SECTION CONTENTS:

Role of Nitrogen in Plants

Plants are surrounded by the nitrogen (N) in our atmosphere. Every acre of the earth's surface is covered by thousands of pounds of this essential nutrient, but because atmospheric gaseous nitrogen is present as almost inert nitrogen (N_2) molecules, this nitrogen is not directly available to the plants that need it to grow, develop and reproduce. Despite nitrogen being one of the most abundant elements on earth, nitrogen deficiency is probably the most common nutritional problem affecting plants worldwide.

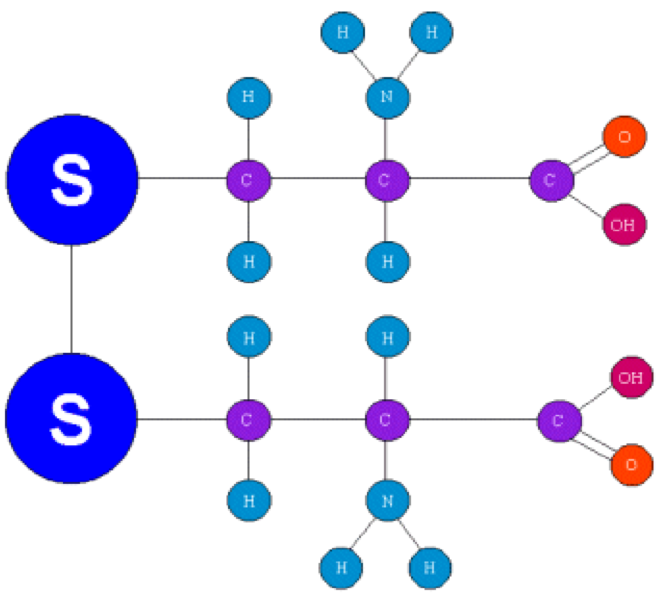

Figure 5.1 Sulphur is Required for the Synthesis of Vitamins, and is a Constituent of Certain Amino Acids Which are the Building Blocks from Which Proteins are Created. Without Proteins, Plants Wither and Die.

Healthy plants often contain 3-4% nitrogen in their above-ground tissues. These are much higher concentrations than those of any other nutrient except carbon, hydrogen and oxygen, nutrients not of soil fertility management concern in most situations. Nitrogen is an important component of many important structural, genetic and metabolic compounds in plant cells. It is a major component of chlorophyll, the compound by which plants use sunlight energy to produce sugars from water and carbon dioxide (i.e. photosynthesis). It is also a major component of amino acids, the building blocks of proteins. Some proteins act as structural units in plant cells while others act as enzymes, making possible many of the biochemical reactions on which life is based. Nitrogen is a component of energy-transfer compounds, such as ATP (adenosine triphosphate) which allow cells to conserve and use the energy released in metabolism. Finally, nitrogen is a significant component of nucleic acids such as DNA, the genetic material that allows cells (and eventually whole plants) to grow and reproduce. Nitrogen plays the same roles (with the exception of photosynthesis) in animals, too. Without nitrogen, there would be no life as we know it.

Soil Nitrogen

Soil nitrogen exists in three general forms - organic nitrogen compounds, ammonium (NH_4^+) ions, and nitrate (NO_3^-) ions.

At any given time, 95-99% of the potentially available nitrogen in the soil is in organic forms, either in plant and animal residues, in the relatively stable soil organic matter or in living soil organisms, mainly microbes such as bacteria. This nitrogen is not directly available to plants, but some can be converted to available forms by microorganisms. A very small amount of organic nitrogen may exist in soluble organic compounds, such as urea, that may be slightly available to plants.

The majority of plant-available nitrogen is in the inorganic (sometimes called mineral nitrogen) NH_4^+ and NO_3^- forms. Ammonium ions bind to the soil's negatively-charged cation exchange complex (CEC) and behave much like other cations in the soil. Nitrate ions do not bind to the soil solids because they carry negative charges, but exist dissolved in the soil water, or precipitated as soluble salts under dry conditions. Some NH_4^+ and NO_3^- may also exist in the crystal structure of certain soil minerals, and may be quite available; however, such nitrogen is important in only a few soils.

Natural Sources of Soil Nitrogen

The nitrogen in soil that might eventually be used by plants has two sources - nitrogen-containing minerals and the vast storehouse of nitrogen in the atmosphere.

The nitrogen in soil minerals is released as the mineral decomposes. This process is generally quite slow and contributes only slightly to nitrogen nutrition on most soils. On soils containing large quantities of NH_4-rich clays (either naturally occurring or developed by fixation of NH_4 added as fertilizer), however, nitrogen supplied by the mineral fraction may be significant in some years.

Atmospheric nitrogen is thought to be a major source of nitrogen in soils. In the atmosphere it exists in the very inert N_2 form and must be converted before it becomes useful in the soil. This conversion is accomplished two ways. Some N_2 is oxidized to NO_3 by lightning during thunderstorms. The NO_3 dissolves in raindrops and falls into the soil. The quantity of nitrogen added to the soil in this manner is directly related to thunderstorm activity, but most areas probably receive no more than 20 lb nitrogen/acre per year from this source.

Some microorganisms can utilize atmospheric N_2 to manufacture nitrogenous compounds for use in their own cells. This process, called biological nitrogen fixation, requires a great deal of energy; therefore, free-living organisms that perform the reaction, such as *Azotobacter*, generally fix little nitrogen each year (usually less than 20 lb nitrogen/acre), because food energy is usually scarce. Most of this fixed nitrogen is released for use by other organisms upon death of the microorganism. Bacteria such as *Rhizobia*, that infect (nodulate) the roots of, and receive much food energy from, legume plants can fix much more nitrogen per year (some well over 100 lb nitrogen/acre). When the quantity of nitrogen fixed by *Rhizobia* exceeds that needed by the microbes themselves, it is released for use by the host legume plant. This is why well-nodulated legumes do not often respond to additions of nitrogen fertilizer. They are already receiving enough from the bacteria.

Nitrogen Transformations and Losses in Soils

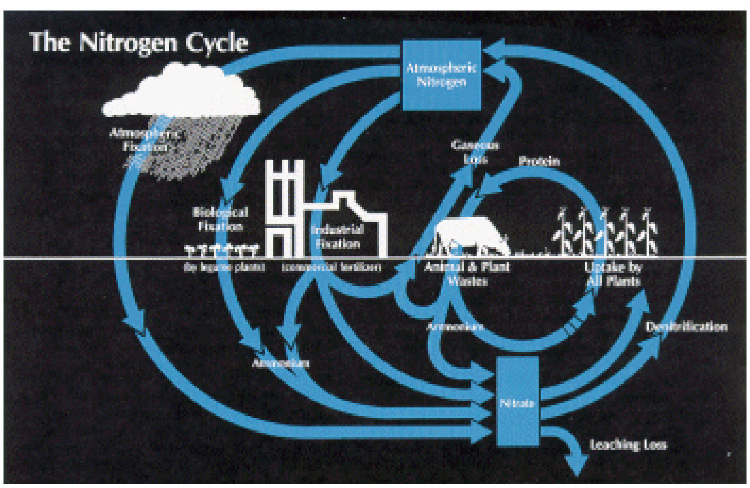

Figure 5.2 Nitrogen Cycle (click on image to see larger version).

Nitrogen can go through many transformations in the soil. These transformations are often grouped into a system called the "nitrogen cycle", which can be presented in varying degrees of complexity. The nitrogen cycle presented in Figure 5.2 is appropriate for understanding nutrient and fertilizer management. Because microorganisms are responsible for most of these processes, they occur very slowly, if at all, when soil temperatures are below 50° F, but their rates increase rapidly as soils become warmer.

The heart of the nitrogen cycle is the conversion of inorganic to organic nitrogen, and vice versa. As microorganisms grow, they remove NH_4^+ and NO_3^- from the soil's inorganic, available-nitrogen pool, converting it to organic nitrogen in a process called immobilization. When these organisms die and are decomposed by others, excess NH_4^+ can be released back to the inorganic pool in a process called mineralization. Nitrogen can also be mineralized when microorganisms decompose a material containing more nitrogen than they can use at one time, materials such as legume residues or manures. Immobilization and mineralization are conducted by most microorganisms, and are most rapid when soils are warm and moist, but not saturated with water. The quantity of inorganic nitrogen available for crop use often depends on the amount of mineralization occurring, and the balance between mineralization and immobilization.

Ammonium ions (NH_4^+) not immobilized or taken up quickly by higher plants are usually converted rapidly to NO_3^- ions by a process called nitrification. This is a two step process, during which bacteria called Nitrosomonas convert NH_4^+ to nitrite (NO_2^-), and then other bacteria, Nitrobacter, convert the NO_2^- to NO_3^-. This process requires a well-aerated soil, and occurs rapidly enough that one usually finds mostly NO_3^- rather than NH_4^+ in soils during the growing season.

The nitrogen cycle contains several routes by which plant-available nitrogen can be lost from the soil. Nitrate-nitrogen is usually more subject to loss than is ammonium-nitrogen. Significant loss mechanisms include leaching, denitrification, volatilization, and crop removal.

The nitrate form of nitrogen is so soluble that it leaches easily when excess water percolates through the soil. This can be a major loss mechanism in coarse-textured soils where water percolates freely, but is less of a problem in finer-textured, more impermeable soils, where percolation is very slow. These latter soils tend to become saturated easily, and when microorganisms exhaust the free oxygen supply in the wet soil, some obtain it by decomposing NO_3^-. In this process, called denitrification, NO_3^- is converted to gaseous oxides of nitrogen or to N_2 gas, both unavailable to plants. Denitrification can cause major losses of nitrogen when soils are warm and remain saturated for more than a few days.

Losses of NH_4^+ nitrogen are less common and occur mainly by volatilization. Ammonium ions are basically anhydrous ammonia (NH_3) molecules with an extra hydrogen (H^+) attached. When this extra H^+ is removed from the NH_4 ion by another ion such as hydroxyl (OH^-), the resulting NH_3 molecule can evaporate, or volatilize from the soil. This mechanism is most important in high pH soils that contain large quantities of OH^- ions.

Crop removal represents a loss because nitrogen in the harvested portions of the crop plant are removed from the field completely. The nitrogen in crop residues is recycled back into the system

and is better thought of as immobilized rather than removed. Much is eventually mineralized and may be reutilized by a crop.

Nitrogen Needs of and Uptake by Plants

Plants absorb nitrogen from the soil as both NH_4^+ and NO_3^- ions, but because nitrification is so pervasive in agricultural soils, most of the nitrogen is taken up as nitrate. Nitrate moves freely toward plant roots as they absorb water. Once inside the plant NO_3^- is reduced to an NH_2 form and is assimilated to produce more complex compounds. Because plants require very large quantities of nitrogen, an extensive root system is essential to allowing unrestricted uptake. Plants with roots restricted by compaction may show signs of nitrogen deficiency even when adequate nitrogen is present in the soil.

Table 5.1: Utilization of Nutrients by Various Crops.

Crop	Yield Per Acre	N	P_2O_5	K_2O	Mg	S
Alfalfa	8 tons	450	80	480	40	40
Corn	180 bu.	240	100	240	50	30
Coastal Bermuda	10 tons	500	140	420	50	40
Soybeans	60 bu.	324	64	142	27	25
Wheat	80 bu.	134	54	162	24	20

(Source: PPI)

Most plants take nitrogen from the soil continuously throughout their lives and nitrogen demand usually increases as plant size increases. A plant supplied with adequate nitrogen grows rapidly and produces large amounts of succulent, green foliage. Providing adequate nitrogen allows an annual crop, such as corn, to grow to full maturity, rather than delaying it. A nitrogen-deficient plant is generally small and develops slowly because it lacks the nitrogen necessary to manufacture adequate structural and genetic materials. It is usually pale green or yellowish, because it lacks adequate chlorophyll. Older leaves often become necrotic and die as the plant moves nitrogen from less important older tissues to more important younger ones.

On the other hand, some plants may grow so rapidly when supplied with excessive nitrogen that they develop protoplasm faster than they can build sufficient supporting material in cell walls. Such plants are often rather weak and may be prone to mechanical injury. Development of weak straw and lodging of small grains is an example of such an effect.

Organic Nitrogen in Soils

The supply of available nitrogen in soils is often supplemented by nitrogen released from soil organic matter or organic materials added to soils (manure, residues of forage legumes, etc.). The quantity of nitrogen released from any of these materials depends on the composition of the material, particularly its ratio of carbon to nitrogen, and the weather. When microorganisms decompose materials such as manure and alfalfa residue, that have C/N ratios of 10:1 to 20:1 (lb carbon per lb nitrogen), net mineralization occurs, because the microbes are releasing nitrogen from the residue faster than they can utilize it. When they are decomposing residues such as cornstalks or wheat straw, that have much larger C/N ratios, they must take some extra mineral nitrogen from the soil to utilize all of the carbon they are digesting, so net immobilization occurs. The rate at which these processes occur depends on weather and soil conditions. When soils are warm and moist, decomposition proceeds rapidly, and nitrogen released from legume residues or manures may be significant, but when soils are cold and wet, or very dry, nitrogen release may be very much less than expected.

There are situations in which nitrogen applications can be reduced or eliminated when corn follows good stands of alfalfa or another legume. However, the nitrogen relationships involved here are so site-specific and weather-related that local recommendations should be consulted before making decisions regarding nitrogen credits. Legume species, stand density, age, soil drainage, and timing of operations are all factors to be considered.

The timing and rate of manure application should also be considered when calculating nitrogen credits, and again, due to influences of weather and soil, local guidelines should be used. Manure can be applied at rates that supply all nitrogen, phosphorus, and potassium to a crop, but such rates usually cause significant over-applications of phosphorus and potassium. Over-applications of phosphorus are important water quality concerns in many regions, so manure applications should be at rates low enough to avoid this over-application. At such low application rates, supplementary nitrogen-fertilizer applications are usually needed in crops such as corn.

Commercial Nitrogen Fertilizers

At one time the fertilizer industry relied on organic or direct-mined materials as sources of nitrogen. Today, virtually all nitrogen materials are manufactured, usually from ammonia. Such materials are less expensive, more concentrated, and just as plant-available as the organics used in the past.

Readily Soluble Materials

Anhydrous Ammonia (NH_3) and Aqua Ammonia

Anhydrous ammonia is 82% nitrogen and is a gas at normal atmospheric temperatures and pressure. It is stored as a liquid under pressure and is injected several inches below the soil surface, where it vaporizes and dissolves in the soil water to form NH_4^+ ions. Ammonia (not ammonium) is harmful or toxic to living organisms, and applications near living plants may cause temporary injury. Applications too close to seeds or seedlings may cause stand problems. Though some soil sterilization occurs in the immediate zone of ammonia application, the effect is temporary, and soil life is restored in the zone within a few weeks of application. Aqua ammonia, a solution of ammonia in water (usually 21% nitrogen), is sometimes used as a fertilizer. It is also injected underground, due to the ammonia's tendency to volatilize from the solution.

Ammonium Nitrate (NH_4NO_3)

Ammonium nitrate is usually used as a solid material with an analysis of up to 34% nitrogen. It contains both NH_4^+ and NO_3^- forms of nitrogen, and is used as a source of nitrogen in many blends of liquid and dry fertilizers, as well as being applied directly. Pure ammonium nitrate is very hygroscopic and can be explosive under certain conditions; however, present fertilizer grades of the material are specially conditioned, and when stored and handled properly, pose no problem or hazard.

Urea [$CO(NH_2)_2$]$_2$

Urea is a manufactured, organic compound containing 46% nitrogen, that is widely used in solid and liquid fertilizers. It has relatively desirable handling and storage characteristics, making it the most important solid nitrogen-fertilizer material, worldwide. It may contain small concentrations of a toxic decomposition product, biuret; however, urea manufactured using good quality control practices rarely contains enough to be of agronomic significance. Urea is converted to ammonium carbonate by an enzyme called urease when applied to soil. Ammonium carbonate is an unstable molecule that can break down into ammonia and carbon dioxide. If the ammonia is not trapped by soil water, it can escape to the atmosphere. This ammonia volatilization can cause significant losses of nitrogen from urea when the fertilizer is applied to the surface of warm, moist soils, particularly those covered with plant residues (no-till) or those drying rapidly. Relatively high surface pH also aggravates nitrogen volatilization from urea. (See section "Additives for Nitrogen Fertilizer.")

Non-pressure Nitrogen Solutions

These materials are generally composed of urea and/or ammonium nitrate dissolved in water. The most popular are urea-ammonium-nitrate (UAN) solutions. Nitrogen concentrations generally range from 19-32%. These are very versatile materials and are often used as carriers for herbicides or applied in irrigation water. They can be injected, or banded on the soil surface, to minimize potential volatilization losses of the urea component in no-till or surface application situations. Spraying over live foliage can cause severe tissue burn, but the problem can often be minimized by applying in narrow streams rather than by broadcasting. Because the solubility of the nitrogen salts in these solutions decreases as temperature declines, these materials are subject to "salting out". This limits storage and use of more concentrated formulations in cooler seasons and regions.

Ammonium Sulfate [$(NH_4)_2SO_4$]

Ammonium sulfate is a by-product of many industrial processes and contains 20% nitrogen and 24% sulfur. It is not a widely used material, due to its relatively low nitrogen content, but may become more popular as sulfur deficiencies become more widespread. It is not as prone to nitrogen volatilization as urea, but is slightly more so than ammonium nitrate, particularly on alkaline soils.

Ammonium Phosphates

Ammonium phosphates are manufactured in a wide variety of forms and formulations including mono-ammonium phosphate (MAP), diammonium phosphate (DAP) and several ammonium polyphosphates. These materials are used mainly as carriers for phosphorus, but can also be significant in nitrogen management programs, particularly when they are used as starter and row-applied fertilizers. When used in a starter program, DAP (at any rate) is usually placed several inches from the seed to avoid damage due to any ammonia released as the material dissolves.

Nitrate Salts

Several salts of nitrate, including sodium nitrate ($NaNO_3$, 16% nitrogen), calcium nitrate ($Ca(NO_3)_2$, 15.5% nitrogen), and potassium nitrate (KNO_3, 14% nitrogen) are available, but are not widely used due to relatively high cost and low analysis. They are used mainly in specialty situations, such as production of horticultural crops.

Slow-Release Materials

There are a number of materials available that release nitrogen slowly into the soil rather than very shortly after application as do those listed above. They are useful in situations where the producer does not want high levels of soluble nitrogen in the system at any one time, due to potentials for excessive losses or excessively rapid plant growth. Such situations occur in container-based horticultural production and in turfgrass management, among others.

Inorganic compounds, such as magnesium ammonium phosphate, and organic compounds, such as urea-formaldehyde (ureaform) and isobutylidene diurea (IBDU), are often used to supply nitrogen at slow but fairly predictable rates. Nitrogen release from these compounds is slowed by very low solubility in water, and release from the organic materials is usually related to rate of microbial degradation. Simpler nitrogen compounds, such as urea, can be coated with less soluble materials, including polymers and waxes, and nitrogen release controlled by the rate at which the coating deteriorates. Sulfur-coated urea (SCU), made by spraying urea granules with molten sulfur, is a common example of such a product, though more are becoming available. All of these products are relatively expensive sources of nitrogen, and their use is restricted to specialty markets and use on high-value crops.

Fertilizer Management Practices

Rates

Nitrogen fertilizer rates are determined by the crop to be grown, yield goal, and quantity of nitrogen that might be provided by the soil. Rates needed to achieve different yields with different crops vary by region, and such decisions are usually based on local recommendations and experience.

The quantity of nitrogen supplied by the soil is determined by the quantity of nitrogen released from the soil organic matter, that released by decomposition of residues of the previous crop, any nitrogen supplied by previous applications of organic waste, and any nitrogen carried over from previous fertilizer applications. Such contributions can be determined by taking nitrogen credits (expressed in lb/acre) for these variables. For example, corn following alfalfa usually requires less additional nitrogen than corn following corn, and less nitrogen fertilizer is needed to reach a given yield goal when manure is applied. As with rates, credits are usually based on local conditions.

Soil testing is being suggested more often as an alternative to taking nitrogen credits. Testing soils for nitrogen has been a useful practice in the drier regions of the Great Plains for many years, and in that region fertilizer rates are often adjusted to account for NO_3^- found in the soil prior to planting. Over the past 10 years, there has been some interest in testing corn fields for NO_3^- in the more humid regions of the eastern US and Canada, utilizing samples taken in late spring, after crop emergence, rather than before planting. This strategy, the pre-sidedress nitrogen soil test (PSNT), has received a great deal of publicity and seems to provide some indication of whether additional sidedressed nitrogen is needed or not. The test is still in the experimental stage in most states, and interpretations based on local research and experience are essential.

Fertilizer Placement

Placement decisions should maximize availability of nitrogen to crops and minimize potential losses. A plant's roots usually will not grow across the root zone of another plant, so nitrogen must be placed where all plants have direct access to it. Broadcast applications accomplish this objective. Banding does also, when all crop rows are directly next to a band. For corn, banding anhydrous ammonia or UAN in alternate row middles is usually as effective as banding in each middle, because all rows have access to the fertilizer.

Moist soil conditions are necessary for nutrient uptake. Placement below the soil surface can increase nitrogen availability under dry conditions because roots are more likely to find nitrogen in moist soil with such placement. Injecting sidedressed UAN may produce higher corn yields than surface application in years when dry weather follows sidedressing. In years when rainfall occurs shortly after application, subsurface placement is not as critical.

Subsurface placement is normally used to control nitrogen losses. Anhydrous ammonia must be placed and sealed below the surface to eliminate direct volatilization losses of the gaseous ammonia. Volatilization from urea and UAN solutions can be controlled by incorporation or injection. Incorporating of urea materials (mechanically or by rainfall shortly after application) is especially important in no-till and turfgrass situations where volatilization is aggravated by large amounts of organic material on the soil surface. Applying small amounts of "starter" nitrogen as UAN in herbicide sprays, however, is usually of little concern.

Placing nitrogen with phosphorus often increases phosphorus uptake, particularly when nitrogen is in the NH_4^+ form and the crop is growing in an alkaline soil. The reasons for the effect are not completely clear, but may be due to nitrogen increasing root activity and potential for phosphorus uptake, and nitrification of NH_4^+ providing acidity which enhances phosphorus solubility.

Timing of Nitrogen Applications

Timing has a major effect on the efficiency of nitrogen management systems. Nitrogen should be applied to avoid periods of significant loss and to provide adequate nitrogen when the crop needs it most. Wheat takes up most of its nitrogen in the spring and early summer, and corn absorbs most nitrogen in mid-summer, so ample availability at these times is critical. If losses are expected to be minimal, or can be effectively controlled, applications before or immediately after planting are effective for both crops. If significant losses, particularly those due to denitrification or leaching, are anticipated, split applications, where much of the nitrogen is applied after crop emergence, can be effective in reducing losses. Fall applications for corn can be used on well-drained soils, particularly if the nitrogen is applied as anhydrous ammonia amended with N-Serve®; however, fall applications should be avoided on poorly drained soils, due to an almost unavoidable potential for significant denitrification losses. When most of a crop's nitrogen supply will be applied after significant crop growth or positioned away from the seed row (anhydrous ammonia or UAN banded in row middles), applying some nitrogen easily accessible to the seedling at planting ensures that the crop will not become nitrogen deficient before gaining access to the main supply of nitrogen.

Minimizing Nitrogen Fertilizer Losses

The major mechanisms for nitrogen fertilizer loss are denitrification, leaching, and volatilization. Denitrification and leaching occur under very wet soil conditions, while volatilization is most common when soils are only moist and are drying. Practices that can minimize losses due to each of these mechanisms are given in Table 5.2.

Table 5.2: Practices for Avoiding Nitrogen Fertilizer Losses

Denitrification Loss	Leaching Loss	Volatilization Loss
Drainage Improvements	Use ammonium-N	Ammonia
Use ammonium-N	Nitrification inhibitors	Press wheels
Nitrification inhibitors	Split applications	Sealing wings
Split applications		Proper soil conditions
		Urea, UAN
		Inject, incorporate
		Urease inhibitors
		Apply just before rain
		Don't apply over lime

Acidification of Soil

Using an NH_4^+ source of nitrogen acidifies the soil because the hydrogen ions (H^+) released during nitrification of the NH_4^+ are the major cause of acidity in soils. Over time, acidification and lowering of soil pH can become significant.

Nitrogen fertilizers containing NO_3^- but no NH_4^+ make the soil slightly less acidic over time, but are generally used in much lesser quantities than the others. The acidification due to NH_4-nitrogen is a significant factor in the acidification of agricultural fields, but can easily be controlled by normal liming practices.

Table 5.3: Acidity or Basicity of Different Nitrogen Sources

		Approximate $CaCO_3$ Equivalent	
Material	%Nitrogen	lb/Ton of Material*	Per lb of Nitrogen
Anhydrous Ammonia	82	-2,960	1.80
Ammonia Sulfate	21	-2200	5.20
Urea	46	-1,680	1.83
Diammonium Phosphate	18	-1,400	3.8
Urea-Form	38	-1,360	1.79
Monoammonium Phosphate	10	-1,300	6.5
Ammonium Nitrate	33.5	-1,180	1.76
Nitrogen Solutions	19-49	-750 to -1,760	1.97 to 1.79
Calcium Nitrate	15	+400	—
Potassium Nitrate	13	+580	—
Sodium Nitrate	16	+520	—

*A minus sign indicates the number of pounds of calcium carbonate equivalent needed to neutralize the acid formed when one ton of the material is added to the soil. (Note that approximately 2 times this amount would be required if ag-lime is used.) A plus sign indicates the material is basic in nature.

Fertilizing Legumes with Nitrogen

Because the Rhizobia bacteria that infect legume roots normally supply adequate nitrogen to the host plant, well-nodulated legumes rarely respond to additions of nitrogen fertilizer. Occasionally, however, soybeans may respond to applications of nitrogen late in the season, presumably because nitrogen-fixation in the nodules has declined significantly. Such responses are quite erratic, though, and late-season applications of nitrogen to soybeans are not routinely recommended. The amount of atmospheric nitrogen fixed by non-symbiotic soil organisms varies with soil types, organic matter present and soil pH. The approximate amount of nitrogen fixed by various legume crops is shown in Table 5.4.

Table 5.4: Nitrogen Fixed by Various Legume Crops

Crop	lb/acre Nitrogen
Alfalfa	196
Ladino Clover	178
Sweet Clover	116
Red Clover	112
White Clover	103
Soybeans	98
Cowpeas	89
Lespedeza	85
Vetch	80
Garden Peas	71
Winter Peas	54
Peanuts	42

Adapted from *Fertilizers and Soil Amendments* by Follett, Murphy and Donahue.

Additives for Nitrogen Fertilizers

N-Serve

N-Serve (nitrapyrin) is a proven material that selectively inhibits one of the bacteria responsible for nitrification. When added to an NH_4^+ nitrogen material, it delays its conversion to NO_3^- nitrogen for several weeks. It is most effective when mixed with anhydrous ammonia. This delayed nitrification protects the fertilizer from losses due to denitrification and leaching in seasons when excessive rainfall occurs during the period of inhibition. Using N-Serve is somewhat like buying an insurance policy which pays in years when problems develop.

Agrotain

Agrotain (NBPT) is a product that inhibits conversion of urea to ammonium carbonate, thereby reducing the potential for ammonia volatilization from urea materials, including UAN solutions. Like N-Serve , it might be viewed as an insurance policy that will reduce potential nitrogen losses in seasons when cultivation or rain does not incorporate the urea into the soil soon after application. It is most useful when urea or UAN are applied without incorporation to the surface of fields with high levels of crop residue, such as in no-till situations, or fields with high pH levels at the surface.

Production of Major Nitrogen Fertilizers

Anhydrous Ammonia

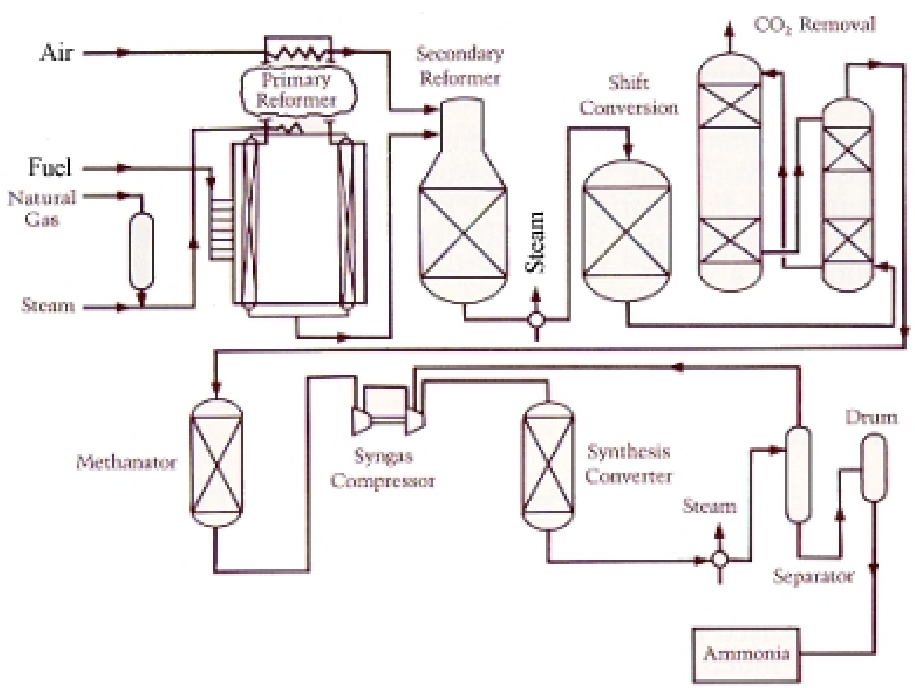

Figure 5.4 Production of Ammonia

Ammonia is a basic industrial material and is the material from which other nitrogen fertilizers are made. It has been manufactured on a commercial scale since 1913, and the process used to produce it, originally developed by Fritz Haber, has changed little since that time. In the Haber process, gaseous H_2 and N_2 are combined under high temperature and pressure conditions to produce ammonia.

Ammonia production is an energy intensive process, not only because of its temperature requirements, but also because it requires large quantities of purified H_2 that is usually derived from natural gas, or methane (CH_4). Naphtha and coal are also used as feedstocks in some parts of the world. Hydrogen is produced from methane (CH_4) in a multi-step process. First, a "synthesis gas" is produced by "reforming" methane and steam to hydrogen and carbon monoxide (CO) over a catalyst at 1300-1600° F. This synthesis gas is mixed with air in a second reforming reaction over another catalyst, producing a mixture of N_2, H_2, CO, CO_2 and steam. The carbon monoxide and steam then undergo a final "shift conversion", producing carbon dioxide and more hydrogen. This final synthesis gas is then purified to remove CO_2 that would poison the ammonia-synthesis catalyst. Any remaining traces of carbon oxides are removed by absorption into other materials or are converted back to methane over a methanation catalyst.

The purified N_2-H_2 synthesis gas is compressed to pressures of 2000-5000 psig (depending on process) and passed over an iron catalyst where ammonia is formed. The resulting gas mixture is cooled to condense and remove ammonia. Unreacted products are recycled through the synthesis converter. The resulting liquid ammonia is then stored in insulated tanks.

Ammonium Nitrate

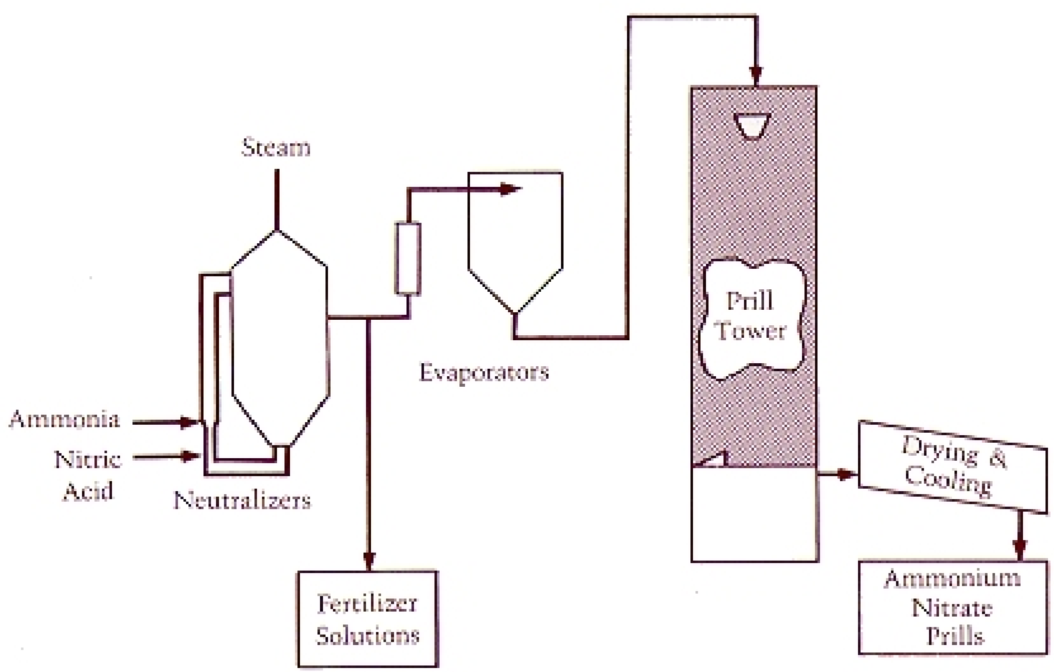

Figure 5.5 Production of Ammonium Nitrate

Ammonia can be oxidized in air to produce nitric acid (HNO_3). This nitric acid can then be neutralized with more ammonia to produce a solution that is typically 83% ammonium nitrate and 17% water. This solution can be used to produce nitrogen fertilizer solutions or can be processed further to produce solid ammonium nitrate. The ammonium nitrate solution is concentrated to 96-99% NH_4NO_3 and the "melt" transported to the top of a prilling tower, where it is sprayed into a rising air stream. The droplets crystallize and condense into hard, spherical "prills" that are dried, cooled, and sized for shipment. Ammonium nitrate can also be granulated by several processes.

Urea

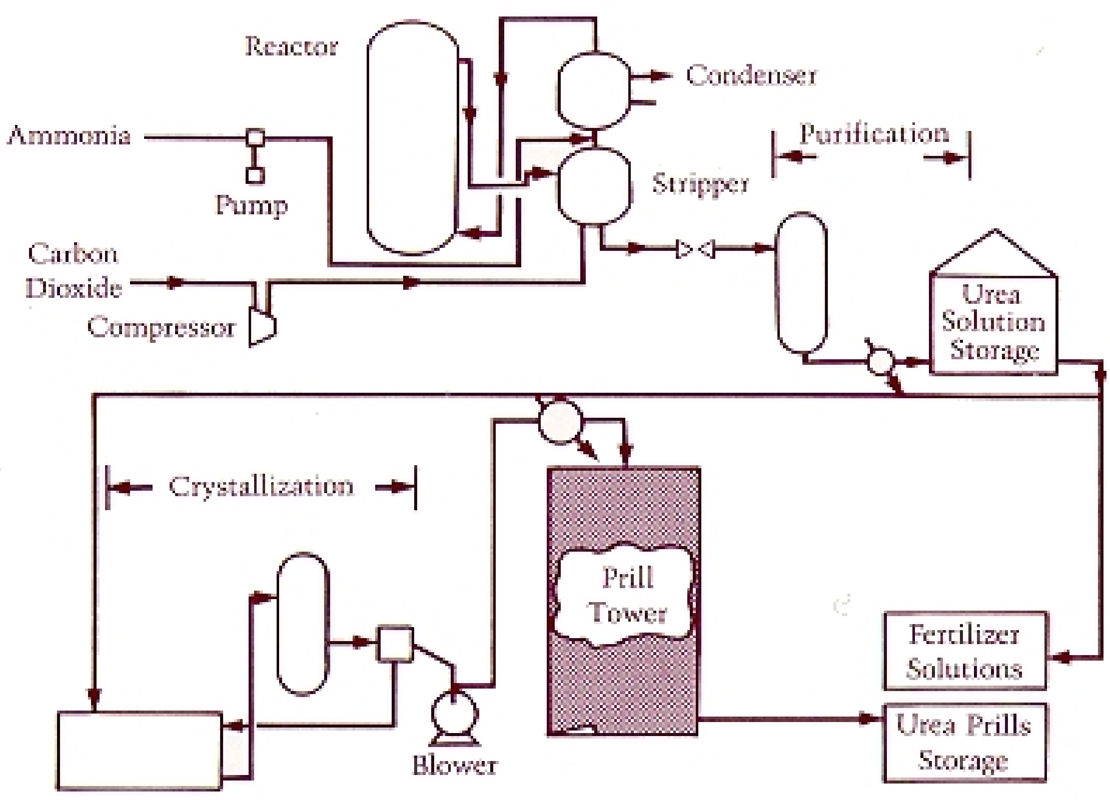

Figure 5.6 Production of Urea

Pressurized carbon dioxide gas and heated liquid ammonia are mixed in a condenser to form a mixture containing an intermediate compound, ammonium carbamate. The mixture flows to a reactor where it is dehydrated to convert a portion of the carbamate to urea. This mixture then passes through a stripper, where a stream of carbon dioxide removes unreacted ammonia and recycles it back to the condenser. In the stripper, unreacted ammonium carbamate is decomposed back to ammonia and carbon dioxide, and is also recycled to the condenser. The remaining urea solution is removed from the stripper and purified. The solution can then be used to make nitrogen fertilizer solutions, or can be concentrated and used to produce solid urea in prills or granules.

UAN Solutions

Urea-ammonium-nitrate solutions are made by mixing the final solutions produced during production of urea and ammonium nitrate. Mixing in various ratios allows production of materials with different nitrogen concentrations, from 19 to 32 percent.

Ammonium Sulfate

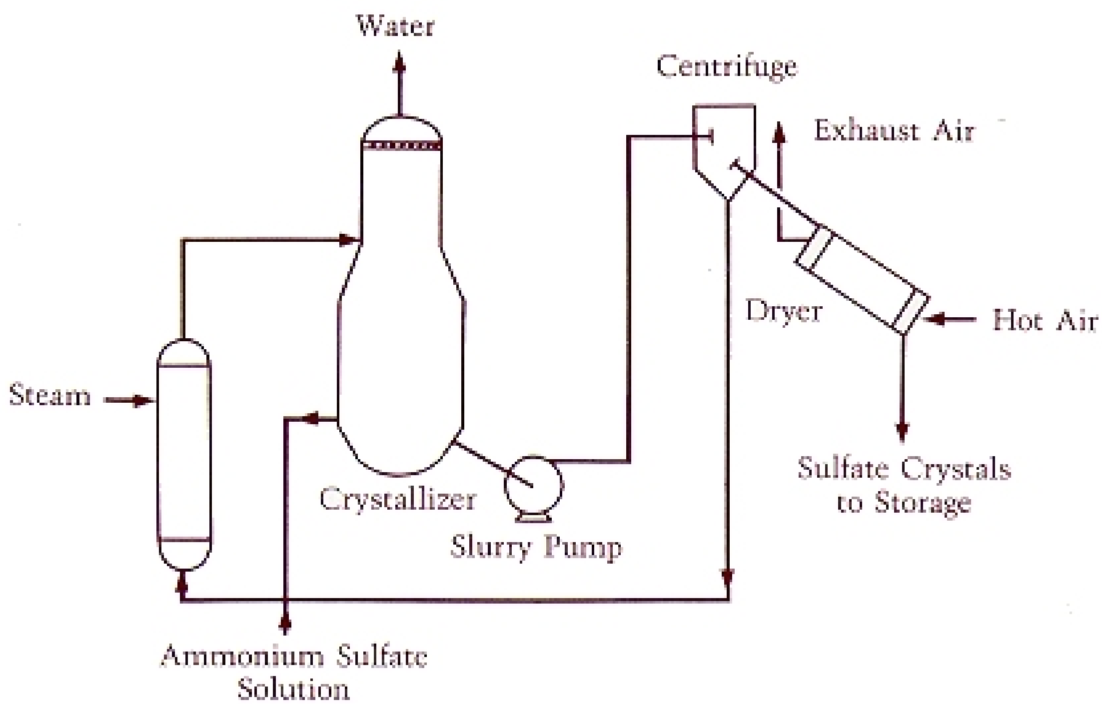

Figure 5.7 Ammonium Sulfate Crystallization

Ammonium sulfate is a byproduct of the steel and caprolactam industries, made by neutralizing waste sulfuric acid with ammonia. Solid ammonium sulfate is removed from the solution by heating the solution to boiling, evaporating water and concentrating the salt which eventually crystallizes out. The crystal slurry is dewatered in a centrifuge and the wet crystals dried in warm air.

Ammonium Phosphates

These materials are produced by neutralizing wet process phosphoric acid (H_3PO_4) with anhydrous ammonia to produce ammonium orthophosphates (diammonium phosphate (DAP), monoammonium phosphate (MAP)) or by neutralizing concentrated "superphosphoric" acid with ammonia to produce ammonium polyphosphates. The orthophosphates are generally granulated as dry materials, while the polyphosphates are used as fluid materials.

Water Quality Concerns Involving Nitrogen

Nitrogen fertilizer use is currently linked to some water quality problems involving surface and underground drinking water supplies. Current public health regulations in the United States and other countries require water suppliers to notify customers when NO_3^- nitrogen concentrations in their water exceed 10 micrograms per liter. This is because ingestion of large amounts of NO_3^- by very young infants can lead to development of a potentially fatal, but treatable, condition called methemoglobinemia. Nitrate ingestion is usually not harmful to older children or adults.

Nearly all natural water contains some NO_3^- at some time during the year and in some regions water has always shown elevated NO_3^- concentrations. However, concentrations may rise temporarily in streams draining watersheds in intensive agricultural production in some years, or may become elevated in groundwater in agricultural regions. Pollution of individual wells can often be traced to improper well construction, coupled with a concentrated loading, such as feedlot runoff. Elevated concentrations in streams or aquifers are often due to excessive nitrogen applications (often as manure) or failure of the crop to efficiently utilize the nitrogen applied. High NO_3^- concentrations in water, logically, often occur in years following droughts. While droughts, and their effects, cannot be predicted in advance, following best management practices for nitrogen use will help ensure that most NO_3^- concerns do result from abnormal weather rather than improper management decisions.

Nitrate Problems in Animal Nutrition

High NO_3^- concentrations in forage can cause sickness and death in livestock. Under normal conditions, NO_3^- absorbed by plants is quickly converted to the NH_2 form, and combined with carboxylic acids to produce amino acids and eventually other plant constituents. When this

conversion is suppressed, NO_3^- may accumulate temporarily (sometimes to toxic levels) in the plant. Some conditions that can lead to such accumulations are:

1. Drought
2. High temperatures
3. Cloudy weather
4. Deficiencies of other nutrients
5. Plant damage due to insects or disease

Other conditions that interfere with the proper development of the plant can also cause NO_3^- accumulation. Young plants are more likely to show accumulations than older ones, and because the reduction of NO_3^- to NH_2 requires light, accumulations are likely to be greater earlier in the day.

Sorghum, sorghum-sudangrass crosses and small grains are especially sensitive to excessive NO_3^- accumulations, though the effect is also seen in corn, particularly during severe drought. Care should be taken when grazing cattle on such species, particularly when high rates of nitrogen have been applied.

When high NO_3^- concentrations in forage are suspected, plant tissue analysis can determine whether a problem exists or not.

Links to other sections of the EFFICIENT FERTILIZER USE MANUAL
History • MEY • Soil • pH • Nitrogen • Phosphorus • Potassium • Secondary • Micronutrients • Fluid-Dry • Sampling • Testing • Site-Specific • Tillage • Environment • Appendices • Authors