oxidation States

Nitrogen ions and molecules that are of interest in soil fertility and plant nutrition cover a range of N apparent oxidation states from -3 to +5. It is most convenient to illustrate these oxidation states using common combinations of N with H and O, because H can be assumed in the +1 oxidation state (H^{+1}) and O in the -2 oxidation state ($O^{=}$). The apparent N oxidation state, and the electron configurations involved may be depicted as follows.

Hydrogen:

The electron configuration in the ground state is 1s1 (the first electron shell has only one electron in it), as found in H_2 gas. Since the s shelll can hold only two electrons, the atom would be most stable by either gaining another eclectron or losing the existing one. Gaining an electron by sharing occurs in H_2, where each H atom gains an electron from the other resulting in a pair of electrons being shared. The electron configuration about the atom, where: represent a pair of electrons, may be shown as

H:H and the bond may be shown as H-H

Hydrogen most commonly exists in ionic form and in combination with other elements where it has lost its single electron. Thus it is present as the H^+ ion or brings a + charge to the molecule formed by combining with other elements.

Oxygen:

The ground state of O, having a total of eight electrons is 1s2, 2s2, 2p4. Both s orbitals are filled, each with two electrons. The 2p outer or valence orbiatal capable of holding six electrons, has only four electrons, leaving opportunity to gain two. The common gain of two electrons from some other element results in a valence of -2 for O ($O^{=}$). The gain of two electrons also occurs in O_2 gas, where two pairs of electrons are shared as

O::O and the double bond may be shown as O=O

Nitrogen:

The ground state of N is 1s2, 2s2, 2p3. It is very similar to that for oxygen, except there is one less electron in the valence 2p orbital. Hence, the 2p orbital contains three electrons but, has room to accept three electrons to fill the shell. Under normal conditions, electron loss to for N^{+}, N^{2+} or N^{3+} or electron gain to form N^{-}, N^{2-}, or N^{3-} should not be expected. Instead, N will normally fill its 2p orbital by sharing electrons with other elements to which it is chemically (covalent) bound. Nitrogen can fill the 2p orbital by forming three covalent bonds with itself as in the very stable gas N_2.

The Nitrogen cycle is not well understood, largely because of how it is communicated. Similar to the way we communicate the differences between normal, saline, sodic and saline-sodic soils, we should do the same for response variables in the the Nitrogen cycle. In addition to temperature and pH included below, we could add reduction/oxidation, tillage (zero vs. conventional), C:N ratios, fertilizer source and a number of other variables. These mechanistic models would ultimately lead to many 'if-then' statements/decisions that could be used within a management strategy.

Temp
>50F

denitrification	volatilization
leaching	leaching

<50F 7.0
Soil pH

Assuming that we could speed up the nitrogen cycle what would you change?

1. Aerated environment (need for O_2)
2. Supply of ammonium
3. Moisture
4. Temperature (30-35C or 86-95F) <10C or 50F

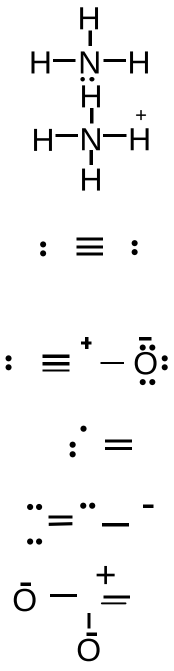
5. Soil pH
6. Addition of low C:N ratio materials (low lignin)

Is oxygen required for nitrification?
Does nitrification proceed during the growing cycle? (low C:N ratio)

N Oxidation States:

oxidized: loses electrons, takes on a positive charge
reduced: gains electrons, takes on a negative charge

Ion/molecule	Name	Oxidation State
NH_3	ammonia	-3
NH_4^+	ammonium	-3
N_2	diatomic N	0
N_2O	nitrous oxide	+1
NO	nitric oxide	+2
NO_2^-	nitrite	+3
NO_3^-	nitrate	+5
H_2S	hydrogen sulfide	-2
$SO_4^=$	sulfate	+6



N: 5 electrons in the outer shell
- loses 5 electrons (+5 oxidation state NO_3)
- gains 3 electrons (-3 oxidation state NH_3)

O: 6 electrons in the outer shell
- is always being reduced (gains 2 electrons to fill the outer shell)

H: 1 electron in the outer shell

N is losing electrons to O because O is more electronegative
N gains electrons from H because H wants to give up electrons

N recommendations

1. Yield goal (2lb N/bu)
    - a. Applies fertilization risk on the farmer
    - b. Removes our inability to predict 'environment' (rainfall)
2. Soil test
    - a. For every 1 ppm NO_3, N recommendation reduced by 2lbN/ac

Nitrite accumulation?

1. high pH
2. high NH_4 levels (NH_4 inhibits nitrobacter)

Factors Affecting Soil Acidity

Acid:	substance that tends to give up protons (H^+) to some other substance
Base:	accepts protons
Anion:	negatively charged ion
Cation:	positively charged ion

Base cation: ? (this has been taught in the past but is not correct)

Electrolyte: nonmetallic electric conductor in which current is carried by the movement of ions

H_2SO_4 (strong electrolyte)
CH_3COOH (weak electrolyte)

$$\underset{\text{potential acidity}}{HA} \xrightarrow{H_2O} \underset{\text{active acidity}}{H^+ + A^-}$$

1. Nitrogen Fertilization

    A. ammoniacal sources of N

2. Decomposition of organic matter

$$OM \longrightarrow R\text{-}NH_2 + CO_2$$
$$CO_2 + H_2O \longrightarrow H_2CO_3 \text{ (carbonic acid)}$$
$$H_2CO_3 \longrightarrow H^+ + HCO_3^- \text{ (bicarbonate)}$$

humus contains reactive carboxylic, phenolic groups that behave as weak acids which dissociate and release H^+

3. Leaching of exchangeable bases/Removal
   Ca, Mg, K and Na (out of the effective root zone)
   -problem in sandy soils with low CEC

   a. Replaced first by H and subsequently by Al (Al is one of the most abundant elements in soils. 7.1% by weight of earth's crust)
   b. Al displaced from clay minerals, hydrolyzed to hydroxy aluminum complexes
   c. Hydrolysis of monomeric forms liberate H^+
   d. $Al(H_2O)_6^{+3} + H_2O$ -----> $Al(OH)(H_2O)^{++} + H_2O^+$

<u>monomeric</u>: a chemical compound that can undergo polymerization
<u>polymerization</u>: a chemical reaction in which two or more small molecules combine to form larger molecules that contain repeating structural units of the original molecules

4. Aluminosilicate clays
   Presence of exchangeable Al
   $Al^{+3} + H_2O$ -----> $AlOH^{=} + H^+$

5. Acid Rain

Acidification from N Fertilizers (R.L. Westerman)

1. Assume that the absorbing complex of the soil can be represented by CaX
2. Ca represents various exchangeable bases with which the insoluble anions X are combined in an exchangeable form and that X can only combine with one Ca
3. H_2X refers to dibasic acid (e.g., H_2SO_4)

$(NH_4)_2SO_4$ -----> NH_4^+ to the exchange complex, $SO_4^{=}$ combines with the base on the exchange complex replaced by NH_4^+

Question: Volatilization losses of N as NH_3 preclude the development of H^+ ions produced via nitrification and would theoretically reduce the total potential development of acidity.

Losses of N via denitrification leave an alkaline residue (OH^-)

Table X. Reaction of N fertilizers when applied to soil.

1. Ammonium sulfate
   - **a.** $(NH_4)_2SO_4 + CaX \text{ ----> } CaSO_4 + (NH_4)_2X$
   - **b.** $(NH_4)_2X + 4O_2 \xrightarrow{\text{nitrification}} 2HNO_3 + H_2X + 2H_2O$
   - **c.** $2HNO_3 + CaX \text{ ----> } Ca(NO_3)_2 + H_2X$

     Resultant acidity = $4H^+$ /mole of $(NH_4)_2SO_4$

2. Ammonium nitrate
   - **a.** $2NH_4NO_3 + CaX \text{ ----> } Ca(NO_3)_2 + (NH_4)_2X$
   - **b.** $(NH_4)_2X + 4O_2 \xrightarrow{\text{nitrification}} 2HNO_3 + H_2X + 2H_2O$
   - **c.** $2HNO_3 + CaX \text{ ----> } Ca(NO_3)_2 + H_2X$

     Resultant acidity = 2H+ /mole of NH_4NO_3

3. Urea
   - **a.** $CO(NH_2)_2 + 2H_2O \text{ ----> } (NH_4)_2CO_3$
   - **b.** $(NH_4)_2CO_3 + CaX \text{ ----> } (NH_4)_2X + CaCO_3$
   - **c.** $(NH_4)_2X + 4O_2 \xrightarrow{\text{nitrification}} 2HNO_3 + H_2X + 2H_2O$
   - **d.** $2HNO_3 + CaX \text{ ----> } Ca(NO_3)_2 + H_2X$
   - **e.** $H_2X + CaCO_3 \xrightarrow{\text{neutralization}} CaX + H_2O + CO_2$

     Resultant acidity = $2H^+$ /mole of $CO(NH_2)_2$

4. Anhydrous Ammonia
   - **a.** $2NH_3 + 2H_2O \text{ ----> } 2NH_4OH$
   - **b.** $2NH_4OH + CaX \text{ ----> } Ca(OH)_2 + (NH_4)_2X$
   - **c.** $(NH_4)_2X + 4O_2 \xrightarrow{\text{nitrification}} 2HNO_3 + H_2X + 2H_2O$
   - **d.** $2HNO_3 + CaX \text{ ----> } Ca(NO_3)_2 + H_2X$
   - **e.** $H_2X + Ca(OH)_2 \xrightarrow{\text{neutralization}} CaX + 2H_2O$

     Resultant acidity = 1H+/mole of NH_3

5. Aqua Ammonia
   - **a.** $2NH_4ON + CaX \text{ ----> } Ca(OH)_2 + (NH_4)_2X$
   - **b.** $(NH_4)_2X + 4O_2 \xrightarrow{\text{nitrification}} 2HNO_3 + H_2X + 2H_2O$
   - **c.** $2HNO_3 + CaX \text{ ----> } Ca(NO_3)_2 + H_2X$
   - **d.** $H_2X + Ca(OH)_2 \xrightarrow{\text{neutralization}} CaX + 2H_2O$

     Resultant acidity = 1H+/mole of NH_4OH

6. Ammonium Phosphate
   - **a.** $2NH_4H_2PO_4 + CaX \text{ ----> } Ca(H_2PO_4)_2 + (NH_4)_2X$
   - **b.** $(NH_4)_2X + 4O_2 \xrightarrow{\text{nitrification}} 2HNO_3 + H_2X + 2H_2O$
   - **c.** $2HNO_3 + CaX \text{ ----> } Ca(NO_3)_2 + H_2X$

     Resultant acidity = 2H+/mole of $NH_4H_2PO_4$

NITROGEN USE EFFICIENCY

In grain production systems, N use efficiency seldom exceeds 50 percent. Variables which influence N use efficiency include

a. Variety
b. N source
c. N application method
d. Time of N application
e. Tillage
f. N rate (generally decreases with increasing N applied)
g. Production system

    1. Forage
    2. Grain

Olson and Swallow, 1984 (27-33% of the applied N fertilizer was removed by the grain following 5 years)

h. Plant N loss
i. Soil type (organic matter)

Calculating N Use Efficiency using **The Difference Method**

Applied N kg/ha	Grain Yield kg/ha	N content %	N uptake kg/ha	Fertilizer Recovery %
0	1000	2.0	20	-
50	1300	2.1	27.3	27.3-20/50=14.6
100	2000	2.2	44	44-20/100=24
150	2000	2.3	46	46-20/150=17

Estimated N use efficiency for grain production systems ranges between 20 and 50%. The example above does not include straw, therefore, recovery levels are lower. However, further analysis of forage production systems (Altom et al., 1996) demonstrates that N use efficiency can be as high as 60-70%. This is largely because the plant is harvested prior to flowering thus minimizing the potential for plant N loss. Plant N loss is known to be greater when the plant is at flowering and approaching maturity. It is important to observe that estimated N use efficiencies in forage production systems do not decrease with increasing N applied as is normally found in grain production systems. This is suggestive of 'buffering' whereby increased N is lost at higher rates of applied N in grain production systems, but which cannot take place in forage production systems.

Work by Moll et al. (1982) suggested the presence of two primary components of N use efficiency: (1) the efficiency of absorption or uptake (Nt/Ns), and (2) the efficiency with which the N absorbed is utilized to produce grain (Gw/Nt) where Nt is the total N in the plant at maturity (grain + stover), Ns is the nitrogen supply or rate of fertilizer N and Gw is the grain weight, all expressed in the same units. Other parameters defined in their work and modifications (in italics) are reported in Table 3.1.

Recent understanding of plant N loss has required consideration of additional parameters not discussed in Moll et al. (1982). Harper et al. (1987) documented that N was lost as volatile NH_3 from wheat plants after fertilizer application and during flowering. Maximum N accumulation has been found to occur at or near flowering in wheat and corn and not at harvest. In order to estimate plant N loss without the use of labeled N forms, the stage of growth where maximum N accumulation is known to occur needs to be identified. The amount of N remaining in the grain + straw or stover, is subtracted from the amount at maximum N accumulation to estimate potential plant N loss (difference method). However, even the use of difference methods for estimating plant N loss are flawed since continued uptake is known to take place beyond flowering or the point of maximum N accumulation.

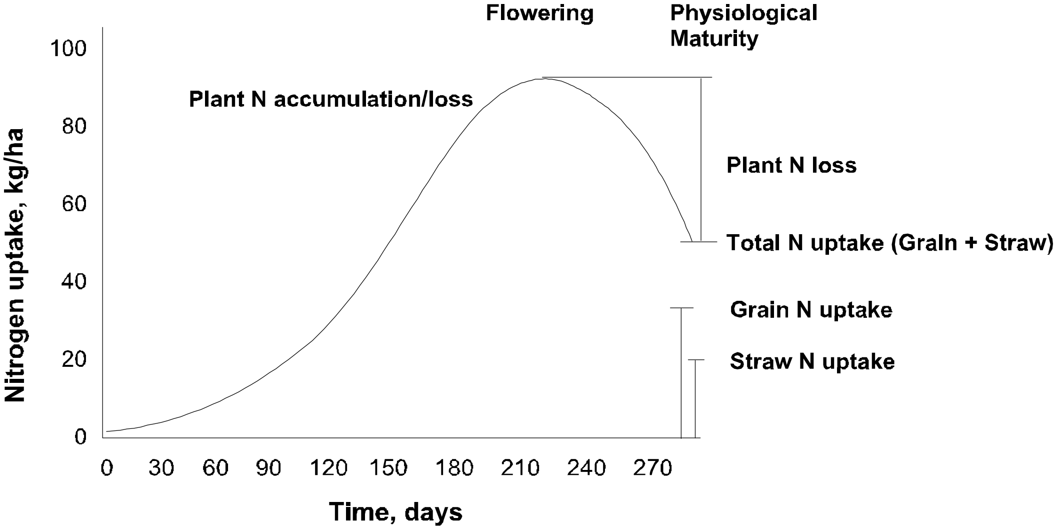


Figure 4.1 Total N uptake in winter wheat with time and estimated loss following flowering.

Francis et al. (1993) recently documented that plant N losses could account for as much as 73% of the unaccounted-for N in ^{15}N balance calculations. They further noted that gaseous plant N losses could be greater when N supply was increased. Similar to work by Kanampiu et al. (1997) with winter wheat, Francis et al. (1993) found that maximum N accumulation in corn occurred soon after flowering (R3 stage of growth). In addition, Francis et al.

(1993) highlighted the importance of plant N loss on the development and interpretations of strategies to improve N fertilizer use efficiencies.

Consistent with work by Kanampiu et al. (1997), and Daigger et al. (1976), Figure 4.1 illustrates winter wheat N accumulation over time. Estimates of plant N loss are reported in Table 4.1. Harper et al. (1987) reported that 21% of the applied N fertilizer was lost as volatile NH_3 in wheat, of which 11.4% was from both the soil and plants soon after fertilization and 9.8% from the leaves of wheat between anthesis and physiological maturity. Francis et al. (1993) summarized that failure to include direct plant N losses when calculating a N budget leads to overestimation of N loss from the soil by denitrification, leaching and ammonia volatilization.

$$NO_3^- + 2e \xrightarrow[\text{(nitrate reductase)}]{} NO_2^- + 6e \xrightarrow[\text{(nitrite reductase)}]{} NH_4^+$$

Reduction of NO_3^- to NO_2^- is the rate limiting step in the transformation of N into amino forms.

Does the plant wake up in the morning and turn on the TV to check the weather forecast, to see if it should assimilate NO_3 and attempt to form amino acids?

Could we look at the forecast and attempt to communicate with the plant, letting it know that weather conditions will be good (or bad), thus proceeding with increased NO_3 uptake?

<u>Major pathways for assimilation of NH_3</u>

1. incorporation into glutamic acid to form glutamine, a reaction catalyzd by glutamine synthetase (Olson and Kurtz, 1982)
2. Reaction of NH_3 and CO_2 to form carbamyl phosphate, which in turn is converted to the amino acid arginine.
3. Biosynthesis of amides of amides by combination of NH_3 with an amino acid. In this way aspartic acid is converted to the amide, asparagine

Table 4.1. Means over N rate and variety for protein, NUE components and estimated plant N loss , Perkins, OK 1995 (from Kanampiu et al., 1997)

	Protein %	N-use efficiency (Gw/Ns)	Uptake efficiency (Nt/ Ns)	N-utilization efficiency (Gw/Nt)	Fraction of N translocated to grain(Ng/Nt)	Grain yield/ grain N (Gw/Ng)	N loss (kg ha^{-1}) (Nf-(Ng+Nst)
N rate, kg ha^{-1}	-- means ---						
0	14.8	0	0	23.2	0.60	38.8	16.4
45	15.9	23.3	1.0	22.9	0.63	36.5	25.0
90	17.4	11.0	0.6	20.2	0.61	33.2	25.8
180	17.6	7.0	0.4	20.5	0.62	33.5	31.4
SED	0.40	1.1	0.05	1.12	0.03	0.89	6.74
Variety:							
Chisholm	16.3	11.8	0.5	22.4	0.6	35.3	21.8a
Karl	17.5	13.1	0.6	23.0	0.7	33.0	26.6a
2180	17.4	18.1	0.8	22.7	0.7	33.4	27.9a
TAM W-101	15.5	11.7	0.6	21.4	0.6	37.4	24.7a
Longhorn	15.0	14.7	0.8	19.5	0.5	38.5	22.3a
SED	0.45	1.5	0.07	1.27	0.04	1.18	7.33

The ability of the soil-plant system to efficiently utilize N for food production (grain or forage) can be considered in four aspects: (1) efficiency of the plant to assimilate applied N, (2a and 2b) once assimilated, the ability of the plant to retain and incorporate N into the grain, (3) efficiency of the soil to supply/retain applied N for plant assimilation over long periods of time and (4) composite system efficiency.

Uptake efficiency should be estimated using Nf/Ns (Eup) instead of Nt/Ns (Eha) as proposed by Moll et al. (1982). More N is assimilated at earlier stages of growth, therefore, uptake efficiency should be estimated at the stage of maximum N accumulation and not at maturity when less N can be accounted for. The component Nt/Ns as proposed by Moll et al. would be better defined as harvest uptake efficiency or physiological maturity uptake efficiency. We define uptake efficiency as the stage where maximum N is taken up by the plant divided by the N supplied.

(1) Uptake efficiency Eup=Nf/Ns

Unlike the description by Moll et al. (1982), uptake efficiency should be partitioned into two separate components since plant N loss (from flowering to maturity) can be significant (Daigger et al., 1976; Harper et al., 1987; Francis et al., 1993). The fraction of N translocated to the grain should be estimated as Ng/Nf and not Ng/Nt as proposed by Moll et al. (1982) since more N was accumulated in the plant at an earlier stage of growth (Kanampiu et al., 1997). Plants losing significant quantities of N as NH_3 would have very high fractions of N translocated to the grain when calculated using Nt instead of Nf. In terms of plant breeding efforts, this could be a highly misleading statistic. A second component, the translocation index is proposed that would reflect the ability of a plant genotype or management practice to incorporate N accumulated at flowering into the grain.

(2a) fraction of N translocated to the grain Et=Ng/Nf
(2b) translocation index Eti=Ng/Nf * (1/Nl)

The ability of the soil-plant system to utilize outside sources of N for food production (grain or forage) depends on the efficiency of storage in the soil. The efficiency of the soil to supply N to plants is strongly influenced by immobilization and mineralization with changing climate and environment.

Over a growing season, storage efficiency will be equal to the difference between fertilizer N added (Ns) minus maximum plant uptake (Nf) plus the difference between total soil N at the beginning and end of the season, all divided by fertilizer N added.

Esg = [(Ns-Nf)-(St1-St2)]/Ns

(3) soil (management system) supply efficiency $Es=Ns/(Sv+Sd+Sl)$ where Sv, Sd and Sl are estimates of soil volatilization, denitrification and leaching losses from the soil, respectively.

Lastly, a composite estimate of efficiency for the entire system (soil and plant) can be estimated as follows

(4) composite system efficiency $Ec=Eup*Es=Nf/(Sv+Sd+Sl)$

It is important to note that these efficiency parameters can be determined without having to determine total N in the soil. Avoiding total soil N analyses is noteworthy since the precision of present analytical procedures (Kjeldahl or dry combustion) approach ± 0.01%. This translates into approximately ± 220 kg N/ha (depending on soil bulk density) which is often greater than the rate of N applied, thus restricting the ability to detect N treatment differences.

Will Increased NUE lead to Increased NO_3 leaching?

Data from Kanampiu et al. (1995)

NUE Sinks:	Increased NUE	No Change
	------------- kg / ha	--------------
Total N Applied	180	180
Plant N uptake (at flowering)	68	71
Final Grain N uptake	42	40
Plant N loss	26	31
Denitrification	10	15
Immobilization	80	80
Balance	22	14
Leaching	?	?

Table 4.2. Components of nitrogen use efficiency as reported by Moll et al. (1982) and modifications (in bold italics) for grain crops.

Component	Abbreviation	Unit
Grain weight	Gw	kg ha^{-1}
Nitrogen supply (rate of fertilizer N)	Ns	kg ha^{-1}
Total N in the plant at maturity (grain + stover)	Nt	kg ha^{-1}
N accumulation after silking	Na	kg ha^{-1}
N accumulated in grain at harvest	Ng	kg ha^{-1}
Stage of growth where N accumulated in the plant is at a maximum, at or near flowering	***Nf***	***kg ha^{-1}***
Total N accumulated in the straw at harvest	***Nst***	***kg ha^{-1}***
Estimate of gaseous loss of N from the plant	***Nl =Nf-(Ng+Nst)***	***kg ha^{-1}***
Flowering uptake efficiency	***Eup=Nf/Ns***	
Harvest uptake efficiency **(Uptake efficiency)**	***Eha=Nt/Ns***	
Translocation index (accumulated N at flowering translocated to the grain)	***Eti =Ng/Nf * (1/Nl)***	
Soil supply efficiency	***Es=Ns/(Sv+Sd+Sl)***	
Composite system efficiency	***Ec=Eup*Es=Nf/(Sv+Sd+Sl)***	
Utilization efficiency	Gw/Nt	
Efficiency of use	Gw/Ns	
Grain produced per unit of grain N	Gw/Ng	
Fraction of total N translocated to grain	Et=Ng/Nt	
Fraction of total N accumulated after silking	Na/Nt	
Ratio of N translocated to grain to N accumulated after silking	Ng/Na	

N DISCUSSION

Magruder Plots
1892: 4.0 % organic matter = 0.35+ 1.8 OC
OC = 2.03
TN = 0.16
Pb = 1.623 (0-12")

lb N/ac = Pb * ppm N * 2.7194
= 1.623 * 1600 * 2.7194
=7061

1997
OC = 0.62
TN = 0.0694
lb N/ac = 1.623*694*2.7194
=3063

Difference: 7061 - 3063 = 3998 lbs N

Grain N removal
14.6 bu/ac * 60 lb/bu = 876 lbs
876 lbs * 105 years = 91980 lbs grain
91980 lbs * 0.022086 %N = 2031 lbs N

Plant N loss
10.7 lb/ac/yr (Kanampiu et al., 1995)
105 * 10.7 = 1130 lbs N

Denitrification
2.85 lb/ac/yr (Aulakh et al. 1984)
105 * 2.85 = 300 lbs N

Balance 537 lbs N

Year 1 denitrification, ammonification
Denitrification, ug/g = 50.0 * OC + 6.2 (Burford and Bremner, 1975)
= 50.0 * 2.03 + 6.2
= 107.7 ug/g
= 107.7 * 1.623 * 2.7194
= 475.34 lb/ac (0-12")

New Balance 61.66 lb N/ac
(0.58 lb N/ac/yr unaccounted)

Not included in this balance sheet is the amount of N that would be deposited via rainfall, and the amount lost via ammonification, both of which would be important.

Denitrification losses the first year were likely much higher since increased NO_3-N would have been present as a result of mineralized N from a very large total N pool. Burford and Bremner (1975) applied the equivalent of 800 lb NO_3-N/ac and found that denitrification losses were extremely high. Although their work has little relevance to annual denitrification losses expected under field conditions, it does provide some insight into what might have happened in the first year when soils were first tilled.

Miscellaneous

When adequate inorganic N was present, the incorporation of straw in conventional till or the application of straw on the surface of zero till approximately doubled the accumulative gaseous N losses (increased supply of energy to denitrifying organisms). Aulakh et al. (1984)

From 71 to 77% of the surface applied fertilizer N remaining in the profiles was in the 0 to 0.1 m soil layers (Olson and Swallow, 1984).

Late N application can be efficiently taken up by plants, and does not decrease soil N uptake. To achieve acceptable grain protein levels for bread wheat in this irrigated cropping system, N should be supplied late in the season to improve N uptake during grain fill (Wuest and Cassman, 1992)

NITROGEN

Form taken up by plant:	NH_4^+, NO_3^-
Mobility in soil:	NH_4^+: no; NO_3^-: yes NO_3^- water soluble, not influenced by soil colloids
Mobility in plant:	Yes
Deficiency symptoms:	Chlorosis in older leaves, under severe deficiency lower leaves are brown, beginning at the leaf tip and proceeding along the midrib.
Soil pH where deficiency will occur:	None due to nitrate's mobility
Role of nutrient in plant growth:	N assimilation into amino acids for protein and amino acid synthesis, component of chlorophyll, vegetative growth
Enzymes that require N:	Nitrate reductase, nitrite reductase, nitrogenase
Role of nutrient in microbial growth:	Necessary for the synthesis of amino acids
Concentration in plants:	Wheat 1.7 - 3.0% Grain 2.0% Forage 3.0 % Straw Corn 2.7 - 3.5% Soybeans 4.2 - 5.5% Grain sorghum 3.3 - 4.0% Peanuts 3.5 - 4.5% Alfalfa 4.5 - 5.0% Bermudagrass 2.5 - 3.0%
Effect of pH on availability:	
Precipitated forms (low pH):	*none*
Precipitated forms (high pH):	*none* *at pH>8, no nitrification; at pH>7,* NO_2^- *accumulates*
Interactions with other nutrients:	Si: enhances leaf erectness, thus neutralizing the negative effects of high nitrogen supply on light interception (leaf erectness usually decreases with increasing nitrogen supply); P: symbiotic legume fixation needs adequate P or a N deficiency

can result; Mo: component of nitrogenase therefore could have Mo induced N deficiency in N_2 fixing legumes (especially under acid soils conditions); Fe: necessary for nitrogenase and ferredoxin (electron carrier), legume hemoglobin, deficiency reduces nodule mass, and nitrogenase;

Fertilizer sources: ammonium sulfate, anhydrous ammonia, ammonium chloride, ammonium nitrate, ammonium nitrate-sulfate, ammonium nitrate with lime, ammoniated ordinary superphosphate, monoammonium phosphate, diammonium phosphate, ammonium phosphate-sulfate, ammonium polyphosphate solution, ammonium thiophosphate solution, calcium nitrate, potassium nitrate, sodium nitrate, urea, urea-sulfate, urea-ammonium nitrate, urea-ammonium phosphate, urea phosphate.

References:

Burford, J.R., and J.M. Bremner. 1975. Relationships between the denitrification capacities of soils and total, water-soluble and readily decomposable soil organic matter. Soil Biochem 7:389-394.

Marschner, Horst. 1995. Mineral Nutrition in Higher Plants. Academic Press, London.

Tisdale, S.L., W.L. Nelson, J.D. Beaton, and J.L. Havlin. 1993. Soil Fertility and Fertilizers. MacMillan Publishing Co., New York, N.Y.

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