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NITROGEN in Kentucky Soils

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Nitrogen (N) is one of the major nutrient elements essential to plant growth. An adequate supply of N is required for high yields of good quality crops. Sound N management is important for both profitability and protection of ground and surface water.

Plants growing with a low available N supply are pale green or yellow. They grow slowly, become dwarfed in total growth and produce low yields. Excessive available N may result in excessive vegetative growth, tall plants subject to lodging, a greater likelihood of disease and delayed maturity — all conditions that may lower yields and quality.

Of the nutrient elements required by plants, N ranks fourth behind carbon, hydrogen and oxygen in total amounts needed. Nitrogen accounts for about 2 to 3% of the dry matter weight of field crops. A 5-ton yield per acre of dry matter would require 200 to 300 lb of N. Since most soils in Kentucky do not supply nearly that much N, added N from fertilizer must supplement the native soil N for nonleguminous crops.

Where trade names are used, no endorsement is intended, nor criticism implied of similar products not named.

Soil Nitrogen Content

Except for a relatively small amount that exists in ionic form (1 to 2%), all of the N in soils of humid regions is contained in and is an essential part of the organic matter or humus. Thus, the N content of a soil is indicative of the humus content and vice versa. Nitrogen constitutes about 5 to 6% of the soil organic matter by weight. The N in soil results from biological fixation and from accumulation of plant residues over a long period of time.

For mineral soils in the United States, the approximate range of total N content in the surface six inches is .02 to .50%; most cultivated Kentucky soils range from .05 to .10% N (1000 to 2000 lb/acre). Only a small portion of this becomes available during a growing season. Since N is contained largely in humus that forms from plant residues, its concentration decreases with depth in the soil profile.

Climatic factors influence the N content of soils through the effects of temperature and water supply on the growth of plants and activities of soil microorganisms. Production of plant material — and consequently plant residues and the resultant soil N con-

tent — generally is greatest in areas of highest rainfall and decreases as amounts of annual rainfall decrease. Soils in areas with higher temperatures usually have lower organic matter content than in areas with lower temperatures. This is because of more rapid decomposition of plant residues with warmer temperatures.

Over narrow geographical areas, soil N content is affected by the texture of the soil, generally higher in finer texture soils. Therefore, clayey and silty soils would be expected to be higher in N than sandy soils. Differences in water-holding character- istics or in drainage, aeration or fertility, and the tendency for lignin and certain clay minerals to form complexes with organic N materials may be responsible for the variation in soil content with texture.

Forms of Nitrogen in Soils

Nitrogen is found in the environment in both inorganic and organic forms. It does not exist as an important component of any soil mineral. Nearly all residual soil N is in organic forms. Some rocks and clay minerals contain a trace of ammonium N, but the total amount is low and contributes little to the available N content of soil.

Inorganic Nitrogen

Inorganic N exists in soil primarily in three forms: elemental N (N_2), ammonium (NH_4^+) and nitrate (NO_3^-). Elemental N occurs in the air as a nearly inert gas. Elemental N does not react with the soil and cannot be used directly by plants. However, some bacteria, particularly rhizobia that live in association with leguminous plants, can use elemental N from the air and change it to forms that can be used by plants. The manufacture of com- mercial N fertilizer is largely based on the use of
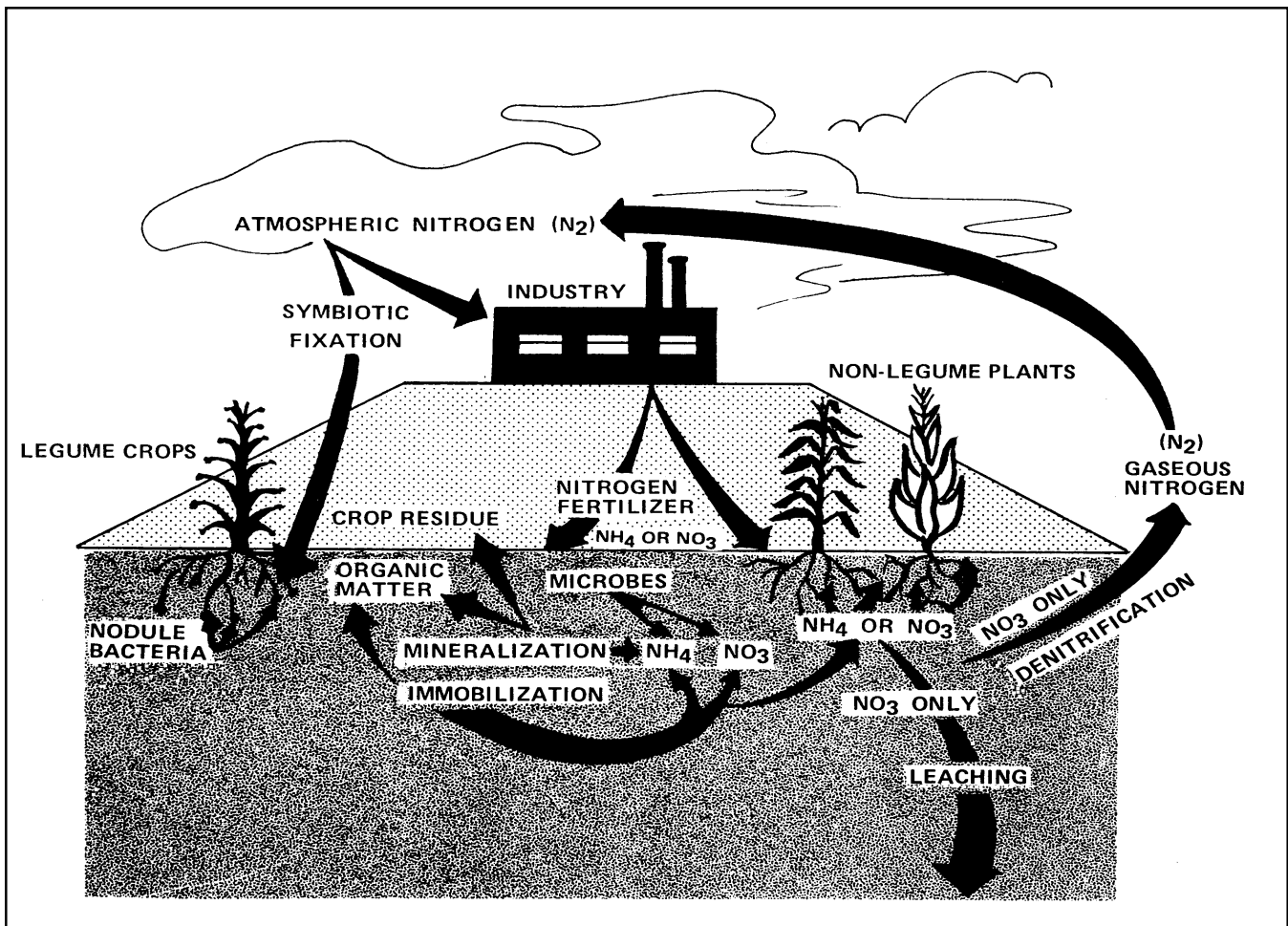

Figure 1— Diagram of some of the more important forms and reactions of nitrogen.

atmospheric N and its combination with other elements.

From the standpoint of plant nutrition, NO_3^- and NH_4^+ are of great importance. These two ionic forms react differently in soil. Ammonium (NH_4^+) is a positively charged ion and is attracted to the negatively charged sites on soil particles. In this position, it is available to plants but held tightly enough to prevent leaching.

Nitrate ions react much less with the soil than do ammonium ions, and most nitrate remains in the soil solution, moving with the soil water. However, in subsoils with a high iron oxide content, nitrate is absorbed to some extent. In such soils, leaching is slower.

During periods of excess rainfall, nitrate can leach below the root zone of plants; during dry periods, nitrate may move up and accumulate at the soil surface. Also, under conditions of excessive rainfall, the soil's oxygen content may be used up by microbial populations in the soil. Under these conditions, the microbes use nitrate instead of oxygen, resulting in the reduction of nitrate to elemental nitrogen which is unavailable to nonleguminous plant species. This reduction process is called *denitrification*.

Organic Nitrogen

Soil organic matter is a general term used to refer to organic material in all stages of decomposition. It includes relatively stable materials termed *humus*, which are only very slowly decomposed. It also includes organic materials that may be decomposed rather rapidly and that range from fresh crop residues to those that, by a chain of reactions, are approaching humus.

Organic N occurs in crop residues and organic matter as protein compounds, amino acids, amino sugars and complex, largely unidentified substances. The latter groups comprise from one-half to two-thirds of the total nitrogen in soil and are so resistant to decomposition that their nitrogen is very slowly released to plants.

Soil organic matter is of importance in soil fertility primarily as a reservoir of N, phosphorus and sulfur. The organic N that becomes available to plants during their growth is that which is released into inorganic N when a portion of the organic matter decomposes. **Thus, much of the N in a soil is in a reserve that can be drawn from slowly.**

Nitrogen Transformations in Soil

Soil moisture, temperature and microbial activity all influence the forms of nitrogen in the soil. Figure 1 shows some of the major changes that take place in the forms of nitrogen.

Mineralization

The process of transforming organic N to inorganic N in soil, known as *mineralization*, occurs in a number of steps. The decomposition of organic matter proceeds by the breaking down of complex molecules to smaller and more soluble ones. Much of the initial mechanical breakdown of plant residues is performed by soil animals (fauna). The soil microorganisms (flora) attack the materials remaining and carry out enzymatic decomposition. Since they are living organisms, they are greatly affected by environmental factors. They also have relatively short life spans. Upon their death, they too are decomposed by other microbes.

The process of changing N from the amide form (the form in proteins and many other organic N compounds) to ammonium is sometimes called *ammonification*. This is carried out by most soil microbes under a variety of conditions. Both aerobic and anaerobic organisms carry out ammonification. The energy for the reactions is derived from carbon contained in the organic material undergoing decomposition. Consequently, fresh plant materials added to soil stimulate microbial activity greatly, whereas without such additions, activity proceeds at a slow or more constant rate.

Whether the decomposing substrate is native soil organic matter, added plant residues or animal manures, many factors affect the rate of mineralization in soil. Among these factors are the chemical nature of the organic matter, age and species of plant material, particle size of plant residue, N content of the residue, the carbon:N ratio of the residue and type and amount of clay minerals present. Generally, soluble organic materials with simple molecular structures, young leguminous plants and residues of high N content and low carbon:N ratio decompose most rapidly. The presence of clay minerals, especially those with large surface areas and expanding lattice structures, tends to lower the rate of decomposition. Additionally, soils with oxygen content above 5%, moisture near field capacity, temperature near 90 to 100°F and soil reaction near neutral are ideal for mineralization.
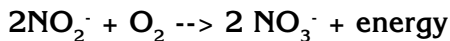
Nitrification

In most soils ammonium N is oxidized to nitrate soon after it is formed. Ammonium added in fertilizer undergoes the same process (*nitrification*). The oxidation is carried out in two steps, as represented in the following equations:

(a)

$$2NH_4^+ + 3O_2 \longrightarrow 2NO_2^- + 2H_2O + 4H^+ + energy$$

(b)

$$2NO_2^- + O_2 \longrightarrow 2NO_3^- + energy$$
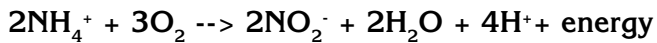
The microorganisms carrying out these reactions are able to meet their carbon needs for growth by using only carbon dioxide from the air and do not require organic or other chemically combined carbon. They are rather specific for these reactions. Whereas many different microorganisms may carry out ammonification, only a few species carry out nitrification.

Nitrification usually proceeds rapidly in warm (75 to 85° F), well-aerated soils with pH between about 6.0 and 8.0 and with good water and nutrient levels. Nitrification is slow in excessively wet, cold or acid soils. From the above equations, one may note that hydrogen ion is released as ammonium is oxidized. Consequently, when large amounts of ammonium fertilizers are added to soil, the soil pH will decrease as nitrification occurs.

Immobilization

Just as ammonium and nitrate may be released by decomposition of microbial cells, added nitrate and ammonium may be converted to microbial cells when the microbial population is high and the soil has an abundance of available carbon. Most typically this happens when a large amount of low N-containing crop residue, such as wheat straw, is mixed with the soil. The addition of the residue stimulates the growth of such a large population of microorganisms that the supply of nitrate or ammonium can be exhausted.

If crop plants are being grown at the same time as the decomposition of residue is taking place, they will suffer from a lack of N, at least temporarily. This possible damage to crop yield can be averted by mixing such residue with soil well ahead of the next cropping season.

Sources of Nitrogen in Soils

Biological Fixation of N_2

One of the chief means of nitrogen accumulation in soils is the combining of N gas in the atmosphere (the air contains about 35,000 tons of N above each acre) into organic N by the bacteria (rhizobia) that live on legume roots. These are found in the nodules on roots of properly inoculated leguminous plants, such as clover, alfalfa, lespedeza, soybeans and peas. As a result, legumes grown in association with grasses will supply enough available N for the grasses (from the decaying of the legume plant residues) while also providing for their own requirements as a legume crop.

Another group of soil microorganisms, called non-symbiotic nitrogen fixers, incorporate some atmospheric N into their cells. This can later become available for plant growth. Usually less than 10 lb/acre/year, it is not considered a very important source of plant-available N in agricultural soils. Very small amounts of ammonia and nitrate N from the atmosphere are returned to the earth in rainfall each year. This may be a little greater near industrial areas, but since it is only about 5 to 10 lb/acre/year, it cannot be considered a major source of soil N.

The amount of biologically fixed N is variable with climate, species of plants and bacterial activity but ranges from almost 0 to 300 lb/acre/year. Most fields with high densities of legumes will fix at least 25 lb/acre/year.

Crop Residues

Crop residues returned to the soil are important sources of N for succeeding crops if they are properly managed. Mineralization of N from legume or legume-grass residues can release as much as 100 lb N/acre when cover crops or sods are killed or plowed under. However, decomposition of some residues such as straw, cornstalks and sawdust, which contain very little N relative to their carbon content, may reduce the amount of N available to the crop during the initial stages of decomposition. Since these residues are high in carbonaceous material, the microbial population of the soil increases rapidly during the early stages of decomposition and will compete with the growing crop for nitrogen. More N fertilizer is needed when large quantities of these high-carbon crop residues are added to the soil just prior to planting a crop. This

microbial tie-up of plant-available N is not important if the crop residues contain much N (legumes or young plants) or when these more carbonaceous residues are applied well ahead of crop planting time.

Manures

The N content of manures varies considerably, depending on the kind of livestock, age of animals, ration fed and amount of bedding. As a general rule-of-thumb, a ton of barnlot manure contains about 10 lb of N. About one-half of this will be available to plants during the first growing season after the manure is applied. Table 1 lists the N content, as well as P_2O_5 and K_2O, of some manures and tobacco stalks and stems.

Table 1. — N-P_2O_5--K_2O Content of Animal Manures and Tobacco Stalks and Stems

Material Applied	Pounds Per Ton		
	N	P_2O_5	K_2O
Animal Manure[1]			
Dairy Cattle (80% water)	11	5	12
Hogs (75% water)	10	6	9
Poultry (55% water)	31	18	8
Horses (60% water)	14	5	14
Sheep (65% water)	28	10	24
Tobacco Stalks	30	10	70
Tobacco Stems	30	10	140

[1]*For tobacco production, do not apply more than 10 T/A of animal manure because of its high chlorine content.*

Commercial Fertilizer

Industrial processes used to manufacture commercial N fertilizers usually combine atmospheric N with hydrogen and/or oxygen and/or carbon and then convert the products into various N fertilizers such as ammonium nitrate, anhydrous ammonia or urea. These N fertilizers can be applied directly to soil or may be further processed into other solid or liquid fertilizers. Since most Kentucky soils do not supply adequate amounts of N for profitable production of nonlegume crops, such as corn, tobacco, small grains and grasses, the use of N fertilizers is essential.

N

Nitrogen Fertilizers

Mixed Fertilizers

Most of the mixed fertilizer used in Kentucky contains some N, the amounts varying considerably, depending on the grade. The first number in the guaranteed analysis of a fertilizer refers to the percentage of N. A 5-10-15 grade is 5% N and contains 5 lb of N in each 100 lb, while a 12-12-12 contains 12 lb of N in each 100 lb of fertilizer. A fertilizer having a zero as the first number of the guaranteed analysis, e.g., 0-20-20, contains no guaranteed N. Most of the N in mixed fertilizer is in the ammonium form. Diammonium phosphate and monammonium phosphate are also commonly available N-containing fertilizers with all the N being in the ammonium form.

Nitrogen Materials

Fertilizers that contain only N are sometimes referred to as straight N fertilizers. In recent years the tonnage of these straight N fertilizers has increased rapidly in Kentucky. They are marketed in two physical forms: solid and liquid. N materials commonly sold in Kentucky are discussed below.

Ammonium Nitrate (NH_4NO_3) is a solid N fertilizer and contains 33.5 to 34.5% N. Half the N is in the ammonium form, and half is in the nitrate form. Ammonium nitrate dissolves rapidly in the soil, and a large proportion of ammonium reacts with the negatively charged soil particles while the nitrate ions remain in the soil solution and move with the soil water.

Urea $CO(NH_2)_2$ contains 45 to 46% N in the solid form. When applied to the soil, the enzyme urease quickly converts urea N to ammonium. Consequently, urea behavior in soil is essentially that of ammonium, except for a potential for some ammonia volatilization loss unless it is mixed into or is in contact with the soil.

Nitrogen Solutions -- Although the N content of commonly available N fertilizer solutions ranges from 28 to 32%, 28% N solution is used mostly in Kentucky because of its low salt-out potential. Half of the N is from ammonium nitrate, and half is from urea in N solutions most commonly used for direct soil application.

Anhydrous Ammonia (NH_3) is the highest analysis N fertilizer available. It contains 82% N. At ordinary temperatures and at atmospheric pressure, it is a gas. For this reason, it must be kept under pressure to stay in liquid form, which is necessary for transportation, handling and application.

When anhydrous ammonia is released from the pressure in the applicator tank, the liquid immediately changes to the gas. For this reason anhydrous ammonia must be injected six or more inches deep into the soil and then covered immediately to prevent loss of ammonia gas to the atmosphere. When injected into the soil, the ammonia molecule (NH_3) reacts with water and becomes ammonium (NH_4^+). The positively charged ammonium ion is then held by soil particles until it is either converted to nitrate N by nitrification or is absorbed by plant roots or soil microorganisms.

The depth to which it should be injected to prevent vapor loss will be influenced by several factors. For heavy rates of application, placement should be deeper since the gas will move a greater distance from the point of release. It should also be applied deeper in sandy soils since these soils have fewer colloidal-sized particles, larger pores and less soil water to hold the ammonia. Since ammonia will move farther in a dry soil than in a moist soil, it should be applied no less than six inches deep.

Anhydrous ammonia can also be applied as a supercooled liquid, a process trademarked as "Cold-Flo." In this process, gaseous anhydrous ammonia is released into a specially built converter that cools it enough to convert it to and keep it as a liquid during application. The supercooled liquid can be applied just in front of a disk or other tillage implements that mix it into the soil before it vaporizes.

Ammonium Sulfate ($(NH_4)_2SO_4$ contains about 20% N and 24% sulfur. All the N is in the ammonium form, which is temporarily absorbed by the clay and organic matter of the soil until it is nitrified to nitrate N or used by plants or microorganisms.

Nitrate of Soda ($NaNO_3$) contains 16% N, all of which is in the nitrate form and readily soluble in the soil solution.

Slowly Available Nitrogen Compounds - Some organic N materials, such as cottonseed meal, fish scraps, tankage, sulfur coated urea and urea formaldehyde, are used as slow release N fertilizers since the solubility of their N is slow. Their use has not generally extended to field crops because the cost of the N in these products is much higher than in the more common N fertilizers. Some forms are more commonly used in turfgrass.

Soil Loss of Nitrogen

As previously indicated, available N may be immobilized by soil microbes. Although immobilized N is not lost from the soil, it is not readily available for plant uptake. However, N can be lost from soil by erosion, volatilization, denitrification and leaching. An understanding of conditions contributing to these losses is helpful in managing N fertilization of crops.

Erosion

Most of the organic matter in upland soils is in the top six to eight inches of soil. Therefore, a considerable amount of N may be lost each year by erosion. Good soil conservation practices will minimize N losses by lowering erosion of surface soil.

Leaching

Leaching losses of soil N occur because much of the N added in fertilizers is partially (or soon ends up as) nitrate, which largely remains in solution in the soil water. During periods of excess moisture, particularly in winter and early spring, the downward movement of soil water results in leaching losses of nitrate from the soil.

During the late spring, summer and fall months, transpiration of moisture by the growing crop and evaporation at the soil surface removes moisture rapidly. With rapid removal of soil water during the growing season, precipitation is seldom great enough for water to move through the soil profile beyond the plant root depth, except in sandy soils. So in most years, leaching of N during the growing season is negligible on silt loam and finer textured soils in Kentucky.

Leaching will be favored in soils with good drainage and high infiltration rates. Thus, under some conditions, the risk of leaching loss is higher from no-tillage than from conventional tillage soils.

Soil temperature in Kentucky does not usually stay cold enough over a long enough period to prevent conversion of ammonium to nitrate during the winter. UK field research has shown that considerable N is lost during the winter and early spring when fertilizer N is applied on fallow land in the fall for crops to be planted the following spring.

Denitrification

Anaerobic bacteria in soil reduce nitrate to volatile forms of N under conditions of poor aeration or a low supply of oxygen. The presence of crop residues and other decomposable organic matter, poor soil drainage and high soil water content increase the rate of denitrification. After nitrate is denitrified to nitrous oxide or elemental N, these gaseous forms of N escape to the atmosphere. Most nitrate N may be lost in this manner from low, wet areas of a field, especially during periods of warm weather and heavy rainfall when the soil stays saturated for periods of two to six days. Also, due to the presence of the surface mulch and more moisture, there is some potential for denitrification loss of surface-applied N on no-till crops. A sidedressing of N fertilizer may become necessary following such conditions due to the denitrification loss of previously applied N.

Volatilization

Management steps should be taken when applying anhydrous ammonia, urea and N solutions to minimize the loss of ammonia gas from the soil.

Since urea N is quickly converted to ammonia when applied to soil, some ammonia may escape to the atmosphere before it converts to ammonium and reacts with the soil. These losses are most likely to occur at temperatures above 50°F and on soils having a pH greater than 7.

Another factor influencing the risk of volatilization loss from topdressing is the amount of vegetative cover. When urea is applied to untilled land where much of it is held on the vegetative cover or plant residue, the risk of volatilization loss is greater than when the urea is in contact with bare soil. If rainfall occurs soon after urea is surface-applied, it will wash the urea into the soil and prevent volatilization.

Kentucky studies comparing ammonium nitrate and urea as a N source for topdressing established grass sod have shown urea to be less effective than ammonium nitrate, particularly when applied after May 1. Effectiveness of N solutions has been less than ammonium nitrate but greater than urea in topdressing trials comparing the three N sources.

Efficient Use of Nitrogen Fertilizer

Even though N is important for high production of nonlegume crops, it does not substitute for the other elements essential to plant growth. A proper balance of all the essential elements must be available in the soil so that the crop has a maximum response to N applications.

As N rates are increased, soil acidity increases since most N fertilizers make soil more acid and increase the need for an adequate liming program.

Nitrogen should be applied as near as possible to the time the crop requires it. This will be shortly before rapid growth begins or after the crop is actively growing. Well-timed N application will result in rapid crop uptake which, in turn, will reduce the risk of N loss by leaching, denitrification or other mechanisms. Four to six weeks after planting is the optimal time to apply most of the fertilizer N to corn. Part of the N should be applied as a sidedressing on sandy soils because of the high risk of leaching losses from coarse-textured soils. Sidedressing with N may also be profitable on soils that remain wet for several days following rains since much of the nitrate may be lost by denitrification. Sidedressing and delayed application of N have been consistently beneficial on no-tillage soils because of the high potential for early season N losses with no-tillage. Two or three applications during the growing season will result in more uniform growth of grass sods.

Use of the trademarked nitrification inhibitor, N-Serve , and the urease inhibitor, DCD, has been shown to have about the same effect as delayed application of N on no-till corn where it is sprayed onto ammonium nitrate or urea immediately before topdressing.

Except for urea and anhydrous ammonia, fertilizer placement is not usually as important with N as with other plant nutrients. This is because nitrate N moves with the soil water and is carried to the plant roots during periods of adequate rainfall. Some research indicates that denitrification and immobilization losses are reduced by subsurface banding of N below the organic matter accumulation at the surface on no-tillage soils.

When buying N fertilizers, each source has certain advantages and disadvantages. Table 2 shows the amounts of different N materials required to supply given rates of N/acre. Rates shown in the table may be doubled or combined to calculate the amount of material required for heavier N rates.

N

Table 2.—Amount of Material Required to Supply the Desired Rate of Nitrogen

Material	Percent Nitrogen	Pounds of Nitrogen Per Acre			
		25	50	75	100
		------- lb of material[1] -------			
Ammonium nitrate	33.5	75	150	225	300
Urea	45.0	55	110	165	220
Nitrate of soda	16.0	155	315	470	625
Nitrate of potash	13.0	190	385	575	770
Ammonium sulfate	20.5	120	245	365	490
Anhydrous ammonia	82.0	30	60	90	120
UAN Solutions*	28.0	90	180	270	355

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[1]*Rounded to nearest five pounds.*

Nitrogen content of solutions may vary. The guaranteed analysis shows the pounds of nitrogen in each 100 lb of solution. The rates shown in the table are the pounds required for a 28% solution. Most UAN solutions weigh between 10 and 11 lb/gallon.

High crop yields require relatively large amounts of nitrogen. Unfortunately, most soils in Kentucky will not supply an adequate amount of nitrogen in an available form for the most profitable yields of nonlegume crops without fertilization. Many factors related to the soil and the crop being fertilized influence the rate and time of application.

For recommendations of nitrogen fertilization for the various crop and soil conditions, see Cooperative Extension publication AGR-1, *Lime and Fertilizer Recommendations,* published by the Agronomy Department, UK College of Agriculture.