Fate & Transformation of Fertilizers in Soils

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Geographic/Moisture regime:
- High Plains of Colorado, 16.5 inches average annual precipitation

Pertinent research/Projects:
- Fertilizer requirements in no-till dryland rotations
- Nitrogen fertilizer requirements of sunflower, millet, corn and wheat;
- Cropping sequences in no-till rotations
- Planting dates for dryland corn; Fallow management after sunflowers;
- Stripper header versus conventional headers for wheat harvest and effects on subsequent corn crops
- Grain sorghums for dryland rotations
- Planting winter wheat into millet versus planting winter wheat into winter wheat (the Millet Flu experiment).

Fate and Transformation of Fertilizers in Soils

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What happens to fertilizer nitrogen (N) and to the soil in the fertilizer application zone when N fertilizer is applied? Are chemical fertilizers bad for the soil? How long do the reactions take? What is the effect of temperature? What affect does surface crop residues have on the transformations? These are some of the questions that we will try to answer in this writeup. First some definitions and background.

Definitions:

<u>inorganic N</u> ($\mathbf{NH_3^o}$, $\mathbf{NH_4^+}$, $\mathbf{NO_3^-}$, N_2, NO, N_2O, others)
<u>organic N</u> (several forms)
<u>Ammoniacal N</u> (ammonia $\mathbf{NH_3^o}$, and ammonium $\mathbf{NH_4^+}$)

* Anhydrous ammonia and Urea (pH of soil in injection zone increases to 9.0)

1. **Physical sorption**

a. ammonia dissolution in soil water (about 10%)

$NH_3^o + H_2O \equiv NH_4^+ + OH^-$ This is essentially NH_4OH (ammonium hydroxide)
ammonia ammonium

b. H^+ bonding to soil clays

$NH_3^o + H^+\text{-soil} \equiv NH_4^+\text{-soil}$

2. **Chemical sorption** (Cation exchange capacity (CEC)/titratable acidity) about 1/3 of a soils CEC has the ability to retain ammonia. Since CEC varies with pH it is not a fixed quantity and therefore not a good predictor of the size of a soils ammonia retention zone, but titratable acidity is. Typical CEC's in Kansas/Nebraska/Colorado soils are between 14 and 25 meq/100g of soil but are as low as 3-5 meq/100g in our sandhill soils.

(about 70-85 % of the ammonia is retained in a soil by chemical sorption)

3. **Ammonia fixation**

a. by Organic matter NH_3^o (3-5%)
b. by soil clays NH_4^+ (5-7 %)

These processes are immediate. Within 10-20 minutes after application they are complete

4. **Ammonia diffusion:** In a "uniform soil", diffusion is in a cylindrical pattern. This cylinder of ammoniated soil is called an ammonia retention zone. The size of the

retention zone depends on the rate of N application, the H buffering capacity of the soil and soil water content.

Typical **retention zone sizes** were 4-7 inches in diameter where 100 lbs of N/acre was applied on 30 inch centers, in Kansas soils. (Isaurralde et al 1987 SSSAJ)

The size of the retention zone is **established within 24 hours** after injection.

Microbial transformations of the ammoniacal N then begins to dominate. **Nitrification** begins on the outer most edge of the retention zone and works its way inward. Microbes within the center of the retention zone are killed by the ammonia.

Ammonia is toxic to seedlings and microbes. The high pH of 9 is part of the toxic effect. Concentrations of 0.15-0.20 milli-Molar ammonia in the soil solution are toxic to seedlings (A.C.Bennett and Fred Adams 1970. SSSAP 34:255-263).

Practical application

That means that wheat planted in rows 12 inches apart should not have more than 15 lbs of N/acre applied directly with the seed. Wheat planted in 7-8 inch rows ought not have more than 20 lbs of N/acre applied with the seed.

These recommendations are applicable to hoe and disc drill type openers that deliver the seed in a single narrow row.

Farmers using new air seeders that deliver seed and fertilizer together in a 3-5 inch wide band may be able to exceed these rates and not have damage. Some have reported that rates of up to 60 lbs of N/acre can be applied directly with the seed without damage. (I do not know if this true or not and have not done any research to confirm those reports)

5. **Nitrification**: conversion of ammoniacal-N to nitrate-N (a two step process)

NH_4^+ ---soil + nitrosomonas bacteria + 1.5O_2 6 NO_2^- + 2 H^+ + H_2O

NO_2^- + nitrobacter bacteria + 0.5O_2 6 NO_3^-

(Others) nitrate

Nitrate is negatively charged (an anion) and can be leached from the root zone, it moves freely with soil water and is not held by soil CEC.

Nitrification is essentially **complete in two-four weeks** during spring and summer if soil moisture is adequate.

Nitrification is slow (it essentially **stops) at soil temperatures below 50EF.**

N immobilization: uptake and utilization of fertilizer N by microbes decomposing manure, crop residues, and native soil organic matter.

How much fertilizer N is immobilized? If the fertilizer is placed below the residue layer, immobilization is less of a problem than if the fertilizer is applied directly on the residue. Under ideal conditions (a lab study) we measured 0.002 lbs of N immobilized per lb of straw for residues with a C/N ratio of 33 (about 4lbs of N per ton of residue). For corn stover with a C/N ratio of 80/1 we measured 10 lbs of N immobilized per ton.

In an irrigated corn field we easily raise 5 tons of stover per year. If that stover were uniformly mixed in the top 6 inches of soil (disked two or three times) we would need 50 lbs of N to satisfy the microbes. Much of this 50 lbs of N would not be available for crop use. If this was no-till corn you might have another 3 ton of old residues from previous years on the soil surface. Now from a practical standpoint all this residue is not a problem with respect to N fertility management unless the residue is mixed (tilled) with the fertilizer.

If we don't mix the fertilizer with the residues then we don't have to supply the additional N to feed the microbes. This is why **knifing the N below the soil/residue surface** works so well. If the power requirement and soil disturbance that goes with knife application is too much for you then dribble the N on the surface in a concentrated band.

If you are concerned about N immobilization or other losses then don't surface broadcast fertilizer N, unless you plan to **incorporate soon** with tillage or with overhead sprinkler irrigation. Remember you bought the N for your crop to use and not to feed microbes.

Lets compare the surface area contact between the fertilizer and the soil when placed in a concentrated zone on the soil surface verses a broadcast application on the soil surface.

Assumptions: We are applying 60 lbs of N/acre as UAN applied broadcast as a spray or dribbled on the soil surface in a band 0.5-1.0 inch wide where the bands are 10 inches (25.4 cm) apart. For our broadcast spray the average droplet diameter is 1.0 mm.

Get your pencils out and lets draw a picture:

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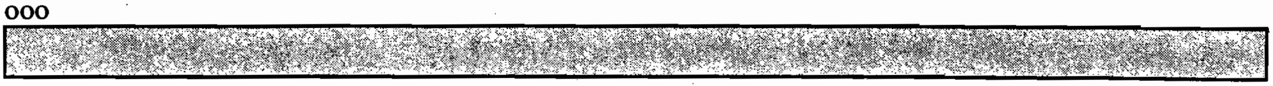

A broadcast application of 60 lb N/acre with 1 mm droplets applied to 1 m^2 of ground area would yield 31,855 droplets that's 31,855 contact points with the soil spaced 0.56 cm apart.

A band application 10 inches (25.4 cm) apart on the same 1 m^2 of soil area would yield a band 3.93 m (12.feet, 11 inches) long with a mean diameter of 0.23 cm thick.

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The actual amount of soil initially contacted (if no surface residue interfered) would be the same in both cases about 50g of soil per m^2.

But what happens after a 5 mm (0.2 inch) rain?

The rain would dilute the fertilizer. The original 50-g of soil contacted would increase to 15,000 g of soil contacted by the broadcast application. The band application would increase to 886 g of soil contacted. About 17 times more soil to fertilizer contact (and therefore microbial contact) with the broadcast application than with the band application. That means 17 times more potential immobilization broadcasting the fertilizer as compared to band application.

UREA fertilizer and Urea-ammonium-nitrate (UAN)

* Urea (46-0-0) and UAN (32 or 28% N solution) have some similarities in behavior and management because 51% of the N in UAN is urea N and 49% comes from ammonium nitrate.

Reactions of urea in soil: **Urea hydrolysis.** The pH goes up (as high as pH 9) as urea hydrolyses because that process uses up H see below.

$$\underset{\text{Urea}}{CO(NH_2)_2} + 2H_2O + H^+ \overset{\text{Urease}}{6} 2HCO_3^- + 2\,NH_4^+$$

$$H^+ + HCO_3^- \equiv CO_2 + H_2O$$

After the ammoniacal N is formed the reactions are essentially the same for urea as they were for ammonia. This is true for the urea in UAN as well.

Volume of a sphere = $4/3\ \vartheta r^3$, Volume of a cone = $h\vartheta r^2$

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