Fertilizer BMPs —

Apply the "Four Rights" for Cotton Production in the Midsouth and Southeast

By C.S. Snyder, S.B. Phillips, and T.W. Bruulsema

There is a lot of discussion about best management practices (BMPs) for agriculture, motivated by increasing energy costs and economic pressures. Farmer interest in BMPs is associated with the increasing awareness that how we manage our soils and landscapes can have a large impact on the surrounding environment. As stewards of the land, farmers in the Midsouth and Southeast USA implemented soil conservation practices to improve their soil and water quality. Reductions in soil erosion and increased moisture conservation have led to higher crop yields and enhanced whole-farm economics.

Fertilizer nutrients play a major role in meeting the crop yield and quality goals of modern agriculture. Better crop and soil management has resulted in higher crop yields. Higher yields, in turn, have increased the need to replace the nutrients removed by the larger crop harvests. How we handle these fertilizer inputs provides the foundation for fertilizer BMPs and positive economic returns from fertilizer.

There are several considerations during the development and implementation of BMPs, but there are four major scientific principles that apply to all crop management BMPs, including fertilizer.

The first is practical measured validation. Applied field testing of BMPs should reflect their effects on basic crop management objectives, including productivity, profitability, cropping system sustainability, and environmental health. The field testing should be scientifically sound by including appropriate replication and randomization, and the results should be verified by peer-reviewed publication in appropriate scientific literature.

The second principle is recognition of the need to adapt to risks. Factors beyond the grower's control...such as weather, pests, and market conditions... can have huge impacts on their management objectives. BMPs containing rigid production guidelines and regulations that don't allow for changes year to year with these conditions fail to address the risks faced by producers and won't be adopted.

Third, BMPs need to be developed with performance indicators in mind. These would be measurable parameters that demonstrate the impact of the practice on the management objectives: productivity, profitability, sustainability, and the environment. Some examples would be yield, net profit, nutrient use efficiency, soil erosion, etc. Not all management objectives can be assessed using a single performance indicator, nor can all indicators relevant to a particular objective be measured.

Best management practices are being tested in research and verified through field evaluation.

Finally, the fourth principle is that BMPs must provide for a dynamic feedback mechanism among the farm, regional, and regulatory level participants. The farm level participants are the growers; the regional participants include agronomic scientists both at universities and in industry, Certified Crop Advisers (CCAs), and other agricultural professionals. The regulatory level participants would be the policymakers. This dynamic feedback mechanism is a critical scientific principle because: "BMPs are dynamic and evolve as science and technology expands our understanding and opportunities. Practical experience teaches the astute observer what does or does not work under specific local conditions" (Fixen, 2007).

Abbreviations and notes for this article: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; C = carbon; ppm = parts per million.

This publication is one of a series prepared by cooperators with the staff of the International Plant Nutrition Institute (IPNI). It is part of a project in cooperation with the Foundation for Agronomic Research (FAR) toward fulfilling the goals of a 3-year Conservation Innovation Grant (CIG 68-3A75-5-166) from the USDA-Natural Resources Conservation Service to identify fertilizer best management practices (BMPs). The intent of this publication is to help develop the BMP definition process in such a way that environmental objectives are met without sacrificing current or future production or profit potential and in full consideration of the newer technologies relevant to fertilizer use. The concept of applying the right fertilizer at the "right rate, right time, and right place" is a guiding theme in this series. For additional information, visit the websites: www.farmresearch.com/CIG and www.ipni.net.
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There are other scientific principles which would be specific to fertilizer BMPs. 1) They must be consistent with understood process mechanisms. We have a good understanding of how nutrients behave in soil and in plants and we must recognize and consider this knowledge when developing fertilizer BMPs. 2) We should recognize interactions with other crop BMPs such as tillage, variety selection, planting date and density, and crop rotation; all of these factors will affect crop response to applied fertilizer nutrients. For example, in cotton, different varieties have been shown to respond differently to K fertilizer applications at a given soil test K level. 3) Developers of fertilizer BMPs also have to recognize that decisions we make regarding management of fertilizer source, rate, and time and place of application are not independent of the others. Selecting a controlled-release fertilizer material for cotton production might be applied appropriately following a different timing schedule than a water-soluble source, for example. 4) Fertilizer decisions influence the quality of the crop as well as the quantity. Cotton price is especially sensitive to changes in quality, which can be greatly affected by fertilizer application, especially N sources. 5) Finally, we have to always consider economics associated with implementing a new fertilizer BMP.

The way fertilizers are managed can have a major impact on the efficiency of nutrient use by crops and potential impact on the surrounding environment. In all instances, we are striving to improve fertilizer use efficiency by increasing the pounds of lint per acre for each unit of nutrient applied, without sacrificing yield potential. This is especially true for N, the major nutrient removed from the soil by cotton and most annual grain crops and perennial forages. **Efficient fertilizer management means paying close attention to the "Four Rights" (4Rs) of fertilizer application: Applying the right nutrient source at the right rate, at the right time in the growing season, and in the right place.**

Right Source

Plants take up the bulk of their nutrients from the soil in forms that are best suited to their use in the crop. Nitrogen is taken up as nitrate (NO_3^-) and ammonium (NH_4^+), P as primary ($H_2PO_4^-$) or secondary (HPO_4^{2-}) orthophosphate, K in its elemental form (K^+), and S mostly as sulfate (SO_4^{2-}). Fertilizers are formulated to be either in these plant-available forms, or converted to these forms after application to the soil. In some instances, this conversion limits immediate use by the plant, requiring specific application management for efficient use. An example of this is elemental S, which must first be converted to SO_4^{2-} to be plant-available, a process that requires surface application of the fertilizer and up to 12 months for the conversion to be completed. In other instances, a fertilizer form may be selected to delay conversion to a plant-available form, minimizing potential losses from the soil.

It is also important to consider the nutrient source most appropriate for the soil and cropping system conditions.

Soil testing is performed in a professional and controlled laboratory environment.

Placing urea-containing N fertilizers beneath the soil surface and crop residues can reduce the volatile losses of ammonia, minimize immobilization in surface residues, increase yields, and enhance fertilizer effectiveness (Howard and Essington, 1998; Kissel, 1988). The benefits to this practice may be more evident in no-till corn (**Figure 1**) than in no-till cotton (**Figure 2**) because of the greater amount of crop residue left on the soil surface with corn. However, it is important to recognize that surface residue

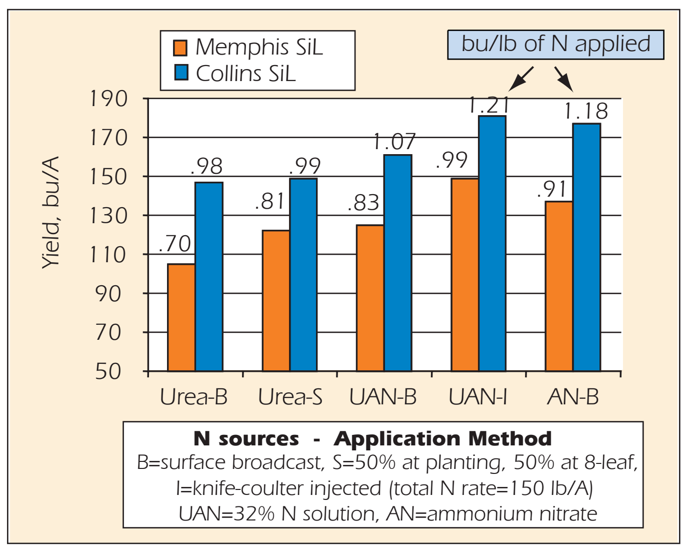


Figure 1. No-till corn response to N source and placement in Tennessee. Source: Howard and Essington, 1998.

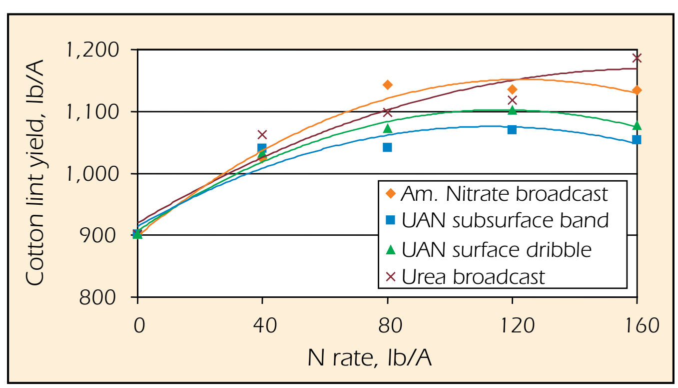


Figure 2. 10-year average response of cotton to N rate and source in Mississippi. Source: Parvin et al., 2003.

is only one factor contributing to surface volatilization of urea. High temperatures, dry conditions, and coarse-textured soils, which are all commonly found throughout the cotton-producing regions of the Midsouth and Southeast, can also increase the potential for volatile N losses following surface-applications of urea.

Other considerations when selecting the right nutrient source include recognizing synergisms among nutrient elements and sources. These would include phosphorus-zinc interactions, N increasing P availability, and mineral fertilizer complementing manure, etc. Blend compatibility can sometimes be an issue. Most fertilizer dealers will recognize this, but there are certain combinations of sources that attract moisture when mixed that limit uniformity of application of the blended material; granule size should be similar to avoid product segregation, etc. We must also recognize crop sensitivities to associated elements. Most nutrients have an accompanying ion that may be beneficial, neutral, or detrimental to the crop. For example, the chloride ion in muriate of potash is beneficial to corn and wheat, but can be detrimental to the quality of tobacco, potato, and some fruits.

Right Rate

Most crop advisers have heard about Liebig's Law of the Minimum, which states that the yield of a crop will be determined by the element present in the most limiting quantity. In other words, the deficiency of one nutrient cannot be overcome by the excess of another. Soil testing and use of crop nutrient uptake and removal information are important guides to ensure that balance among soil available nutrients plus applied fertilizer prevents nutrient deficiencies from limiting crop yields, or some nutrients from being used inefficiently.

An example of proper nutrient balance is illustrated in a cotton study conducted in Tennessee (**Figure 3**). Improved P nutrition, in both disk-till and no-till systems, raised yields and increased the lint yield per pound of N

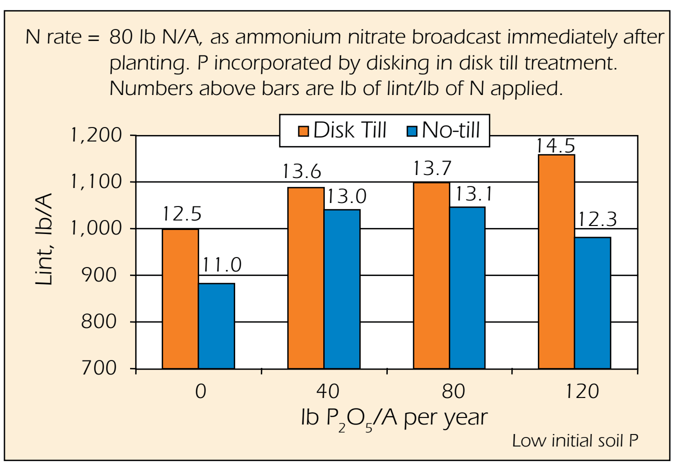


Figure 3. Adequate soil P improves 6-year average cotton yields and response to applied N in Tennessee. Source: Howard et al., 2001.

applied. Being sure to provide adequate P and K nutrition can enhance crop recovery of applied N.

Selecting the right fertilizer application rate begins with using all available information to match soil nutrient supply with crop requirements. Specific BMPs include soil testing, balancing nutrient inputs with crop removal at optimum soil test levels, setting realistic yield goals, and in-season plant nutrient analysis.

a) Soil Testing

The main science-based tool used to estimate the soil nutrient supply on agricultural lands is soil testing. The success of the soil testing process is based on: soil samples taken from representative areas in a field, analysis using a chemical extraction appropriate for the soils in the region, correlation of soil test values with plant nutrient uptake or crop yield, and calibration with different nutrient application rates at different soil test levels. Resulting fertilizer recommendations would be based on how a particular crop responded to a nutrient, using the average response from a multi-year and multi-site data set. Given that a number of non-fertility factors affect final crop yield (environmental conditions, pests, etc.), remember that fertilizer recommendations based on correlation with a field response database may account for only 50 to 60% of the yield variation in the field (Dahnke and Olson, 1990; Cox, 1994; Sabbe and Marx, 1987). This helps explain why fertilizer recommendations are often made based on yield potential, a reflection of soil water availability, ability to irrigate effectively, and other management conditions for a specific field.

Periodic soil testing of all the fields on a farm acts as an excellent gauge of nutrient sustainability for crop production. These soil test results become part of a record keeping system, including prior soil test data, fertilizer and manure applications, and crop harvest nutrient removal. Together, this information can be used to determine whether soil fertility is increasing, decreasing, or remaining constant.

If nutrient levels in a soil are allowed to decline to the point of limiting yield potential, substantial economic losses and losses in inherent soil fertility can be expected (Mitchell et al., 2005). On a high-P (>100 ppm Mehlich 1 P) Portsmouth sandy loam soil in North Carolina, soil test P declined to half the original values in less than 6 to 8 years as a result of harvest nutrient removal and other factors, in a corn-soybean rotation (McCollum, 1991). Depletion of reserve soil fertility takes years of restoration with fertilizer and/or manure to regain optimum productivity.

b) Nutrient Budgets

Frequently, crop advisers and farmers find that they can make fairly good estimates of crop nutrient requirements based on what was grown previously and what was applied in a specific field. Information such as previous crop yield, soil drainage class, tillage system, and crop residue management can all be used to estimate the status of a nutrient such as N. For most cotton fields, the year-to-year variation in plant-available supply of P and K is usually relatively minor, and annual application based on a balance between soil test levels and crop requirements can avoid depletion or over application. A balanced nutrient budget should never be considered an appropriate replacement for frequent soil testing, given the absolute need to use soil testing to establish a nutrient supply starting point. Often, this type of balancing assessment (input vs. removal) is carried out in the years between which comprehensive soil sampling is conducted.

Nutrient removal information sources are available on the IPNI website >www.ipni.net/nutrientremoval<. While the values in these tables represent averages from field sampled crops, using your own information is always the best source whenever possible.

c) Establishing Realistic Yield Goals

A realistic yield goal should be developed from past performances in a field and current information about those factors that have dominant effects on yield. Available water, via rainfall and/or irrigation, is one of the major factors affecting crop yields. Nutrients also play an important role in improving the use of water by crops by increasing the amount of yield per unit of water used (Stewart, 2001). As a result, a field-specific yield goal is determined based on available soil moisture, precipitation probabilities for the region, crop water use, and soil residual nutrient levels.

A common approach to setting realistic yield goals is selecting a value somewhere between an above average yield and a maximum yield that has been achieved in a specific field, or one of similar production and management history. Setting a target of 10% above the 3- to 5-year average of crops not suffering a severe yield loss due to drought, excessive rainfall, or pests is also a commonly suggested method. This approach requires that individual field records be maintained, and that only those fields of similar production potential be considered in making estimates. An example for a cotton yield is shown below and considers the best 4 of the previous 5 years, scaled up by 10%. While short of the maximum yield grown, it does provide a means of striving for yield increases. It is important to remember that, over time, yield goals will increase as long as the average yield continues to increase.

Year	Cotton yield, lb of lint/A	
2003	1,320	
2004	890	Average yield = 1,265 lb of lint/A (best 4 years out of the last 5)
2005	1,055	Highest yield = 1,415 lb of lint/A
2006	1,415	Realistic yield goal = 1,265 x 1.10 = 1,392 lb of lint/A
2007	1,270	

d) Plant Nutrient Analysis

The term plant nutrient analysis refers to the total or quantitative analysis of nutrients in plant tissue. Unlike tissue sap testing, which is a qualitative measure of nutrient content, plant nutrient analysis works with soil sampling to evaluate soil fertility and overall nutrient availability. Plant nutrient analysis is used in-season (during active crop growth) to help evaluate nutrient deficiencies and help direct corrective action on the current crop, or future crops. It can be a powerful tool in adding accuracy to the monitoring process as nutrient management plans are implemented. While a range of nutrient concentrations is often provided to help guide the plant nutrient analysis interpretation, concentrations can vary with crop, variety, plant part sampled, growth stage when sampled, environment, geographic area, and other factors. Collecting samples from both 'poor' and 'good' areas of a field growing the same crop can be a useful means of identifying nutrient limitations in crop production, especially when soil samples are taken from the same area as the plant samples.

Right Time

The demand for a nutrient by a growing crop generally varies through the growing season, with the highest uptake associated with the period of most rapid growth. Timing fertilizer applications so they provide a plant-available supply of nutrients when the crop needs them is the desired goal.

In cotton, nutrient uptake is typically slow early in the season, accumulating just 20% of the total N requirement in the first two months of growth; peaks just prior to bloom, taking up another 20% of the total in just 10 days; then remains steady through the remainder of the season until maturity (**Figure 4**).

Research in the South has generally shown that when the entire recommended rate of N is applied preplant for non-irrigated cotton, yield is optimized (Ebelhar, and Welch, 1996; McConnell and Mozaffari, 2004). In irrigated environments, however, cotton yields and uptake efficiency are often improved with split applications: one-fourth to one-half preplant with the remainder applied before flowering. Plants subject to a deficiency during peak growth periods may not recover to achieve full yield potential.

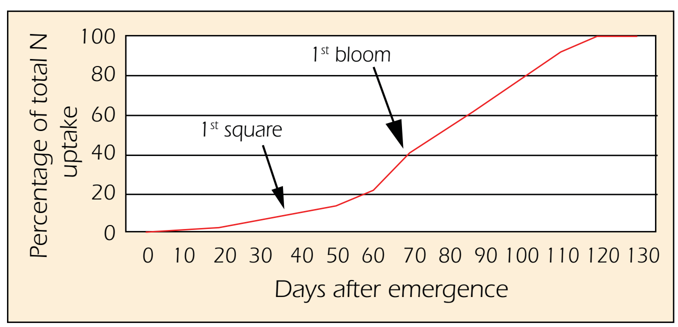


Figure 4. Nutrient demand varies throughout the growing season. Source: Crozier, 2004.

Where fertilizers are subject to transformation in the soil, application timing can play a critical role in optimizing crop nutrient response. Nitrogen is likely the nutrient that is influenced most by the soil moisture and temperature conditions, increasing its demand for management attention. Nitrogen source, placement, timing, and tillage system can all affect crop yields and N effectiveness.

In recent years, some farmers have been delaying N applications in corn and cotton until the stand has emerged. While this can be a successful practice on fertile alluvial soils with a high N mineralization potential (McConnell and Mozaffari, 2004), it may not be an acceptable practice on less fertile or less productive soils which have limited N mineralization capacities. On sandy soils, split applications and use of less mobile N forms may enhance crop yields and fertilizer N recovery (Karlen et al., 1996).

Right Place

An important part of optimizing crop response to a fertilizer nutrient is ensuring that the nutrient is placed in such a way that it provides rapid uptake by the crop, and reduces potential losses. The mobility of a nutrient in the soil plays a large role in the importance of placement. Research in drier regions (e.g. wheat in the Northern Great Plains) has shown that when broadcast-applied on low P soils, optimum short-term P rates can be twice those required when P is seed placed or side banded, and incorporation with tillage is sometimes required to improve exposure to plant roots. Early research with cotton by Nelson and others (1949) showed that placement of P becomes less critical as soil test P increases from low to high levels.

Placement can be a powerful management tool to minimize N losses. Where there is an accumulation of surface residues, it is important to place urea-containing N fertilizers beneath the residues (**Figure 1**). Under ideal conditions, the goal is to apply the N so that it is in the plant-available form and in proximity to the plant roots.

Per-unit production costs can be reduced by increasing fertilizer efficiency. When broadcast urea is applied onto a residue-covered surface of a no-till field and not incorporated, yield may be significantly reduced. When incorporation is not an option with surface applied fertilizer N, selecting a less volatile source such as ammonium nitrate (NH_4NO_3), timing application of urea-containing fertilizers ahead of a rainfall or irrigation (avoiding runoff or significant leaching), or using a urease inhibitor (Earnest and Varco, 2006) can help minimize N losses.

Proper incorporation of P fertilizer or poultry litter into soil can significantly reduce the runoff losses of P. Concentrations and mass losses of P in runoff are not always affected by the P application rate, as shown in a worse-case-scenario study in the North Carolina Piedmont (**Table 1**). Adoption of conservation tillage, to reduce loss of soil and attached nutrients, can significantly improve runoff water quality (MDMSEA, 2001).

Table 1. Flow-weighted runoff losses of different P forms from inorganic fertilizer and broiler litter applied at different P rates, following soil incorporation and then 30 min. of simulated rainfall (>3 in./hr) the day of application.

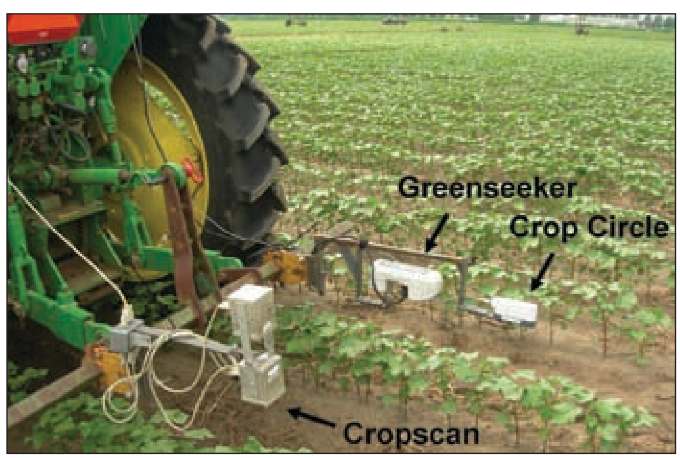
		Runoff P mass losses, lb/A		
P source	P_2O_5 rate, lb/A	Reactive P[1]	Algal available P[2]	Total P[3]
Control	0	0.03	0.18	0.23
P fertilizer	46	0.05	0.42	0.53
	137	0.02	0.16	0.26
	229	0.05	0.27	0.33
Broiler litter	32	0.03	0.21	0.32
	69	0.04	0.28	0.48
	101	0.04	0.28	0.38
	167	0.08	0.38	0.62

[1]Runoff passed through a 0.45-micrometer filter.
[2]Extraction with 0.1M sodium hydroxide and unfiltered before measurement.
[3]Acid digestion of unfiltered samples.
Source: Tarkalson and Mikkelsen, 2004.

Site-Specific Nutrient Management

Precision agriculture and site-specific nutrient management are opportunities to enhance all of the 4Rs. Fertilizing soils rather than fields is an emerging BMP that continues to gain popularity with technology development. Using some form of field diagnostic, such as intensive soil sampling, soil sensing, yield mapping, or scouting records, whole fields are divided into management units where the fertilizer application used is independent of the rest of the field. This form of site-specific fertility management assures that nutrient needs are properly identified and appropriate corrective fertilizer applications are made only where required. This management practice can take into account the natural variation in soil fertility and nutrient supply. However, the nutrient maps and recommendations should consider the level of confidence associated with the estimated soil nutrient values (Birrell et al., 1996).

Aerial imagery and optical plant sensors are being developed that use crop color and biomass as an indication of



Researchers are looking at various types of commercially available sensors. First bloom stage is about the latest time for N fertilization if needed.

N sufficiency (Fridgen and Varco, 2004; Scharf and Lory, 2002). These types of sensing have the potential to provide farmers a practical means of varying the N rate on-the-go. Local calibration of the technology will be needed to make it more useful and economically feasible. In instances where field variability of N is large, this type of application prevents over-application, which is often characteristic of fixed field rates in those areas where the soil N supply is sufficient. Considerable work using this technology is underway with corn (Kitchen et al., 1995; Scharf et al., 2005), but there are few cotton studies to draw upon in the Midsouth.

The most recent research using sensors on cotton in the Midsouth has been done in the bootheel of Missouri (Scharf, 2007). Researchers looked at three types of commercially available sensors and found that at early growth stages (pinhead square) they had some correlation between sensor readings and optimum N rate. This would be the ideal time to make a fertilizer N decision; however, the results were too inconsistent for making an N recommendation. By mid-square, however, results were much better and N fertilization equations were constructed. The equations continued to work well later in the season (up to early bloom), showing the same accuracy in predicting plant N need as they did at mid-square. It is important to ensure that other nutrients (such as K) are not limiting, for the best sensor performance (Fridgen and Varco, 2004).

Minimizing Nutrient Transport from Fields

From an environmental impact perspective, the goal of land managers should be to retain soil and associated nutrients within the boundaries of a field and the rooting zone of the crops grown. Fertilizer BMPs based on the 4Rs help to ensure that proper rates are recommended and appropriately applied. This improves plant nutrient use efficiency and reduces the potential for residual nutrients to accumulate to excessive levels in a field and pose an environmental threat.

a) Nutrient Leaching

Retention of soluble nutrients in the rooting zone of crops ensures efficient recovery and efficient use in food production systems. Leaching occurs when excessive residual nutrients are left in the soil profile and moved below the rooting zone (36 to 48 in. or more) by precipitation. While leaching can be a problem in sandy soils in the humid South (Wiatrick et al., 2002), NO_3-N may not accumulate in silt loam to silty clay loam soil profiles under cotton when the N rate is appropriate for the soil moisture/irrigation regime and the crop yield potential (McConnell et al., 1996). While there are no reported incidences of P leaching when fertilizer is used at soil test recommended rates, leached P has been reported with the application of livestock and poultry manure at rates grossly in excess of crop requirements.

While excess nutrients can result in leaching, withholding needed fertilizer may be more damaging to the environment than applying fertilizer. When N is applied alone, and not in balance with required P, more leached N has been found below the crop rooting zone of corn (Schlegel et al., 1996). Ensuring an agronomic balance of applied fertilizer N with P improved the recovery of N by the crop and removal in the harvested crop, which left less residual N in the soil with the potential to leach below the rooting zone. Use of the pre-sidedress nitrate test (PSNT) (Savoy, 1999) has been shown to be of benefit for improved corn N management in some humid areas, and has led to reduced nitrate-N leaching (Durieux et al., 1995).

b) Conservation Tillage, Soil Erosion, and Carbon Sequestration

Farmers in the South are increasingly adopting conservation tillage practices. The retention of crop residues on the soil surface has significantly reduced the water erosion loss of soil, while at the same time improving moisture conservation and cotton yields (Mitchell et al., 2005). When fertilized according to soil test recommended rates, increased cotton yields may lead to higher levels of crop residues returned to the surface of conservation-till fields for erosion protection.

Proper crop nutrition increases crop yields and crop biomass, can raise soil organic matter (C) content, and can improve the soil supply of organic N. The amount of crop residue returned to the soil is often directly attributed to the positive benefits of fertilization. By allowing crops to capture more carbon dioxide (CO_2) from the atmosphere, more stable soil organic matter can be produced and less atmospheric CO_2…a greenhouse gas…may be released. In long-term rotation studies with cotton in Alabama, yields were found to be highly correlated with soil organic matter content (Mitchell et al., 2002).

c) Field Buffer Strips

The movement of N and P into surface waters with eroded soil poses a serious threat to aquatic ecosystems. Some nutrients are required for the healthy function of aquatic ecosystems, but too much can lead to a decline in aquatic ecosystem productivity. Stopping soil erosion from agricultural lands has been a high priority for all farmers. Any eroded soil means loss of nutrients, organic matter, and future crop productivity. The adoption of conservation practices such as no-till, strip-till, and buffer strips adjacent to surface water have been shown to reduce this unwanted movement of nutrients.

Taking Stock of Your Fertilizer Management

For many farmers and crop advisers, it is time to take stock of how you measure up in the use of fertilizer BMPs. Using the reference chart on page 7, evaluate the number of practices under which you rank in the first two categories. If a suitable fit in these top two categories is not found, you may want to re-evaluate some current management practices. Ensuring that we have either achieved or are working towards fertilizer BMPs is an important measure of production system success.

Fertilizer BMPs for Cotton in the Midsouth and Southeast USA			
Principle	**Best Practice**	**Making Progress**	**Improvements Required**
Right Source			
Supply plant-available form of nutrient	Consider plant availability and make appropriate adjustments in application strategy	Aware of plant availability; occasional adjustments in application strategy	No consideration for plant availability of nutrients
Select nutrient source appropriate for soil and cropping system	Select nutrient forms that minimize potential losses (i.e. leaching, surface volatilization) or make necessary adjustments in timing and placement of fertilizer	Recognize risks associated with specific nutrient sources; occasional adjustments in application strategy	Unaware of any source effects and no consideration of potential nutrient losses
Select an appropriate fertilizer blend	Consider synergy among elements, blend compatibility, potential effects of accompanying ions, and all nutrient requirements	Blends are changed based on changing nutrient requirements but no consideration for other factors	Fertilizer is applied as a fixed blend based on a single nutrient
Right Rate			
Use soil testing	Annually test for N where justified by university research. Test every 2 or 3 years for P and K, and follow recommendations	Soils tested, but less frequently than recommended or soils tested regularly, but recommendations not followed	Never test, or last soil test more than 5 years old
Prepare nutrient budgets	Consider last year's crop removal and this year's realistic yield goal, in matching fertilizer applied with current soil test results	Consider crop nutrient removal based on a desired yield goal, or replace last year's removal regardless of soil test level	No consideration for crop nutrient removal or past production
Establish realistic yield goals	Develop crop- and field-specific yield goals based on measured yield history and crop sequence	Develop yield goals for each crop on the farm, regardless of field	No yield goals considered in planning, or arbitrary or unrealistic yield goals are used
Use plant tissue analysis	Routinely use tissue sampling to evaluate effectiveness of fertility program	Occasionally use tissue sampling for diagnostic purposes	No tissue samples collected
Use site-specific management	Evaluating field variation when making fertilizer application decisions and adjust fertilizer rates accordingly	Fields are grouped based on similar production potential, but variability within a field is not considered	No consideration of field variability in fertilizer application
Right Time			
Apply fertilizer to match crop nutrient uptake	Consider timing of crop uptake and plant source availability and use split applications wherever practical	Apply most nutrients at or before seeding; occasionally split N applications	All nutrients applied well in advance of planting
Assess environmental and cropping system conditions	Consider rainfall/irrigation patterns, soil texture, and tillage and adjust application timing accordingly to minimize potential losses	Recognize risks associated with specific nutrient timing; occasional adjustments in application strategy	Unaware of any timing effects and no consideration of potential nutrient losses
Right Place			
Consider localized placement of immobile nutrients	Use band or starter placement wherever recommended	Broadcast and incorporate all nutrients	Nutrients surface applied without incorporation
Assess potential for nutrient losses	Place volatile N sources and manures beneath soil surface or incorporate; limit applications near grassed waterways and drainage areas	Broadcast and incorporate all fertilizer within a few days following application	Broadcast application without incorporation.
Use site-specific management	Establish management zones within fields based on measured data and apply fertilizers only where they are needed	Management zones established for some fields or certain crops	No consideration of spatial variability

Author information

Dr. Snyder is IPNI Nitrogen Program Director, located at Conway, Arkansas; e-mail: csnyder@ipni.net. Dr. Phillips is IPNI Southeast Region Director, located at Owens Cross Roads, Alabama; e-mail: sphillips@ipni.net. Dr. Bruulsema is IPNI Northeast Region Director, located at Guelph, Ontario; e-mail: tom.bruulsema@ipni.net.

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International Plant Nutrition Institute (IPNI)
3500 Parkway Lane, Suite 550 • Norcross, GA 30092-2806 U.S.A.
Phone: 770-447-0335 • Fax: 770-448-0439 • E-mail: info@ipni.net • Website: www.ipni.net

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