NITROGEN

Nitrogen is the basic building block of all living matter, both plant and animal. Plants and animals need plentiful supplies of nitrogen to insure respiration, growth and reproduction.

Nitrogen in its pure state is a colorless, odorless, inert gas comprising 78% of the air we breathe. In this form it cannot be used by non-legume plants. Nitrogen must be converted by soil microorganisms or industrial processing into forms crops can use.

There is about 35,000 tons of nitrogen over every acre of land. This inexhaustible supply remains constant, because nitrogen is being returned to the atmosphere at about the same rate as it is being removed.

Functions of N in Plants

Nitrogen (N) is the nutrient most commonly limiting for crop growth and development and is required in larger quantities by plants than any other mineral nutrient. There are just two forms of N which plants may utilize – nitrate-N and ammonium-N. The nitrate form is negatively charged, and as a consequence, is not held to the clay particles in the soil. The ammonium form of nitrogen carries a positive charge, and thus is held tightly to the clay particles in the soil.

There are many complex plant components that require N, the most important of which are:

- *Protein*: Nitrogen is an essential part of amino acids that are the building blocks of protein molecules. The use of nitrogen fertilizer has greatly increased the production of plant protein in a world in which protein supply is inadequate for human nutrition.

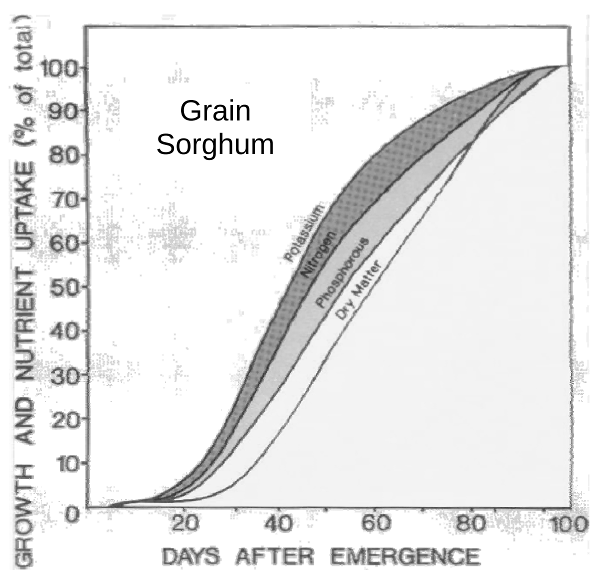
  Protein content is calculated by multiplying the percentage N in plant tissue by 6.25 for most grain and forage crops. For wheat grain, percent N is multiplied by 5.7 to calculate protein content.

- *Enzymes*. All plant enzymes are proteins, so N is required for all enzyme reactions.

- *Chlorophyll*: Nitrogen is a constituent of the chlorophyll molecule, the green pigment that allows plants to use sunlight energy to convert carbon dioxide and water into food (carbohydrates).

Nitrogen fertilization normally increases the yield of grain, fruit, or forage of non-legume plants. An important effect of N is that it promotes vegetative growth.

Applied in correct amounts, N produces a dark green, healthy plant that reaches maturity more rapidly than N-deficient plants. Nitrogen can occasionally delay crop maturity, if applied in amounts greater than the crop needs. For example, excessive rates of N on tomatoes or melons may produce large, readily growing plants that set less fruit. Too much nitrogen may result in low sugar contents in sugar beets or in poor quality malting barley.



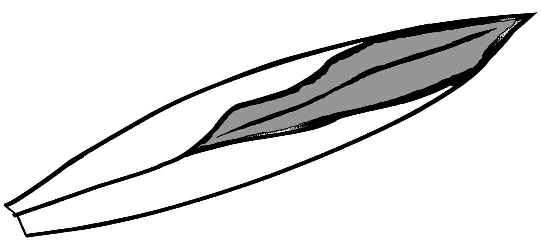
Nitrogen uptake occurs at a faster rate than dry matter accumulation. During the early growth stages following emergence, grain sorghum will take up no more than 5% of their total seasonal N needs. Still, N is important to get seedlings off to a rapid start. During the second month until near maturity grain sorghum requires large amounts of N each day. Corn, wheat and other crops will follow similar N uptake trends.

Nitrogen Deficiency Symptoms

Crops with a well balanced, adequate supply of nitrogen will have a rich green color and extensive root system. Corn and sorghums will have sturdy stalks and plump, firm ears and heads. Small grains will have well-filled heads with plump kernels and high protein content.

When N is deficient in plants symptoms are generally relatively obvious. Deficiency symptoms include:

- *Slow growth* and stunted plants.
- *Pale green or yellow color* (lack of chlorophyll). Nitrogen is mobile in the plant; thus deficiency symptoms occur first in the oldest leaves. In grass-type plants, yellowing begins at the leaf tip and proceeds down the mid rib. If the deficiency is severe, leaves fire and die.
- Reduced tillering of small grains.



V-Shaped Firing

Nitrogen deficiency symptoms on corn, sorghums and small grains include pale green color, poor root development, spindly stalks, small ears and heads, and starchy looking kernels. In extreme cases ears and heads will not set on the stalks. In corn and sorghums the leaves will turn yellow and die at the mid-ribs. This occurs first on the lower leaves and progresses up the plant, since nitrogen is a mobile nutrient in plants and older plant parts will give up nitrogen to the newly developing plant parts. In severe cases nearly all the leaves will die prematurely.

Even legumes like alfalfa and soybeans exhibit symptoms of pale color and, in severe cases, dying of the leaves. Of course, growth is also retarded. Often in cold wet springs alfalfa, particularly the first year after planting, will show some nitrogen deficiency symptoms. This is the basis for recommendations of some nitrogen on new seedings of alfalfa in order to provide needed N until nodules are formed and functional.

However, crops can be affected by too much nitrogen. An oversupply of nitrogen may cause excessive vegetative growth of crops which would result in lodging problems. Excessive nitrogen may also be a factor in the occurrence and severity of certain diseases.

The Nitrogen Cycle

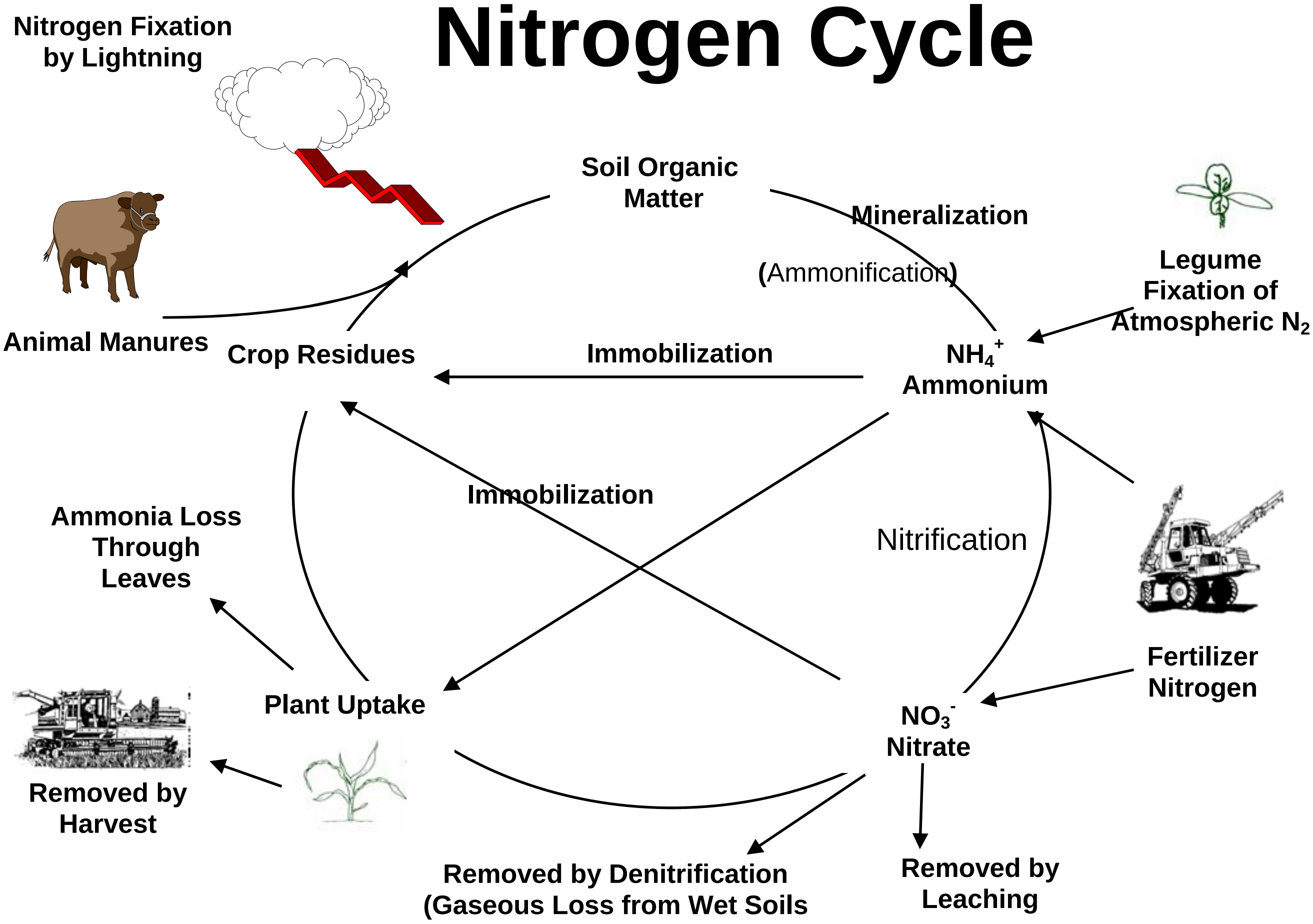
Nitrogen is a rather complex element, existing in many different forms. Nitrogen availability to plants is affected by several physical, chemical and biological processes. These transformations are collectively called the nitrogen cycle.

Plants grow and die. Animals eat plants, produce manure, and die. The residues of this animal and plant growth become incorporated in the soil and are decomposed by bacteria. From this decomposition, ammonium compounds are formed which may be utilized by growing plants. Other soil bacteria change ammonium into nitrate nitrogen. Nitrate nitrogen is then available for new plant growth and the cycle starts again. Nitrogen loss pathways create agronomic, environmental and health concerns.

Rainfall. Nitrogen is supplied to the soil in rainfall. Heat generated by lightning causes nitrogen and oxygen gases to combine as nitrate, which is then washed out of the air by precipitation. Ammonia and dust containing organic nitrogen are also washed out. About 5 to 10 lbs. N/acre are deposited annually with precipitation.

Symbiotic N Fixation. Some plants, such as alfalfa, clover, and soybeans, have a unique symbiotic relationship with special bacteria that convert nitrogen gas (N_2) from the air to a form plants use. These plants are called legumes.

Nitrogen Cycle



A species of bacteria called *Rhizobium* infect the roots of legume plants and form growths called nodules. Inside these nodules, the bacteria convert atmospheric N to ammonium-N (termed fixation) which the legume plant also utilizes.

Well nodulated legume crops rarely need N fertilization. In fact, if N is applied, the legume responds by producing less N of its own in the nodules. Occasionally, legumes planted on low organic matter, sandy soils do benefit from N fertilizer until the nodules are formed.

Nitrogen remaining in the nodules and other plant tissue and in the soil after a legume crop provides N for succeeding crops through mineralization. . Legume crop residues have a lower C:N ration compared to crops such as corn, sorghum and wheat. The amount of N credit varies with crop, stand, yield, and other factors. A farmer is wise to consider the value of this N when determining his N fertilizer program for successive crops such as corn, sorghum, and wheat.

It is interesting to note that soybeans and other legumes actually remove more nitrogen from the soil than they produce in their nodules. The term “Nitrogen Replacement Value” may be more accurate than nitrogen carry-over for legume N contributions.

Manure. Manure and municipal wastes have long been used as fertilizer. The nutrient value to the following crop varies considerably depending on animal species, feed ration, method of manure storage, method of application, incorporation method, etc. Detailed crediting of manure N to crops can be found in the Manure Management chapter.

Previous Crop	Nitrogen Credit (lb N/A)	
	Warm Season	Cool Season**
Alfalfa -		
Excellent Stand (5 or more plants/ft^2)	120	60
Good Stand (2-4 plants/ft^2)	80	40
Fair Stand (1-2 plants/ft^2)	40	20
Poor Stand (less than 1 plants/ft^2)	0	0
Sweet Clover -		
Excellent Stand	110	55
Good Stand	60	30
Poor Stand)	0	20
Red Clover -		
Excellent Stand	80	40
Good Stand	40	20
Poor Stand)	0	0
Soybeans	40	0

- N credits in no-till systems may be less.
- Cool season crops include winter small grains which grow in cool months of the year.
- Warm season crops include corn, sorghums, sunflowers and others which grow in summer

Immobilization and Mineralization. Immobilization is the conversion of plant available, inorganic soil nutrients to plant unavailable organic forms of nutrients by soil micobes. Immobilization of N occurs when microorganisms, during the process of crop residue decomposition, utilize soil N, rendering it at least temporarily unavailable to plants. If the C:N ratio of the organic material being decomposed is greater than about 30:1, the soil microorganisms utilize the carbon and N in these residues. But, since most crop residues contain too little N in relation to carbon they must also remove inorganic soil N in order to function. This ties up plant available N in the decomposed residue and soil microorganisms themselves.

Use of N fertilizer to hasten the breakdown of high carbon crop residues is recommended in some cases (10-20 lb. N/ton of residue). However, most soils contain enough N to break down the crop residue without additional N. Size of residue particles, temperature, and moisture usually affects the rate of decomposition more than lack of N.

As an example, high C:N ratio plant material such as wheat straw contains too little nitrogen relative to carbon to be a balanced diet for soil microorganisms active in the decomposition process. When continuous wheat is grown and excessive straw is incorporated by tillage or a dry summer occurs, the following wheat crop can be seriously affected. In this case about 20 pounds of N per acre for each ton of wheat straw turned under will be necessary to balance the C:N ratio and permit rapid decomposition. In general, nitrogen recommendations take into account normal amounts of crop residue.

When a crop residue containing a wide C:N ration is added to soils, microbial activity increases and soil nitrate levels decrease. The length of the depression period and the new level of nitrates in the soil are determined by the C:N ratio of the residue added, the amount of residue and environmental conditions for decomposition.

No till and reduced tillage concentrate crop residues near the soil surface. If N fertilizer is broadcast on the soil surface, relatively high amounts of N can be tied up or immobilized by crop residues. As a result, injection below the surface residue often provides higher N efficiency and crop yields with tillage systems that leave large amounts of crop residue on the soil surface. If N must be surface-applied on heavy crop residues, dribbling or banding the fertilizer reduces immobilization through reduced fertilizer residue contact.

Crop Residue	%C	%N	C:N Ratio
Alfalfa	42	3.0	14:1
Soybean residue	--	--	15:1
Cornstalks	42	0.7	60:1
Small grain Straw	42	0.5	84:1
Microorganisms	50	6.2	8:1
Soil O.M.	58	5.0	12:1
Grain Sorghum	42	0.6	70:1
Manure	--	--	<25:1
Wood chips	420	0.1	400:1
Glyphosate herbicide			3:1

Mineralization is the term used to describe the conversion of plant unavailable organic nutrients to plant-available, inorganic forms of crop nutrients by soil microbes. For nitrogen, mineralization occurs when soil bacteria decompose organic matter, amines, and amino acids to ammonium ions. Mineralization of nitrogen (ammonification) occurs when the organic material being decomposed is relatively rich in nitrogen. If decomposing material is high in N compared to carbon (C:N ratio of less than 20:1, as in alfalfa or soil organic matter) the net effect will be an increase in the soil nitrogen supply since they contain more than enough nitrogen for the soil microbes and a net gain of soil inorganic nitrogen results.

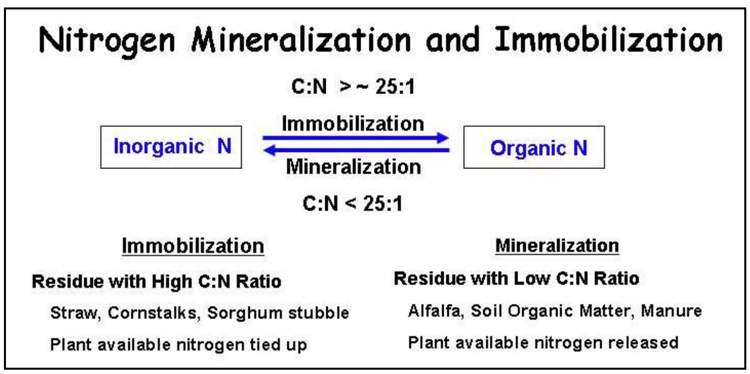
Soil organic matter may contain 90%, or more, of the total N found in agricultural soils and serves as an important source of plant available nitrogen when mineralized. Soil organic matter contains approximately 5%.nitrogen. Typically, about 1-3% of the soil organic matter nitrogen will be mineralized annually by microorganisms to available inorganic forms if moisture, temperature, and other conditions are favorable.

Assuming that 1% soil organic matter in the surface 6-7 inches of soil represents about 20,000 pounds of soil organic matter per acre – or about 1,000 pounds of organic nitrogen. As a result, about 10-30 pounds of organic N is mineralized each year for each 1% soil organic matter.

Factors that affect the rate of mineralization include:

- *Soil moisture and temperature*. When soils are very wet (anaerobic) or excessively dry, or when they are cold or hot, the rate of mineralization is reduced. As a result, the annual N release from soil organic matter can vary widely It appears that in years when climatic conditions are ideal for good crop yields, conditions are also ideal for mineralization.
- *Soils with a history of high N inputs* will tend to mineralize more N than soils which have received lower N inputs.

- *Reduced tillage systems*, such as no-till, reduce the rate of organic matter decomposition and subsequent N mineralization.



Nitrification. Nitrification is a two-step process carried out by two types of bacteria, *nitrosomonas* and *nitrobacter*. The rate at which this conversion process takes place is largely dependent on four soil factors:

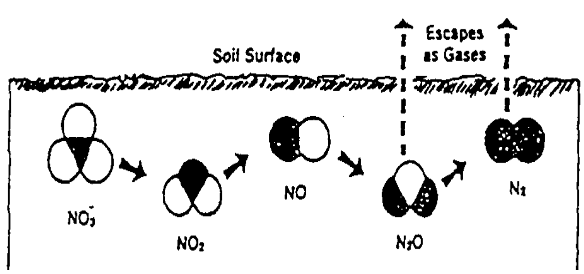
a. Soil oxygen- Oxygen is necessary for the production of nitrates and for the growth of nitrifying bacteria. With excess water in the soil and poor oxygen supplies, the rate of nitrification will be slowed, sometimes stopped completely. Soil compaction can also results in poor oxygen levels in the soil.

b. Soil pH- The bacteria responsible for nitrification are sensitive to the acidity or alkalinity of the soil. Nitrification can proceed at near optimum between pH 6.5 and 7.5.

c. Soil temperature- The optimum soil temperature for nitrification is between 65°F and 90°F. Nitrification may take place with temperatures above 32°F; however, the rate is slowed considerable below a temperature of about 50°F. The practice of delaying fall application of ammonium fertilizers until soil temperature at a 4" depth is below 50°F is intended to minimize nitrification.

d. Soil moisture- Nitrifying bacteria remain active in very dry conditions but inactive in waterlogged soils. Soils with sufficient moisture to grow crops will have optimum moisture for normal nitrification. Saturated soils do not contain enough oxygen for nitrifying bacteria. The main hindrance of the nitrification rate will come from excess moisture conditions, which in turn affect the oxygen supply. Extreme dry conditions may also slow down the nitrification process.

<u>Denitrification</u>. Nitrogen can be lost from soil through denitrification, a process in which oxygen is removed rather than combined with nitrogen. In poorly aerated, water-logged soil, soil bacteria change available nitrate nitrogen into N_2 gas which is lost from the soil. Soil pH, organic matter, soil moisture and soil oxygen supply may all affect the denitrification process.



However, the major factor is the level of oxygen. When soils become water-logged for a period of 36 hours or more, oxygen is excluded from the soil and anaerobic microorganisms use oxygen present in nitrates (NO_3^-) thus converting the nitrate to N_2 gas. An Illinois study found that when soils were saturated for 3 to 4 days, losses of 30 to 40 lb. of N per acre occurred even though the water was ponded only a few hours. After 6 days of saturated conditions, 60 to 70 lb of N were lost.

Several conditions are required for microbial denitrification to occur:

a. Lack of soil oxygen. If oxygen is not available, as in poorly aerated, compacted or waterlogged soils, denitrifying organisms use NO_3 as an oxygen source. The nitrogen is lost as a gas back to the air

b. Nitrogen must be in the nitrate form for the process to occur. Ammonium N cannot be denitrified.

c. Warm soil temperatures. Denitrifying microorganisms are inactive in cold soils. Very little denitrification occurs below 40°F. Denitrification takes place very rapidly in warm soils. Studies have shown that the rate of denitrification can double or triple for every 20° rise in soil temperature between 50°F and 90°F. If water stands on the soil for as little as 2 or 3 days during the growing season, significant amounts of nitrate nitrogen can be lost.

d. Presence of soil organic matter or crop residues as a source of carbon and energy for denitrifying microorganisms.

Yellowing of crops grown on water logged soils can be due in part to both nitrogen deficiency and a lack of oxygen. There are several management decisions that can reduce denitrification including:

- Avoiding nitrogen application in fall or early spring on soils that may become waterlogged. Topdressing or sidedressing reduces the potential for N loss by applying N nearer to the time of crop use.

- On soils that frequently become waterlogged, using a nitrification inhibitor such as N-Serve (registered trademark of the Dow Chemical Company). which slows the activity of the *nitrosomonas*, soil microbes that nitrify ammonium into nitrate.

Leaching. Leaching of nitrate nitrogen can be a serious problem especially on sandy soils. Since sandy soils retain only about one inch of water per foot of soil, relatively small amounts of rain or irrigation water readily move nitrates below the root zone. Well-drained silty and clay loam soils retain about three inches of water per foot of soil, so very little leaching occurs on these soils, except when rainfall is abnormally high.

Ammonium (NH_4^+) nitrogen is held on soil particles and is essentially non-leachable. Nitrate (NO_3^-) nitrogen is not held by soil particles and can be leached below the root zone. But this does not mean that ammonium nitrogen is more effective than nitrate nitrogen. As pointed out previously, ammonium nitrogen quickly changes to nitrate nitrogen under optimum soil conditions. As a result, very little difference in nitrogen loss occurs between ammonium and nitrate forms of nitrogen, even on sandy soils where excessive leaching may occur.

Nitrogen leaching losses can be minimized by reducing the time period nitrates are present before utilized by the crop. Delayed N application as sidedress or with irrigation water or the use of nitrification inhibitors can effectively reduce nitrate leaching, particularly on sandy soils.

Leaching of nitrate from the root zone is not only an economical concern but an environmental and health concern. Nitrate that ends up in drinking water can cause “blue baby syndrome” or methemoglobinemia. The maximum nitrate-N concentration set as safe for babies is 10 ppm.

An environmental consequence of nitrate in surface water is an increase in the growth of aquatic microorganisms such as algae. Excessive algae growth lowers oxygen levels creating an oxygen deficiency (hypoxia). Inadequate oxygen in water adversely affects other aquatic life including fish.

When the rate of N applied is based on yield goal, the amount of nitrate available for leaching is usually not high. However, when rates of N exceed that required by the crop, excessive nitrate is subject to leaching into groundwater.

Volatilization. When manure, urea fertilizer or solutions containing urea are surface applied and not worked into the soil some nitrogen can be lost as ammonia gas. Of course, direct loss of ammonia can occur from anhydrous ammonia or solutions containing ammonia if the material is not properly injected into the soil. Proper injection of solutions containing ammonia and immediate corporation of manure and fertilizer containing urea eliminates volatilization losses. Volatilization of ammonia will not take place when ammonium nitrate, ammonium sulfate or ammonium phosphate are surface applied to non-calcareous soils.

Ammonia Loss from Plant Leaves. Nitrogen loss can occur from above ground parts during grain fill. Ammonia is volatilized as organic N compounds are translocated in the plant as it matures.

Losses as high as 70 lbs/acre have been reported for corn and wheat and 40 lbs for soybeans. These losses are frequently not considered when calculating efficiency of N fertilizer utilization by crops.

Fertilizer Sources of Nitrogen

At one time, nearly all N fertilizer used was in natural organic materials. “Guano” (bird or bat manure) from Chile and other areas was the first N fertilizer sold in the U.S. Organic sources such as chicken litter, cottonseed meal, and steamed bone meal have also been used. Less than one-half percent of the fertilizer sold in the U.S. today is organic. Also, manure is an important N fertilizer and is covered in a separate chapter

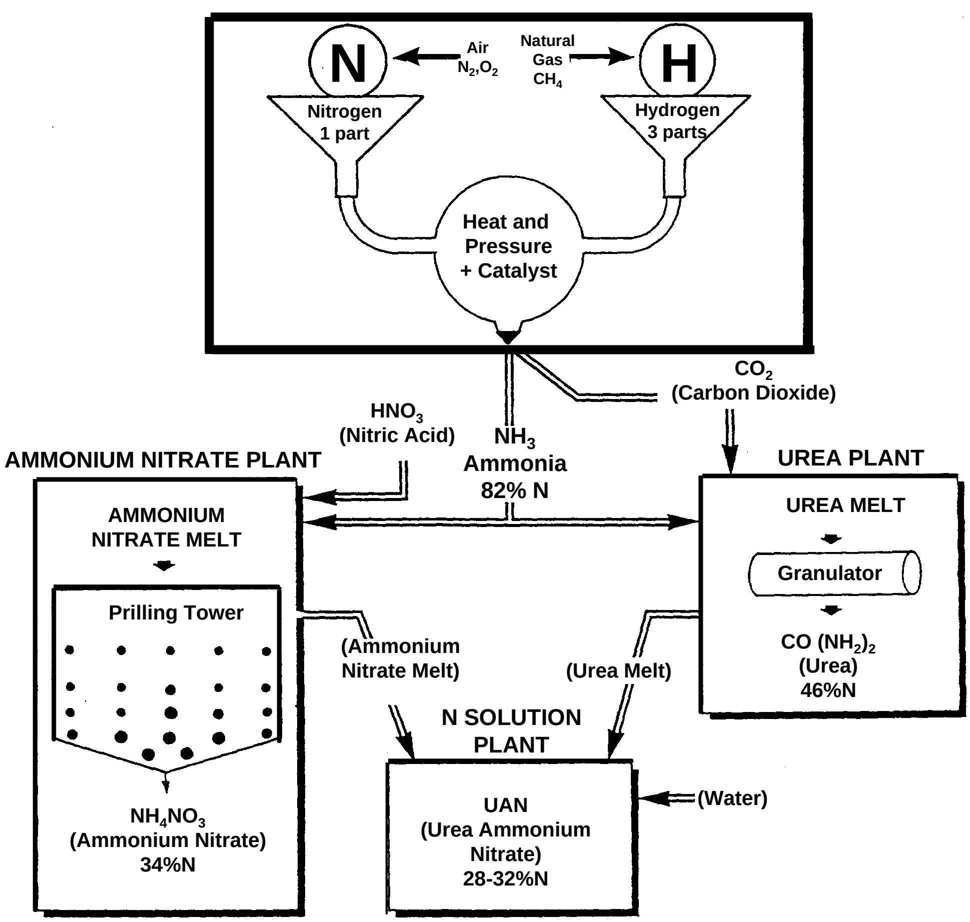
The major N fertilizer materials today include anhydrous ammonia, urea, urea-ammonium nitrate solution (UAN, typically 28% and 32% N) and ammonium nitrate.

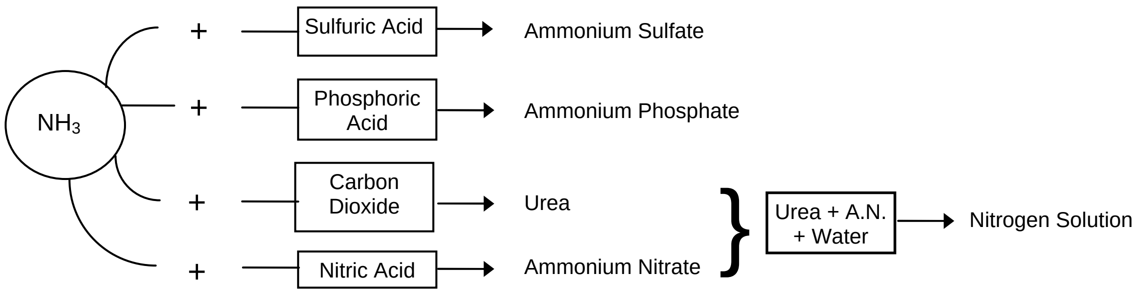
Almost all modern N fertilizers are based on the synthetic fixation of atmospheric N to produce anhydrous ammonia.

For ammonia production, hydrogen is almost universally supplied by natural gas (CH_4) - with about 32, 000 to 35,000 cu ft of natural gas required per ton of ammonia produced. As a result, natural gas accounts for 80%or more of the total cost of manufacturing anhydrous ammonia. Coal could also be used as a substitute source of hydrogen but is cost prohibitive. Coke, a residue from petroleum refining, is also used as a hydrogen source to a limited degree.

Other N containing fertilizers, such as various ammonium phosphates and ammonium sulfate, are also made from anhydrous ammonia

ANHYDROUS AMMONIA MANUFACTURING PLANT





Anhydrous Ammonia (NH_3)

Anhydrous ammonia is the most used nitrogen source in Kansas due to mainly to the fact that it has been the most economical source of N. Research has shown it to be equal to other forms of nitrogen fertilizer, pound for pound of actual nitrogen applied, in promoting plant growth.

Since NH_3 is a gas at atmospheric pressure it must be handled with equipment designed for NH_3 use and must be injected into the soil to a depth capable of holding the NH_3. Proper application depth will depend on soil physical characteristics, applicator NH_3 release spacing and NH_3 application rate.

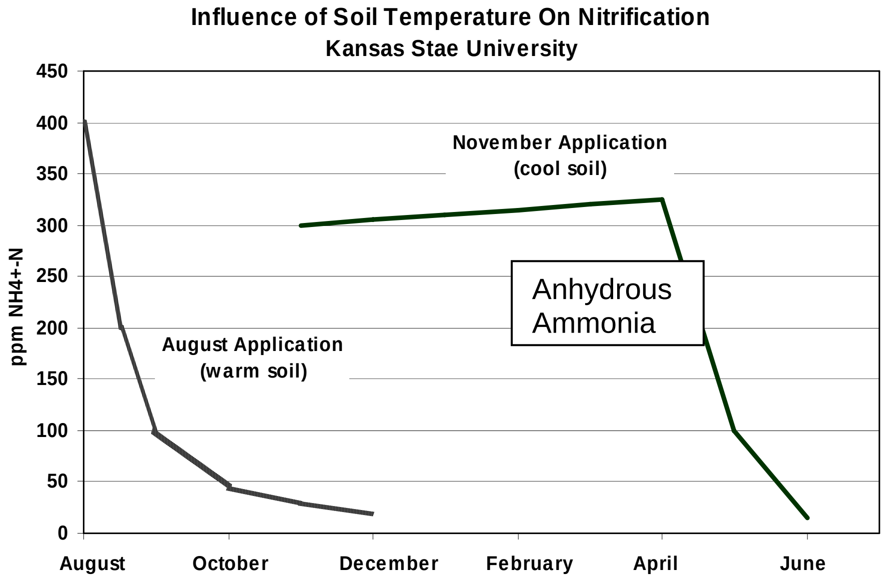
Anhydrous ammonia can be applied prior to or after planting as a separate treatment, or in combination with tillage operations. Many farmers have equipped chisel plows, sweep-type implements, and other tillage equipment with anhydrous ammonia attachments that combine tillage and fertilizer application into one field operation. Vapor loss can occur during and after application if soil does not seal off and trap the gaseous fertilizer in the soil. Soils can be both too dry and cloddy as well as too wet. In either instance, poor sealing behind the injection knife permits vapors to escape.

In general, soil moisture levels considered ideal for tillage are also best for applying anhydrous ammonia. The key to successful NH_3 application is good soil physical condition.

Anhydrous ammonia can be toxic to crop seeds and roots, if seeds are planted in or near the zone of application, or if side-dressed too close to the roots. To avoid possible germination injury, it is suggested that planting be delayed a few days after NH_3 applications. However, in cases where NH_3 applications have been made at minimum depths of 5-6 inches and seeding depth carefully controlled so as not to exceed

Properties Of Anhydrous Ammonia		
N Content	82%	
H Content	18%	
Water Content	<5%	
Weight, lb, gal.	5.7 at 28°F	
	5.3 at 32°F	
	5.1 at 60°F	
	4.9 at 100°F	
Expansion Rate	1 cu. ft. liquid becomes 850 gallons vapor	
Flammable Limits	16% to 25% by volume in air at 1500°F	
Specific Gravity	0.616 of 60°F	
Solubility	Extremely water soluble	
	°F	Lbs. NH3/gal. of Water
	50	5.7
	68	4.3
	86	3.4
Boiling point	-28°F	
Vapor Pressure at 0°F	15.7 psi	
Vapor Pressure at 70°F	114.1 psi	
Vapor Pressure 100°F	197.2 psi	

one and one-half inches, farmers have been able to successfully seed right behind the NH_3 application.



One big advantage of anhydrous ammonia is that it can be applied to the soil in last fall and winter without being changed to nitrates and subjected to leaching losses. This, of course, assumes there is sufficient clay in the soil to react with the ammonia. When soil temperatures are below 50^{o}F there is little microbiological activity and ammonia will not be converted to nitrates.

Research conducted by the Department of Agronomy, Kansas State University, tested the effect of temperature on change of ammonia to nitrates under field conditions. A large amount of anhydrous ammonia was applied in August and the soil was tested for ammonia each month through the following spring. In November, additional treatments were applied to adjoining plots and tested for ammonia through the following June. Data indicated that the August application was mostly transformed to nitrates before soil temperatures got below 50^{o}F. Then the change was rapid.

The direct application of ammonia is still the single most important source of N for Kansas crops. It is stored as a liquid under pressure and released as a gas. Some properties of ammonia that affect its use are:

Anhydrous ammonia is stored, transported, and otherwise handled as a liquid by keeping it under pressure in special containers, tanks, pipes, and hoses. The pressure increases as the temperature rises. As result, do not fill tanks over 85% full to allow for expansion as temperature increases.. Under normal climatic conditions, pressure ranges from 75 to 150 psi.

As a liquid, ammonia weighs about 5 lb. per gallon but the weight or density varies with pressure and temperature. This variation in weight can be as much as 1/2 lb. per gallon. These large density changes must be considered in filling tanks, inventories, and in regulating the flow for application.

Anhydrous means ‘’without water’, but anhydrous ammonia has a tremendous affinity for water. Ammonia reacts with water to form ammonium ions in soils.

$$NH_3 + H_2O \rightarrow NH_4^+ + OH^-$$

If liquid ammonia is released in the atmosphere, it rapidly expands into a gas. This gas is invisible although it produces a dense cloud of white water vapor condensing from the atmosphere. One cu ft of the liquid expands to 113 cu ft (850 gal) of vapor.

Advantages of anhydrous ammonia include:

- Highest analysis N product (82% N)
- Lowest purchase cost per pound of N.
- Most resistant to leaching and denitrification losses
- Excellent source for fall, preplant, and sidedress application.
- Injection places N below crop residue in no-till or reduced tillage system where it often outperforms surface-applied N sources.

Disadvantages of anhydrous ammonia include

:

- Higher power requirement for application if not combined with tillage.
- Requires high-pressure storage and handling equipment.
- Requires high level of safety awareness.

Soil application of anhydrous ammonia takes advantage of the rapid expansion of the liquid to a gas and its high affinity for water. The liquid flows down hoses into the soil where it is released below the soil surface. On release, it rapidly expands to a gas, spreads out into the soil, and dissolves immediately in soil water. It then attaches as ammonium to organic matter and clay particles.

Many farmers combine the application of ammonia with some other farm operation, such as tillage. With the ammonia tank mounted on the tractor or trailer, hoses can be routed to direct the ammonia below the soil surface. The ammonia can be trapped in the soil with a moldboard plow, disk plow, one-way, Noble blade, chisel plow, or even a disk harrow. This eliminates the usual application expense and further reduces the cost of the applied nitrogen.

Some commonly asked questions regarding the application of anhydrous ammonia are:

Is soil moisture content a factor when applying anhydrous ammonia?

Soil moisture is an important consideration in providing proper soil physical conditions to assure rapid and complete sealing of the injection channel. In soils that are too wet, the shank opening or injection channel tends to stay open and the ammonia gas comes to the surface and is lost. If the soil is too wet, freezing of injection points may be a problem. In dry soils, losses will be minimal and infrequent if the soil has good tilth. However, if the soil is dry *and* cloddy, the ammonia gas can escape to the atmosphere.

What injection spacing is best to obtain uniform application of anhydrous ammonia?

Injection spacing will depend on the extensiveness of the root system of the crop, soil conditions, application rate and the time of the year the application is made

For preplant application on small grains, 15" to 18" spacing may be optimum to prevent nitrogen streaking., while 18" to 20" spacing are also used successfully. For corn or sorghum, 30" spacing is generally adequate. On soils with very low ammonia-holding capacity, wide spacing produce higher ammonia concentrations at the point of injections. Higher concentrations increase the potential for the ammonia gas to escape.

Research in Illinois and Minnesota has shown that 60" spacing is as effective as 30" spacing for 30"corn <u>if</u> the location of the rows is known (no-till, sidedress, etc.). The following chart shows 3 year corn yield average in Illinois with different knife spacing and location relative to the corn row. Yields were similar except where the knife was 30" away under the adjacent row.

Spacing and Location of NH_3 knife	Corn Yield, bu/A
30", beneath corn row	144
30", between corn row	148
60", beneath corn row	149
60", between corn row	145
60", beneath adjacent row	139

How can ammonia toxicity to seedlings be avoided?

A high concentration of ammonia or ammonium in contact with seed may be harmful. Anhydrous ammonia, applied under cool soil temperatures in the spring may "linger" in the soil for some time. Corn seeds, planted in this zone of ammonia may show germination and seedling damage. Seedling damage is affected by N rate, depth of application, time between application and planting, and direction of application.

A study conducted by University of Illinois has shown that seedling damage may be eliminated by proper application of the ammonia. When ammonia was applied at rates of up to 400 lb of

Effect of Application Depth and Time of Planting on Ammonia Toxicity to Corn Stands Days delay in Planting After NH_3 Application						
Depth of Application	0	7	14	0	7	14
	200 lb. N			400 lb. N		
(Inches)	Stand (% of Normal)					
4	60	96	100	35	60	90
7	100	100	100	80	100	100
10	100	100	100	100	100	100

N/acre at a depth of 7” to 10”, corn planted the same day, showed only slight stand reductions. However, when 200 lb of nitrogen were applied at a depth of only 4”, some ammonia damage to corn seedlings occurred when planting was delayed 7 days. It is apparent from this study that the key to avoiding seedling toxicity problems is to know where the seeds are planted with respect to ammonia zones created by spring preplant application.

Proper application of ammonia in the spring prior to planting is essential with a minimum recommended depth of 7” for row crops and 5” for small grains. Check the applicator to be certain all knives or sweeps are at the same depth

Fall application of ammonia drastically reduces the potential for damage to spring seeded crops. Applying the ammonia diagonally with respect to row direction can also reduce injury to consecutive plants in a row.

Effect of NH_3 on Bacteria Population*			
*Days After	Injection Point	1” Away	2” Away
	Bacteria/Gram Dry Soil		
0	260,000	4,600,000	2,300,000
3	7,200,000	6,400,000	3,000,000
10	8,400,000	5,400,000	2,000,000

* Original count 2,250,000 bacteria/gm of soil.

Can anhydrous ammonia be used on existing stands of small grains or pastures?

When anhydrous ammonia is applied to existing stands, it is best to use an anhydrous applicator knife mounted behind a coulter to keep mechanical damage to the crop at a minimum. A few plants will be injured or destroyed, but tillering will compensate for any losses. When making applications on grass pastures, attention should be given to assure a good seal of the slot created.

Is anhydrous ammonia toxic? Does it kill microorganisms and earthworms?

As mentioned previously, there can be a germination and/or stand reduction in the ammonia fertilizer application zone. Generally, every organism near the center of this zone will be affected including microorganisms, crop and weed seeds, and earthworms. However, the effect on living organisms is minimal and short term.

Three properties of anhydrous ammonia cause damage to living organisms:

- At the point of release from the injector knife, the temperature will be about -28°F, freezing everything it contacts.
- The soil pH is quite high (9.5-10) for a short period in the injection zone resulting in a toxic condition.

Soil microorganisms population reductions in the injection zone are temporary. Shortly after application, they utilize the applied nitrogen ultimately resulting in an increase in microorganism populations.

Does anhydrous ammonia cause the soil to crust or get hard?

No. A long-term Kansas State University study has shown that ammonia has no short- or long-term effect on soil density, hardness, structure, or any other physical property. Soil compaction by operating heavy equipment on wet soils can occur with the application of ammonia or any fertilizer.

Is speed a factor to consider when applying anhydrous ammonia?

The faster equipment travels, the greater is the tendency for injector knives or shanks to bounce and lift out of the soil. As a result the depth may be more shallow than desired, resulting in ammonia losses or crop damage. The rate of nitrogen applied will also be affected. Variable speed on sloping ground can seriously affect the rate of NH_3 on hillsides. Radar or ground speed controllers are effective at minimizing the effect of speed changes on delivery rate.

precipitates (e.g., calcium and magnesium compounds) can be deposited in the irrigation system. Plugging of the system and/or nozzles can result. Metering of ammonia into irrigation canals and furrows is acceptable.

How can anhydrous ammonia applicators be calibrated?

Accurate application infers the right rate per acre and a uniform application across the applicator. Many applicators are not properly calibrated. Application rate changes with temperature, tank pressure and several other factors. Use of radar or ground speed controller with a heat exchanger minimizes the variability caused by these factors.

Effect Of 20 Years Of N Fertilizers On Soils. Kansas State University)

Nitrogen Source	Soil pH	Soil OM	Bray P-1	NO_3^--N	NH_4^+-N	Density
		(%)	- - - - - ppm	- - - - -		(lb/cu ft)
Check (No N)	6.2	2.0	38	4	5	100
Anhydrous Ammonia	5.2	1.8	27	27	9	99
Ammonium Nitrate	5.2	2.3	26	21	11	99
Urea	5.1	2.3	24	31	12	99
UAN Solution	5.2	2.0	28	20	8	100

How long should tillage operation be delayed after application of anhydrous ammonia?

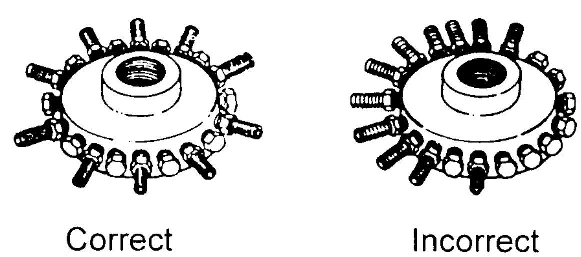
When anhydrous is applied to soils, it converts from NH_3 (ammonia) to NH_4^+ (ammonium) and attaches to exchange sites on clay particles. If a secondary tillage operation is performed before this attachment is complete, some of the ammonia could be lost to the atmosphere. The key to avoiding volatilization is to apply ammonia deeper than subsequent tillage operations. Waiting 3 to 5 days to plow after ammonia application also helps.

Can anhydrous be applied through a sprinkler irrigation system?

Anhydrous ammonia can be converted to aqua ammonia with a low vapor pressure by dissolving in water. Studies have shown up to 60% N loss by application through sprinklers. Therefore, this practice is not recommended. Also, the addition of ammonia to irrigation water increases the pH of the water. Depending on the quality of the irrigation water, substantial amount of

For uniformity from knife to knife across the tool bar check and adjust the following:

- Manifold. Use manifolds with the same number of outlets as knives if possible. If it is necessary to plug unused outlets, do not place plugs consecutively, rather space them as equal as possible. Be sure hose barbs are the same style and size. Check that the manifold is level and there is no rust in the hose inlet or in the manifold. The manifold pressure should be a minimum of 20 psi.



- Hoses: Be certain all hoses are approximately the same length. Do not coil hoses tighter than a 1.5' diameter. A 3/8" hose is preferred for most uses.

- Knives: Be sure all knives on the applicator are the same style with the same size discharge opening. Check for burs (even on new knives). Check for plugging or excessive wear of hole openings. Be sure all knives are placed at the same depth.

Ammonium Nitrate (NH_4NO_3), 34-0-0

Pure ammonium nitrate is 35% nitrogen, but fertilizer grades are typically 34.0% nitrogen. Ine-half of the total N is is nitrate-N and one-half is ammonium-N

Composition and properties include:

Hydrogen	5%
Oxygen	60%
Nitrogen	34-35%
Bulk Density	48 to 58 lb/cu ft.
Critical Relative Humidity	59.4%

The physical form of most ammonium nitrate is prilled or granulated. Prills are formed by dropping liquid melt through a cooling tower. It is coated with a conditioning clay, which retards moisture absorption from the air and caking. Granular ammonium nitrate particles are larger and generally preferred for blending.

Ammonium nitrate is produced from ammonia and nitric acid. Since it supplies both ammoniacal and nitrate forms of nitrogen and is completely soluble, it is an excellent source of nitrogen for plant feeding purposes. The nitrate is mobile and can move quickly to the root for uptake by the plant.

The ammoniacal nitrogen attaches to the particles of clay and organic matter and is gradually converted to the nitrate form which continues to provide nitrate nitrogen for several weeks.

Advantages of ammonium nitrate include:

a. Not subject to volatilization losses except on calcareous soils. Well suited for warm-season grass pastures.

b. Nitrate is a mobile nitrate that can move quickly to the root zone. Ammonium is less mobile but is not subject to leaching or denitrification.

Disadvantages of ammonium nitrate include:

- Production is declining in US due to environmental and economic considerations.
- Can not be shipped internationally
- Nitrate portion is subject to leaching and denitrification.
- Cost of production is higher than for urea.
- More corrosive to concrete and metal than urea.
- Absorbs moisture easily during handling and storage.

Urea, $CO(NH_2)_2$, 46-0-0

Urea is produced by combining ammonia with carbon dioxide, a by-product of an ammonia manufacturing plant.

$$2NH_3 + CO_2 \rightarrow CO(NH_2)_2 + H_2O$$

Ammonia	Carbon Dioxide	Urea	Water

Composition and properties of urea:	
Hydrogen	6.6%
Oxygen	26.7%
Carbon	20%
Nitrogen	46.7%
Bulk Density	45-48 lb/cu ft
Critical Relative Humidity	75.2%

Urea has rapidly replaced ammonium nitrate as the dry N product in the marketplace. Urea is water soluble and can move in soil until hydrolyzed to ammonium. This process can take 2-10 days depending on soil temperature, moisture and urease levels.

Thee are many reasons why urea has replaced ammonium nitrate in the marketplace.

- Dominates international N marketplace. Ammonium nitrate may not be shipped internationally.
- Highest analysis of dry material 46% N provides for efficient shipping and storage.
- Good physical handling and storage properties (low hygroscopicity and corrosiveness).
- Lower production costs per pound of N as compared to ammonium nitrate..
- Fewer environmental pollution problems during manufacture than ammonium nitrate..
- Less plant leaf burn with foliar fluid or dry applications.

Urea is an excellent N fertilizer, but it has certain limitations that must be understood to use it effectively.

Seed Damage: The formation of ammonia as urea decomposes can reduce seed germination. As a result, urea should not be placed in direct seed contact. Placing the fertilizer away from the seed so that there is no seed contact avoids the problem.

Volatilization: As urea is applied to the soil, it dissolves in water and through the action of a commonly occurring enzyme, urease, is converted to ammonium carbonate. This chemical compound is unstable and rapidly decomposes into ammonia, carbon dioxide, and water. An indirect result of the reaction is an increase in pH that further enhances the reaction.

Since ammonia is a volatile gas, it can be lost to the atmosphere. If the ammonium ions have an opportunity to be attached to the soil they will not volatilize. If, however, the ammonium is formed while exposed to the atmosphere, losses can occur. The potential for ammonia loss is eliminated by incorporating urea into the soil with tillage, rainfall, or irrigation.

The actual amount of N loss from unincorporated urea as NH_3 is difficult to predict but is often over exaggerated. Volatilization is generally insignificant, but can be important if certain conditions are met. Several conditions are needed before the potential for volatilization exists:

Urea Hydrolysis

$CO(NH_2)_2$	+ $2H_2O$ →	$(NH_4)_2CO_3$ →	$2NH_3$	+ CO_2	+ H_2O
Urea	Water	Ammonium Carbonate	Ammonia	Carbon Dioxide	Water

a. *Unincorporated surface applications*. Light tillage or rainfall eliminates the potential for volatilization. If urea is incorporated, the potential for volatilization loss is gone.

b. *Warm, Moist, Drying Soil*: Warm, breezy conditions that result in evaporation of moisture from the moist soil surface increases the potential for urea volatilization loss. If soil surface is dry, urea volatilization losses will not occur.

c. *Vegetation/Residue*: The enzyme urease is associated with organic materials (grass, crop residues). Also, crop residues tend to shade/protect the soil surface which increases the probability for a moist soil surface.

d. High Soil pH and/or *Low CEC*: If conditions conducive to urea volatilization losses are present (first three conditions listed), then sandy soils and alkaline soils increase the potential for urea volatilization losses.

There are management practices that minimize the potential for urea volatilization loss. For small grains and cool season grass, urea volatilization losses from urea are not a concern if applications are made early. Urea applied as a fall, winter, or early spring top dressing to wheat and cool season grasses have consistently produced results equal to any N source.

For row crops, urea should ideally be incorporated within 24 to 48 hours. Light tillage, rain, or irrigation can effectively eliminate any potential for volatilization.

In no-till or minimum till systems all nitrogen fertilizers can potentially perform poorly when surface-applied on crop residue because of immobilization. Urea containing sources can also experience NH_3 volatilization loss especially for applications made in mid to late spring if soils are moist and drying. Early applications can help manage this potential. Nitrogen fertilizer effectiveness may also be increased by injecting or surface banding (dribble applications) to improve efficiency of all N sources in these situations.

Aqua Ammonia (NH_4OH)

Although not very common, aqua ammonia is sometimes mentioned as a N source. This product is a mixture of ammonia and water and usually contains about 20% N. It is rarely used because it has a positive vapor pressure and is expensive to transport and handle. Injection at 2" to 4" depths is needed to avoid vapor losses. Aqua ammonia should not be broadcast applied.

Nitrogen Solutions (UAN, 28% and 32% N)

UAN solutions are mixtures of urea, ammonium nitrate, and water. There are two common grades: 28-0-0 and 32-0-0. A mixture of urea and ammonium nitrate is used since a combination of these salts are more soluble than either alone and results in a higher analysis liquid product. The manufacturer can vary the urea: ammonium ratio, depending on the minimum storage temperature requirements.

About 50% of the N in UAN solution comes from urea and 50% from ammonium nitrate. As a result, UAN is approximately 75% ammonium-N, or ammonium forming N and 25% nitrate-N. 32% UAN salts out about 32 degrees while 28% UAN has a salt-out temperature of about 0 degrees. 32% UAN can be diluted to 28% with water for winter storage, if needed.

Characteristics Of UAN Solutions		
N% by weight	28	32
% Ammonium Nitrate	39	45
% Urea	31	35
% Water	30	20
Salt Out, Temp. °F	0	32
Density, lb/gal.@60°	10.6	11.06
Pounds, N. Gal.	3.0	3.5
pH*	5.5-7.2	5.5-7.2

Advantages of N solution include:

- Flexibility, can be adapted to most crop production systems
- No high-pressure equipment needed for storage or application.
- Less power required for application than with anhydrous ammonia.
- Ease of combination with compatible insecticides, herbicides, and fungicides.
- Suited to application in irrigation water.
- Suited to top dressing crops such as wheat, pastures, etc.

Disadvantages of N solution include:

a. Higher purchase price than anhydrous ammonia.

b. Not well-suited to fall application ahead of spring-seeded crops because of its nitrate content.

c. Potential volatilization of urea.

UAN is a salt and can cause some burning or desiccation of plant tissue. If recommended practices are followed, burning is temporary with no effect on crop yields. Foliar burn is less under cool temperatures and low humidity.

Perennial crops such as grass pastures are very tolerant of leaf burn. Small grains are tolerant if application is made at recommended times and rates. Up to 30 lb. N per acre is usually safe for spring wheat. Much higher rates can be tolerated by winter wheat during or shortly after dormancy. Corn and sorghum are tolerant to post emergence UAN; however, post herbicide combinations are not generally recommended.

The burning characteristic of UAN solutions can be used to good advantage to burn down small weeds when tank is mixed with certain herbicides in no-till situations.

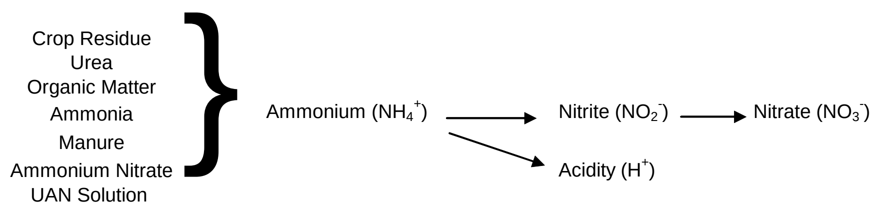
Nitrogen immobilization and volatilization can be minimized by surface banding (dribble) or injection below ground. Some research has shown that adding ammonium thiosulfate can improve performance of surface-applied, unincorporated UAN.

How Nitrogen Fertilizer Affects Soil Acidity

When the nitrification process converts the ammonium ion to nitrate, hydrogen ions are released: Hydrogen ions are soil acidity. Thus, ammonium containing forming N fertilizers result in residual acidity. Urea, ammonium nitrate, anhydrous ammonia, UAN solution and mineralization of organic materials are all equal in the amount of residual acidity produced per pound of N applied. At equal rates of N, however, ammonium sulfate produces 3 times the residual acidity of ammonia, UAN solution, ammonium nitrate or urea.

The effect of N fertilizer is insignificant on high pH, calcareous soils. On medium- to fine-textured, neutral or slightly acid soils, the effect of N on pH is slow but over a period of years can be significant. Soil testing should be used to monitor pH changes over time.

Nitrification results in residual soil acidity. Common N sources are equal



The following table shows the effect of 20 years of N fertilizer applications on soil pH and other soil characteristics. Soil pH declined with N fertilizer addition, but all N sources were equal in this effect.

Effect Of 20 Years Of N Fertilizers On Soils. (Kansas State University)

Nitrogen Source	Soil pH
Check (No N)	6.2
Anhydrous Ammonia	5.2
Ammonium Nitrate	5.2
Urea	5.1
UAN Solution	5.2