



Cotton Nitrogen Management in Tennessee

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Nitrogen (N) fertilizer management is a challenging but critical component of cotton production. While N is essential to plant growth, it is also extremely dynamic in the environment and can be lost easily without proper management. Nitrogen losses have agronomic, economic and environmental implications. Proper N fertilizer management practices, such as those described with the 4Rs (Right rate, Right source, Right time, Right place), can not only increase row crop production efficiency and profitability, but also ease the environmental stresses related to fertilizer application and water quality. The basis of the 4R concept is to precisely manage nutrients on the farm by considering what source to apply, when to apply, where to apply, and how much to apply. A sound fertility program should be based on all of these aspects; for example, when selecting what source to apply, the timing, placement and rate should also be considered. There is no one-size-fits-all management strategy; N management decisions are specific not only to individual producers, but also to individual fields. This publication introduces concepts and provides in-depth, localized information that is essential to sustainable N management in Tennessee.

Nitrogen Cycle

In order to improve N management practices, a basic working knowledge of the N cycle (Figure 1) is necessary. Plants use two main forms of inorganic N: nitrate (NO_3^-) and ammonium (NH_4^+). There are numerous ways these are transformed and/or lost under certain environmental conditions.

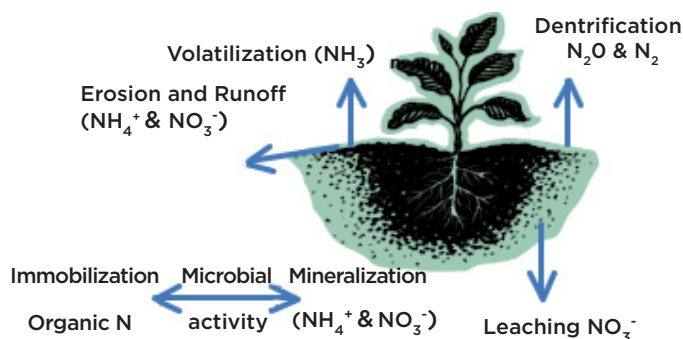


Figure 1. A simplified model of the nitrogen (N) cycle in soils.

Transformation Pathways

Soil microorganisms are responsible for the continuous transformation between organic and inorganic N forms. Tennessee has a relatively warm, humid climate, which promotes soil microbial activity. Organic forms of N found in soil organic matter, residue and animal manures can be converted to plant available forms through a multistep process called **mineralization**. Mineralization occurs when soil microbes break down organic matter into NH_4^+ (ammonium), which is then converted to NO_3^- (nitrate) by nitrification. These soil microbes require N to decompose organic material such as residue. When soil microbes encounter plant residues with a high carbon (C) to N ratio, such as cotton stalks, small grain residues or grass cover crops, they utilize soil N to convert plant available, inorganic forms of N to organic forms in a process called **immobilization**. Once these microbes die, N is eventually mineralized back into the inorganic, plant available form. In no-till systems where there is a lot of surface residue, the potential for immobilization can be reduced by applying inorganic N below the surface or by planting leguminous ground covers.

Loss Pathways

Nitrogen losses can lead to plant deficiencies, yield loss and water quality problems. These losses can occur through several pathways under certain environmental conditions and/or improper management.

Physical movement of N can occur through runoff, erosion and/or leaching — these are significant issues in Tennessee due to our relatively high amounts of annual precipitation and increasing high-intensity rainfall events, especially when N fertilizer is applied early or immediately prior to excessive rain or excessive irrigation. Excessive rainfall and excessive irrigation can cause NO_3^- which is soluble in water and extremely mobile, to move with surface water **runoff** or downward through the soil profile in a process called **leaching**. Leaching potential is dependent on many factors including fertilizer rate, source and timing, plant uptake of NO_3^- , amount and intensity of rainfall/irrigation, and soil texture. Ammonium (NH_4^+) will bind with soil particles and can be lost through soil **erosion**; this loss can be mitigated

through soil conservation techniques such as no-till. These losses of N to surface water and groundwater can cause substantial water quality issues such as degradation of drinking water and aquatic habitats.

Gaseous losses of N, including denitrification and volatilization, are also significant issues in Tennessee due to the warm, wet climate. Under saturated soil conditions and low oxygen levels, some soil microbes will utilize NO_3^- to carry out their functions. These microbes will then release gaseous forms of N (N_2 and N_2O) into the atmosphere in a process called **denitrification**. **Volatilization** occurs when ammonia (NH_3) from the soil surface is released into the atmosphere — NH_3 can be formed directly from a fertilizer source or converted from NH_4^+ . Specifically, in no-till systems, high residue cover can cause higher rates of N loss with urea-based fertilizers because there is an enzyme present in residue that breaks down the fertilizer and the residue physically inhibits nutrients from entering the soil. Both denitrification and volatilization are worsened by wet soil, high temperatures and high soil pH conditions.

Nitrogen Requirements in Cotton

Cotton N requirements change significantly throughout the season, following a sigmoidal curve as shown in Figure 2. Throughout emergence and plant establishment, N requirements are relatively low. Nitrogen uptake begins to increase from first square to first bloom, and then maximum

uptake occurs with boll loading between first bloom and first open boll. Around peak bloom (three to four weeks after first bloom), it has been found that the N uptake rate will be close to 4 lb/acre/day. Once growth ceases and bolls begin to open, the N requirement decreases dramatically. In order to minimize losses and increase efficiency, N fertilizer should be applied as close as possible to the time it will be taken up by the plant.

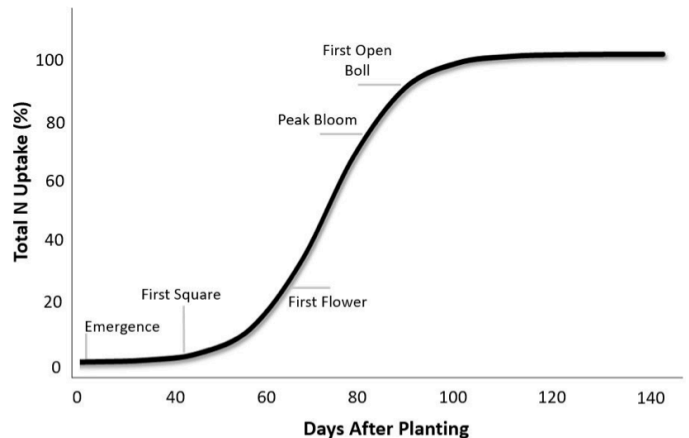


Figure 2. General cotton N uptake curve as a percentage of total N graphed by days after planting.

N Deficiency

It is important to be able to identify N deficiency symptoms (Figure 3) in cotton such that an in-season application can be made to potentially mitigate any negative effect of the deficiency on yield. Nitrogen is mobile within the cotton plant and will travel to support the newest vegetative growth; therefore, the older, lower leaves will show the earliest deficiency symptom by turning a yellowish green color. An advanced N deficiency in cotton will be apparent through red-to-brown leaves, increased boll shed and reduced plant height. If not corrected in time, N deficiency will cause a reduction in the number of fruiting sites and will ultimately reduce yields.



Figure 3. Image on the left captures a cotton leaf which has sufficient nitrogen (N) (in hand) versus leaves that are beginning to show signs of N deficiencies. The image to the right shows both sufficient and deficient areas associated with a nonuniform application of dry N fertilizer.

Excessive N

Just as an N deficiency can cause problems in cotton, so too can excessive amounts of N. Too much N can cause delayed maturity, increased insect and disease problems, boll rot and reduced fiber quality. Excess N or poorly timed, late N fertilizer applications can cause excessive vegetative growth late in the season and problems with defoliation. This excessive vegetative growth occurs instead of reproductive growth, causing a reduction in yields.

Nitrogen Management

As previously discussed, proper N management is critical to cotton yields, profitability and environmental quality. The 4Rs of nutrient management — right source, right rate, right time and right place — should be used as a holistic framework when managing N in cotton.

Source

Selection of an appropriate fertilizer N source, whether it be an inorganic, commercial fertilizer or animal manure, is critical to proper N management. Consideration for application timing and placement must be given to minimize losses. Additionally, sources of N impact soil pH differently and may impact liming. While urea and ammonium nitrate have a moderate acidification potential, ammonium sulfate has a high acidification potential.

Inorganic fertilizer

Commercial fertilizers are the most widely used fertilizer materials in Tennessee and across the world. Table 1 shows the most common inorganic N fertilizers in Tennessee. These come in solid, liquid and gaseous forms to accommodate different crops, climates, application techniques and price ranges. Always consider loss pathways for the specific fertilizer in question.

Table 1. Common nitrogen (N) fertilizers.

FERTILIZER PRODUCT	GRADE
Anhydrous ammonia	82-0-0
Urea	46-0-0
Ammonium nitrate	34-0-0
Urea ammonium nitrate	32-0-0
Calcium nitrate	15.5-0-0

Anhydrous ammonia (NH_3) is transported as a pressurized liquid and becomes a gas when applied to the soil. Because NH_3 is pressurized and can cause human health damage, proper handling and safety precautions must be used during storage, transport and application. Anhydrous ammonia should be applied at least 4 inches below the soil surface to avoid volatilization. Also, avoid planting near recently

applied anhydrous ammonia, particularly in dry soils, to avoid seed or seedling injury.

Urea is a solid N fertilizer that is generally surface-broadcast. It is highly soluble, and soon after application an enzyme called urease will convert the urea back to NH_3 , which can volatilize quickly during hot, dry conditions. In no-till systems, urea should be applied immediately prior to a rainfall event or irrigation and can be used in conjunction with a urease inhibitor to reduce the potential for volatilization.

Ammonium nitrate is a solid N fertilizer source that provides N in two plant available forms — half in NO_3^- and the other half in NH_4^+ . Almost no volatilization losses should occur, but under wet conditions the NO_3^- can leach or be subject to loss by denitrification, so ammonium nitrate should be applied during a moderately dry period. Although ammonium nitrate is an excellent N source, it has limited availability due to being regulated by the U.S. Department of Homeland Security as an explosive precursor chemical.

Urea Ammonium Nitrate (UAN) solutions are made up of urea and ammonium nitrate. As such, the N is supplied in a time-release manner as one-quarter NO_3^- (readily available), one-quarter NH_4^+ (readily available and converted to NO_3^-), and half urea (converted to NH_4^+ , then NO_3^-). UAN can be injected, surface-banded or diluted through foliar application or fertigation. As with urea, urease inhibitors can be used with UAN solutions to reduce NH_3 volatilization.

Calcium nitrate must be stored under cool, dry conditions due to its very hygroscopic nature. In order to prevent it from absorbing water from the air, these sources are sometimes treated with a coating or sold as a liquid. Occasionally, calcium nitrate is applied through fertigation and can be taken up immediately after water moves the fertilizer into the active root zone. Typically, it is not used as the primary source of N fertilizer for cotton due to expense; however, if Calcium (Ca) and N is needed in-season by the crop, calcium nitrate would be the preferred source.

Enhanced-efficiency fertilizers and additives

Enhanced-efficiency fertilizers and additives, like controlled-release and inhibitor technologies, improve nutrient use efficiency and reduce nutrient losses to the environment. These fertilizers utilize or inhibit various chemical and physical processes in the soil in order to prevent nutrient losses to the environment and make them readily available when the crop needs them. Common products that are currently marketed are listed in Table 2 and are discussed further below.

Table 2. Common enhanced-efficiency nitrogen (N) fertilizers and additives.

PRODUCT TRADE NAME	ACTIVE INGREDIENT	MARKETED MODE OF ACTION
Agrotain	N-(n-butyl) thiophosphoric triamide (NBPT)	Urease inhibitor
Environmentally Smart Nitrogen (ESN)	Polymer-coated	Controlled-release
Guardian	Dicyandiamide (DCD)	Nitrification inhibitor
Instinct	Nitrapyrin	Nitrification inhibitor
N-Serve	Nitrapyrin	Nitrification inhibitor
Nutrisphere	Maleic-itaconic acid co-polymer	Urease and nitrification inhibitor
Super-U	DCD, NBPT	Urease and nitrification inhibitor

Nitrification inhibitors

Products that inhibit nitrification work by suppressing the soil microbial activity that causes the conversion from NH_4^+ to NO_3^- . The two most common compounds in these products are 2-chloro-6-(trichloromethyl)-pyridine (Nitrapyrin) and dicyandiamide (DCD). These are generally effective at delaying the conversion to NO_3^- for approximately 25 to 55 days, thus reducing NO_3^- leaching.

Urease inhibitors

Urease inhibitors reduce the activity of the urease enzyme temporarily, decreasing the potential for NH_3 volatilization. The most widely used compound is N-(n-Butyl) thiophosphoric triamide, or NBPT. NBPT has been shown to be effective at restricting urea conversion to NH_3 for one to two weeks.

Nitrification and Urease inhibitors

Ammonium thiosulfate (ATS) has been shown to act as both a nitrification and urease inhibitor, although its performance is inconsistent. ATS works by reacting with manganese oxides to form other compounds that can slow nitrification and inhibit urease activity. Products that contain the maleic-itaconic acid c-polymer claim to inhibit nitrification and urease activity by binding to copper and nickel ions — a mode of action that is not chemically feasible.

Controlled-Release Fertilizers

A controlled-release fertilizer is generally a polymer-coated urea that releases N as a result of changes in soil temperature and moisture. The polymer coating acts as a physical barrier for the urea, protecting it from early N loss and extending N availability into the growing season. Controlled-release fertilizers should be applied timely to ensure N will be available to the crop and not released too late in the season.

Organic fertilizer

Some producers may have the desire to apply animal manures as a nutrient source. The N content of the manure varies depending on the species of animal, among other things. Manures should be tested for nutrient levels and applied based on the most abundant nutrient level (i.e., generally, if manure is applied based on N requirements, phosphorus [P] is greatly over applied). Additionally, only a portion of the N will be made available for plant uptake in the growing season, some will remain in the organic form, and some will volatilize if surface-applied. Manures should always be managed properly to limit adverse effects on air and water quality. While there are many challenges to manure application, it can be a good source of nutrients and organic material.

Biological fixation

Biological N-fixation occurs when Rhizobium bacteria living in root nodules of leguminous plant species convert N_2 from the atmosphere ultimately into NH_4^+ to be used by the plant. When legumes are used as a cover crop, some N will be recycled when the cover crop is terminated. The amount of plant available nitrogen from biological N fixation in cover crops will depend on the legume composition of the stand as well as biomass accumulation. If legumes, such as soybeans, are used in the crop rotation, part of the fixed-N will be harvested and part will be left as crop residue. The availability of the recycled N in terms of timing and quantity is dependent on many factors including soil temperature and moisture.

Rate

Using appropriate N fertilizer rates, as discussed above, is critical in cotton production. Nitrogen inputs should, taking estimated efficiencies into account, be matched to crop uptake. To receive the maximum environmental and financial benefits, an economically optimal rate should be applied for highly mobile nutrients such as N. This rate is defined as the crop response per unit nutrient applied (i.e., the rate at which the highest yields were produced with the least nutrients).

University of Tennessee recommendation

The University of Tennessee N fertilizer rate recommendation for cotton is 60-80 lb N/ac. This recommendation was based on and is updated with multiyear, multisite studies where a range of N rates are applied to a crop in a statistical design. The recommended N fertilizer rate is determined to be the rate found that maximizes yield with the least amount of N fertilizer. Rates higher than recommended threaten to hurt profitability because of the extra fertilizer expense and no additional yield increase. Additionally, excessive rates can impact the environment negatively.

The most recent evaluation of N fertilizer rates in cotton began in 2013 and will continue through 2018 at the UT AgResearch and Education Center at Milan, Ames Plantation AgResearch and Education Center, and the West Tennessee AgResearch and Education Center. Using data from 2013 to 2016, a summarized yield response curve to N fertilizer rates is shown in Figure 4. Note that no additional increase in yield was achieved past the 80 lb N/ac application rate.

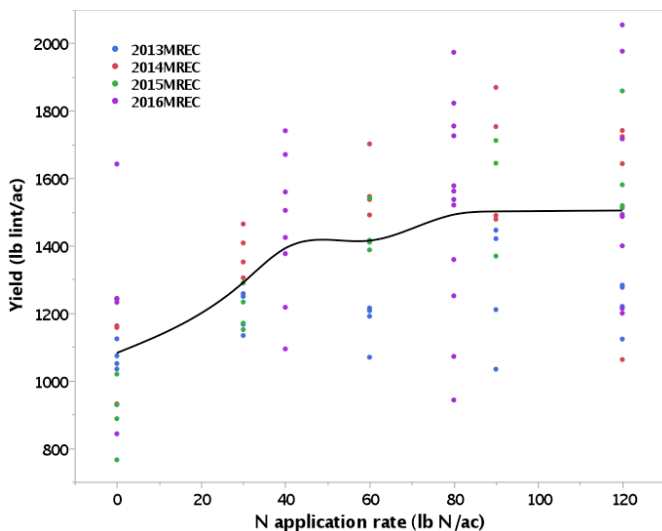


Figure 4. Yield response curve to nitrogen (N) application rates from 2013-2016 data from the UT AgResearch and Education Center at Milan.

Other contributing N sources

Proper N management includes accounting for all contributing N sources when determining fertilizer application rates. Other sources might include irrigation water, manure, legumes and other applied spring fertilizers such as diammonium phosphate (DAP, 18-46-0).

Testing for N sufficiency

Soil nitrate

Soil nitrate testing is not recommended in Tennessee, with the exception of the pre-sidedress nitrate-nitrogen test (PSNT) for corn. As discussed throughout this document, N in the soil is extremely dynamic. Our warm, humid climate promotes continuous transformations and losses, thus the level of NO_3^- in the soil could change substantially between the time of sample collection and lab analysis.

Tissue sampling

Several surrounding states recommend the use of either petiole $\text{NO}_3\text{-N}$ or leaf tissue sampling to determine in-season N status in cotton. Refer to SAAESD (2009) in the References section of this publication for more information.

Variable rate technology

Spatial variability exists in all crop production fields and can be attributed to factors such as soil physical properties, soil fertility, soil moisture, topography, pests and diseases. Technology is available to vary rates of inputs throughout a field as opposed to applying one uniform rate. This site-specific management has the potential to enable cotton producers to optimize N applications. Determinations of these rates can be done from a proactive (pre-season) or reactive (in-season) stance.

Proactive management

One method of site-specific management is to create management zones within fields — areas within a field that have a specific yield potential that respond to management practices in a similar way (Figure 5). The types of information typically used to divide production fields into management zones include past yield maps, soil type via soils map or soil electrical conductivity (EC) maps, topography, and producer knowledge of the field. High-quality data and the ability to manipulate these data are essential for effective management. Based on this information, N rates can be adjusted by zone to match the within zone requirements. Adjusting application rates on the go requires a prescription map based on these management zones.



Figure 5. Variable rate (VR) nitrogen (N) prescription map for a field under zone management.

Reactive management

Spatial variability can also exist with in-season N deficiencies. A common method to monitor in-season cotton N status includes observing plant reflectance along the electromagnetic spectrum. Typical plant reflectance curves are known for healthy and unhealthy plants (Figure 6). Reflectance information can be collected using active sensors (provide a light source) such as the GreenSeeker technology or with passive sensors (uses sun as light source) such as the Yara N-sensor technology or a consumer-grade camera. These technologies use various research-based algorithms to convert plant reflectance readings to appropriate N application rates.

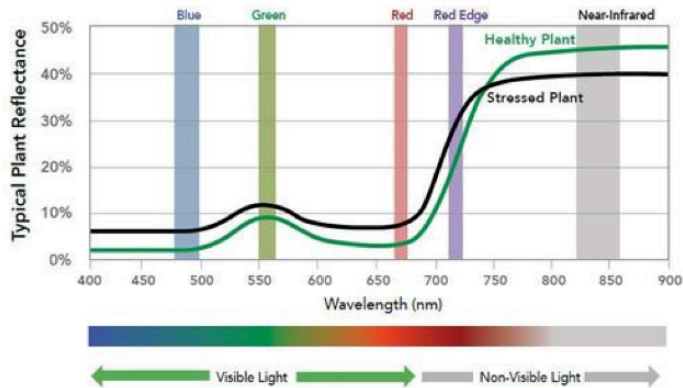


Figure 6. Typical plant reflectance for healthy (green) and stressed (black) plants. Image courtesy of Micasense.

Timing

Timing is an important aspect of fertilizer management in the high-precipitation, humid climate of Tennessee. Nitrogen fertilizer application and/or availability should coincide with crop demand. If N fertilizer is applied when the crop does not need it, it has greater potential to be lost through NO_3^- leaching, denitrification and volatilization, which can lead to lower yields, economic loss, soil acidification and pollution of waterways. Nitrogen fertilizer application timings were evaluated during 2016 and 2017 at several University of Tennessee AgResearch and Education Centers (Figure 7) — these included a control and pre-plant, split and delayed applications of 40, 80 and 120 lb N/ac as ammonium nitrate. These preliminary data show no significant yield response to N fertilizer timing, but studies will be continued to evaluate further the effect of N fertilizer application timing on cotton yields over different growing seasons.

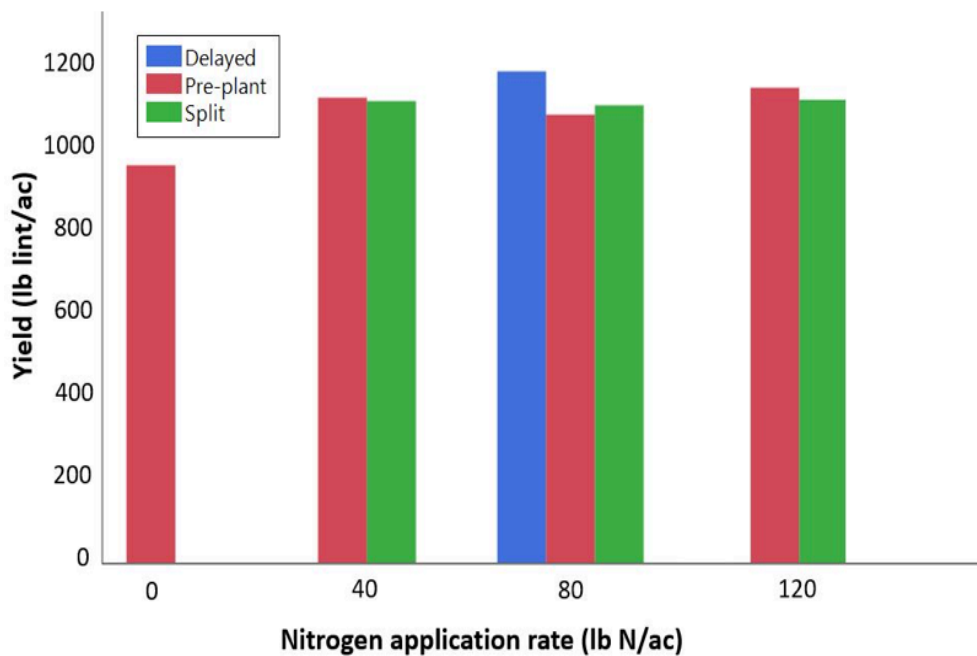


Figure 7. Yield response to pre-plant, split and delayed timings of 40, 80 and 120 lb N/ac from 2016 and 2017 collected at the West Tennessee AgResearch and Education Center, Ames Plantation AgResearch and Education Center, and the AgResearch and Education Center at Milan. Pre-plant applications were applied immediately prior to planting or after emergence. Split applications received half of the rate at planting and the other half immediately prior to first flower. Delayed applications were applied immediately prior to first flower.

Pre-plant applications

At a minimum, N fertilizer should be applied as close to planting as possible to minimize losses. Controlled or slow-release fertilizer forms and other enhanced-efficiency technologies can be used to supply nutrients at times that coincide more closely with the crop demand curve.

Split and delayed applications

To avoid potential denitrification and leaching losses, split or delayed applications of N fertilizer can be used. Matching N availability to crop uptake will increase the nutrient use efficiency, which can lead to higher yields and improved crop quality, as well as reduced environmental impacts. Split applications entail applying one-half or less of the total N fertilizer to be applied pre-plant or at planting, then sidedressing the remainder of the N no later than early square. Another option is using a delayed application where no N fertilizer is applied early when the cotton N requirement is low and then sidedressing the full rate immediately prior to increasing N demand at early square.

Late applications

In N-deficient cotton, late N applications can be made to potentially mitigate some of the effect on yield. Sidedress applications can be made up until the third week of bloom. Foliar applications, albeit fairly expensive, can be used to supplement soil-applied N when there is an obvious N deficiency. Adhere to the fertilizer product label to avoid leaf burn.

Placement

Proper placement of N fertilizer refers to depth within the soil, lateral distance to root, and on a broader scale, addresses spatial variability within the field. The warm, wet climate and high-residue, no-till systems in Tennessee should be considered when selecting a N fertilizer source and application method. Even with perfectly selected N fertilizer rates and placement, there is a risk of uneven application with any method, so equipment should be checked prior to application and maintained properly.

Broadcast

In high-residue systems, broadcasting N fertilizer is not the most effective application method due to reduced contact between the N fertilizer and the soil. If a broadcast application is necessary, either ammonium nitrate or urea should be used. Volatilization can occur when urea fertilizers are surface-applied and not incorporated either by rain, irrigation or tillage. High soil pH and temperature can also increase the rate of volatilization.

Banding

Banding fertilizer creates concentrated zones of nutrients which in turn increases root proliferation in that area and subsequent nutrient uptake. Surface banding can be more effective at reducing the contact between N fertilizer and residue than broadcasting. Subsurface band applications of fertilizer are generally recommended to reduce losses from sources that are at risk of volatilization. Incorporate or inject urea-based fertilizers or use other sources of nitrogen such as anhydrous ammonia. If N fertilizer is to be placed near the cotton seed, the salt index of the fertilizer and the sensitivity of the seed should be considered.

Managing spatial variability

As discussed above, spatial variability occurs in every field. To address this variability within a field, variable rate application (VRA) of fertilizers can be utilized. Using management zones or remote sensing, nutrient prescription maps and VRA can be used to apply the right fertilizer rate in the right place. By matching N supply to where it is needed by the crop, yields can potentially be improved and the risk of nutrient loss to the environment reduced.

Summary

Nitrogen is extremely dynamic and must be managed appropriately to avoid losses. Using the 4R framework to select the right source, rate, timing and placement for a specific field will increase nitrogen use efficiency. Proper N management in cotton is critical to optimizing yields, maximizing profits, and reducing effects on the environment.

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