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Editor's note: This is the fourth article in a five-part series from the International Plant Nutrition Institute titled "Know Your Fertilizer Rights," sponsored by The Fertilizer Institute and the Canadian Fertilizer Institute. The series is based on fertilizer best management practices structured around the "4R" nutrient stewardship concept. For more information, visit www.ipni.net.

The four fertilizer rights: timing

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Effective and appropriate nutrient management for any crop can be described and summarized using the four rights (4R) nutrient stewardship framework: the right source, rate, time, and place. The principles within 4R nutrient stewardship are not new; in fact, agronomists have historically sought to direct nutrient management based on these sound fundamental principles. However, there has been considerable effort recently to coalesce these principles in a unified 4R approach that is useful to industry, extension, academia, and policymakers.

This article targets the timing considerations in nutrient management. While it may be convenient to discuss and analyze each of the four "rights" separately, it is important to remember that they are interdependent, and decisions in each can affect the others, making nutrient management a systemic approach. Indeed, because of this interdependence, it is somewhat difficult to discuss one "right" without extending into others. Accordingly, none of the four can be "right" if any of the others are askew or wrong.

Applying nutrients at the right time requires consideration of agronomic, economic, and environmental consequences. These considerations are interconnected as well, and generally speaking, if good agronomy is practiced, then favorable economic and environmental results will follow. For example, optimal fertilizer application timing ensures an adequate supply of nutrients during peak and critical crop demand periods (agronomic) and reduces the potential for loss of nutrients from the system (economic and environmental) by maximizing nutrient uptake. On the other hand, for some nutrients and production systems, if fertilizer is applied too far in advance of crop demand, loss may occur resulting in negative economic and environmental consequences.

Timing considerations are of course very site specific. However, a few common fundamental factors should be considered in fertilizer timing decisions. Among these common factors are the nutrient element, fertilizer product (source), crop and plant nutrient uptake pattern, soil characteristics, and weather/environment. Timing decisions may be further influenced by farming enterprise constraints and fertilizer distribution logistics, which are considered after the "right timing" is determined for agronomic and environmental optimization. The remainder of this article will address fertilizer timing according to common and basic factors, recognizing that final timing decisions are site and situation specific.

Nutrient and source

The greater potential a particular nutrient has for loss from the soil–plant system, the more important the issue of application timing will be. The best example, of course, is N and its transformations and potential for loss through leaching, denitrification, volatilization, and runoff/erosion (Fig. 1). The N cycle is complex, and because of the multiple avenues of loss and the large fertilization need by most non-leguminous crops, application timing is an important component of effective N management. For example, fall application of N for spring-planted crops such as corn should only be practiced in geographic areas where the risk of loss is low and with special considerations such as in late fall after the soil temperature is below 50ºF (10ºC) and expected to continue cooling. Spring preplant and/or sidedress applications typically provide a lower risk of loss and greater profitability (Table 1) and are preferable to fall application

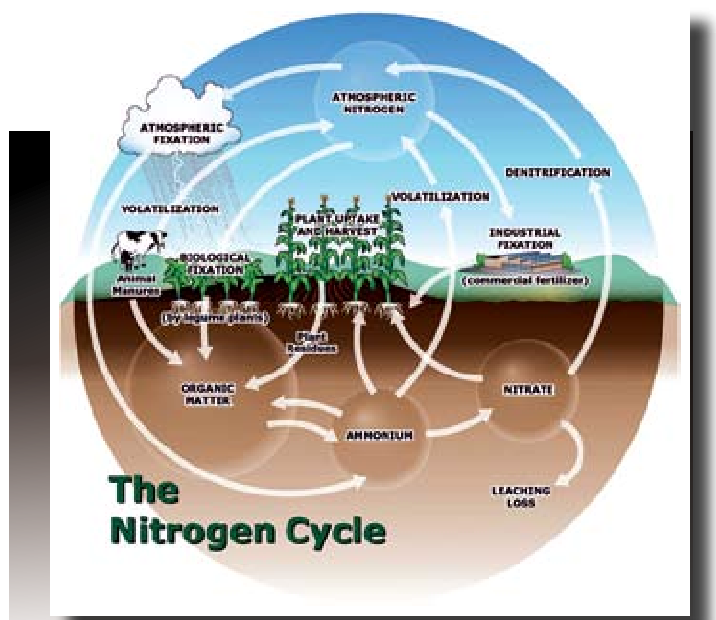

Fig. 1. Abbreviated general N cycle. Because the N cycle is more complex than other nutrients, timing discussions are most commonly centered on N fertilizer.

Table 1. Effect of time of N application and N-Serve on corn yields after soybean from 1987–2001 at Waseca, MN (*Source*: Randall, 2008).

	Time of N application		
Parameter	Fall	Fall + N-Serve	Spring
15-year avg. yield (bu/acre)	144	153	156
15-year avg. economic return over fall N ($/acre/year)†	–	28	48
15-year avg. flow weighted NO_3–N conc. (ppm)	14.1	12.2	12
7-year avg. yield (bu/acre)‡	131	146	158
7-year avg. economic return over fall N ($/acre/year)†	–	52	108
Nitrogen recovery in grain (%)§	38	46	47

† Based on N at $0.70/lb N; N-Serve = $8.00/acre; Corn = $4.00/bu.
‡ Only those seven years when a statistically significant yield difference occurred among treatments.
§ Nitrogen recovery in the corn grain as a percent of the amount of fertilizer N applied.

despite logistical challenges. In contrast, some irrigated corn systems enable growers to apply multiple in-season N applications through fertigation, further optimizing timing to more closely match crop demand efficiency. Thus, use efficiency can be improved and potential for loss reduced.

The N form in a fertilizer product can affect the potential for loss and optimal timing. For example, anhydrous ammonia is the only N fertilizer product suggested for fall application in many areas where fall N fertilization is practiced for corn production (northern USA Corn Belt). In drier areas, urea or all ammonium-containing fertilizers are also fall-applied, but materials containing nitrate are not suggested for fall application. And, even with spring application, materials containing significant portions as nitrate are more susceptible for loss with early preplant application.

Fertilizer technologies to improve N performance have long been available in specialty products and for use in high-value crops. However, over the past few years, some of these enhanced-efficiency technologies have gained attention and some adoption in commodity crop production. These materials include slowly soluble N-containing compounds, coated N fertilizers, and inhibitors designed to retard urea hydrolysis and/or nitrification. The fundamental idea behind these technologies is to control the release of N, or in the case of inhibitors, to delay conversion to nitrate which is most susceptible to loss. Some of these fertilizer products are designed to improve the synchrony between nutrient release and crop uptake. These technologies have the potential to reduce timing sensitivity and increase flexibility in some environments; however, as with any other tool, they must be used where appropriate so as to fully realize benefits.

Timing is usually an N-targeted issue because of the susceptibility of N to several loss pathways. However, in some environments, application timing may be an important consideration with other nutrients as well. For example, where K application is needed, it is usually met with a single preplant application. However, in sandy, low cation exchange capacity soils in high-rainfall areas, splitting or delaying K application can be an effective nutrient management practice because of the potential for leaching in these soil environments. We usually don't consider timing of P application beyond preplant, although placement may be an important issue for certain crops and soil/environment situations. In most cases, P and K fertilizer products can be applied well before planting and, depending on soil conditions, even once for multiple years of crop production. In corn–soybean systems in the majority of the Corn Belt, it is generally accepted that when P and K applications are needed, they may be effectively applied once (generally prior to corn) for multiple years of production, as long as the rate is adequate for each crop.

Crop and its uptake pattern

The uptake of major nutrients and dry matter accumulation patterns are similar for most crops and usually follow a sigmoid or "S"-shaped curve (Fig. 2, next page). This is characterized by rather slow early uptake, increase to a maximum during the rapid growth phase, and decline as the crop matures. Nutrient demand is thus not consistent throughout the season. Applications timed and targeted at specific growth stages may be beneficial to crop yield and/or quality in some production systems and with some nutrients, most notably N. Timed and targeted applications may also be beneficial to reduce the environmental impact of nutrient loss from soil.

Many examples of timing fertilizer applications based on stage of crop growth can be given, but space is limited, so only a couple will be offered here. The majority of both N and K in cotton production are taken up after the appearance of first flower, or the onset of the reproductive phase. It is important to make sure that adequate amounts of these nutrients are available when demand is highest. In some circumstances, foliar application of N and even K starting at ▶

first flower can improve cotton yield and/or quality. Another example is N application to wheat. Most winter wheat recommendations call for some N applied at planting, with the majority topdress-applied by (before) jointing. By the time wheat begins heading later in the season the majority of N has been taken up, and if good N management practices were not previously used, then yield will suffer. Although yield has been determined by this stage, late-season application of N in some wheat production systems can increase grain protein. This may be beneficial where a premium is paid for protein. Care should be taken in these late-season applications to avoid damage that might impact grain fill (e.g., flag leaf burn).

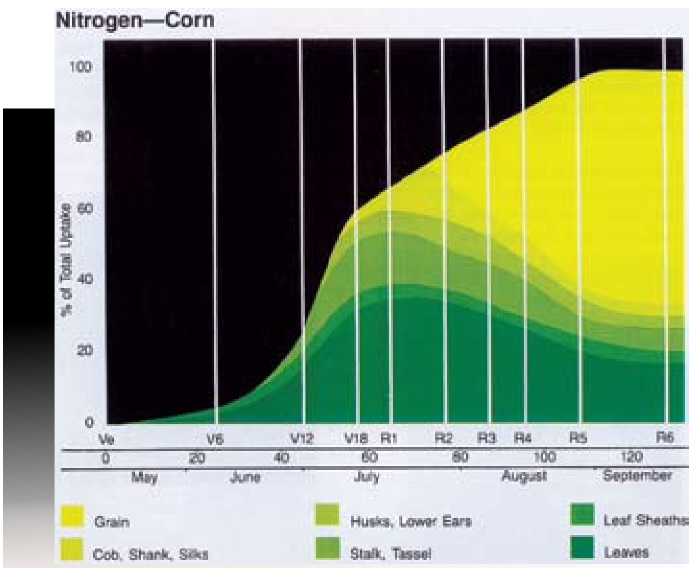

Fig 2. Corn N uptake throughout the growing season (Source: Ritchie et al., 1993).

Another consideration for timing is crop sensitivity to specific nutrient deficiencies, often related to soil conditions. Some crops are more prone to certain deficiencies than others; thus deficiency susceptibility may necessitate consideration of specific fertilizer application and timing. An example of this is the sensitivity of peanut to Ca deficiency. High levels of available Ca are needed in the soil zone where peanuts are developing, and thus pre-bloom applications of soluble Ca materials (i.e., calcium sulfate) are made to most peanuts. Another example is early-season foliar application of Mn to soybean in certain soil and geographic areas of the Corn Belt when deficiency symptoms appear on the plant tissue.

Soil characteristics and environment

Fertilizer application timing decisions are affected by soil characteristics. Soil and site considerations of particular importance are those that affect the potential for nutrient loss from the system (e.g., soil texture, temperature, drainage, and slope), nutrient retention, and supply capacity.

Soil supply capacity is important in fertilizer decisions for obvious reasons. It is arguable that the soil nutrient supplying capability is most relevant to the rate component of the 4Rs, although it can impact timing options and requirements. Put in very general terms, the greater the soil's capacity to retain and supply a crop-available nutrient and provide it throughout the growing season, the less need there will be for a critical timing emphasis for that nutrient. A good example of this is P and K application on most soils in the Corn Belt where fertilizer can be applied once to supply one or multiple crop needs. The applied P and K are held by the soil but remain crop available over time. Similarly, P applications can be made prior to winter wheat planting on sandy soils in the southeastern U.S. Coastal Plain, and P availability is adequate for the double-crop soybeans that are planted the following summer. Conversely, some soils have very high P fixation capacity. Examples are highly weathered soils in the southern USA and calcareous soils of the West. Phosphorus fertilizer applied to these soils can be readily converted to sparingly soluble and unavailable forms of P. Therefore, in these environments, it is common to apply specific P fertilizer products banded at planting to enhance crop supply.

In soil and climatic environments where there is significant potential for loss of nutrients, application timing will need to be more targeted and specific. Appropriate timing of N fertilizers is especially important on sandy-textured soils in areas that may receive high rainfall during winter and spring. For example, in the southeastern Coastal Plain region, N fertilizer applications for winter wheat are routinely split into three applications: preplant, tillering phase of development, and a final application immediately prior to jointing, the period of maximum N uptake. Nitrogen fertilizer applications to corn and cotton grown on these sandy soils are also routinely split between a small application at planting, followed by the majority of the N fertilizer prior to periods of rapid growth and uptake. These practices increase N uptake and reduce the potential for loss to the environment. In contrast, for wheat production in the arid western Great Plains, there may be little advantage to splitting application of N between fall and spring; thus in an environment with low loss potential, applying all N preplant may be as effective as application in the spring or split applications.

The use of optical sensors to determine in-season N input need based on the plant N status has made significant progress in recent years. Sensor technology has the potential to improve synchrony between fertilizer N inputs and crop need and to refine the rate of application. Sensor-based N applications are most likely to show yield and environmental benefits in soil and climatic situations where crops respond to in-season N applications, i.e. adequate moisture and variable climatic events that influence preplant N fertilizer applications during the growing season.

Operational logistics

The logistics of fertilizer distribution, field operations, and application equipment are important factors affecting timing decisions. As farm size has increased, the demand is greater than ever for growers to fine-tune logistics of planting and input timing. Application of fertilizer in the fall for spring-planted crops can reduce the pressure on spring operations. Fall application of P and K fertilizer is generally considered a reasonable practice as the risk of runoff is small in the fall season; however, as previously mentioned, caution should be exercised in applying N in the fall. Fall N application for corn should be avoided in areas with warm/open winters and delayed until soil temperature is below 50ºF (10ºC) and expected to continue cooling in northern geographic areas so as to slow nitrification in the fall and avoid increased nitrate leaching and/or denitrification. Use of a nitrification inhibitor can help further delay nitrification, but even with an inhibitor, fall application, where appropriate, should be delayed until soil temperature cools.

It may not be logistically reasonable in some operations to make multiple N fertilizer applications, and a single application may therefore be desirable. However, as the price of nutrients increase and environmental considerations become more important, changes in logistics and/or product usage may become more economically viable or even required.

Summary

Right fertilizer timing is one of the 4Rs of an effective nutrient stewardship system. The 4Rs—right source, rate, time, and place—are all interconnected and should therefore be considered as an entire system. Appropriate fertilizer timing decisions are nutrient, site, crop, and situation specific and, in some areas, subject to regulatory restrictions for water quality protection. Time of application decisions should be evaluated based on factors such as the soil environment, specific crop demand and uptake dynamics, fertilizer product, and operational logistics and available equipment. Careful planning of fertilizer timing and implementation of the 4R strategy will increase the probability of a favorable agronomic, economic, and environmental outcome in all production systems. ■

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September–October 2009 Self-Study Quiz

The four fertilizer rights: timing (no. SS 03940)

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1. The 4Rs of fertilizer management are

❑ a. independent. ❑ c. inverse.
❑ b. interdependent. ❑ d. irrelevant.

2. Which of the following is important when considering right time of nutrient application?

❑ a. Environmental consequences. ❑ c. Herbicide program.
❑ b. Product color. ❑ d. Fertilizer density.

3. Where N is fall-applied, an important consideration is soil temperature. Soil temperature should consistently be below ___ ºF (ºC) before applying N in the fall.

❑ a. 50 (10.0). ❑ c. 70 (21.1).
❑ b. 60 (15.6). ❑ d. 80 (26.7).

4. Which of the following forms of N should be avoided for fall applications?

❑ a. Ammonium. ❑ c. Urea.
❑ b. Nitrate. ❑ d. Ammonia.

5. Nutrient demand is not consistent throughout the season, and accumulation follows a ___ shaped curve.

❑ a. sigmoid. ❑ c. spheroid.
❑ b. rhomboid. ❑ d. linear.

Quiz continues next page

6. Which of the following is a pathway of N loss from the soil–plant system?

- ❑ a. Nitrification.
- ❑ b. Mineralization.
- ❑ c. Denitrification.
- ❑ d. Immobilization.

7. A soil characteristic that is not important in relation to nutrient loss is ________.

- ❑ a. texture.
- ❑ b. slope.
- ❑ c. color.
- ❑ d. drainage.

8. Enhanced-efficiency fertilizer technologies are

- ❑ a. only used for turf.
- ❑ b. irrelevant in production agriculture.
- ❑ c. a tool to improve nutrient management.
- ❑ d. a magic bullet.

9. Decisions regarding fertilizer application timing

- ❑ a. are of no concern to the farmer.
- ❑ b. are determined by price alone.
- ❑ c. have no environmental consequences.
- ❑ d. require integration of soil, crop, climate, and logistical factors.

10. Considering the N cycle, which of the following is nitrate not subject to?

- ❑ a. Leaching.
- ❑ b. Denitrification.
- ❑ c. Volatilization.
- ❑ d. Crop uptake.

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Rating Scale: 1 = Poor 5 = Excellent

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