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Editor's note: This is the third 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.

Selecting the right fertilizer rate: A component of 4R nutrient stewardship

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The 4R nutrient stewardship concept defines the right source, rate, time, and place for fertilizer application as those best suited to achieve the economic, social, and environmental goals desired by all stakeholders to crop production systems. While this article will discuss only those decisions and principles related to selecting a fertilizer rate, every nutrient application involves all four components, and all nutrient best management practices link to one or more of the 4R components.

Liebig's Law of the Minimum 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. Thus, all of the 17 essential nutrients must be present in quantities sufficient to meet the requirements of the growing crop. The dilemma for crop advisers and growers is how to determine those quantities and answer the question: What is the "right" fertilizer rate for my cropping system?

Under- or overapplication of a particular nutrient may have crop production, economic, and/or environmental consequences. When fertilizer and other nutrient sources are relatively inexpensive compared with the value of the crop being produced, the incentive to make a precise nutrient recommendation is small unless the crop responds negatively to excessive nutrient levels (e.g., too much N causing lodging of small grains, reduced sugar content of beet, or rank cotton) or a perceived environmental consequence of the nutrient is acknowledged and valued (e.g., P contamination of the Everglades or Chesapeake Bay). However, in times of higher nutrient costs and/or lower crop prices, grower interest in developing efficient fertilization programs increases considerably.

Selecting appropriate nutrient application rates is always important regardless of crop price and nutrient cost.

Total crop nutrient requirement

A key scientific principle of selecting the right fertilizer rate is matching nutrient supply with plant nutrient uptake requirements. Nutrient uptake refers to the total amount of nutrients that will be taken up by the crop during the growing season. Some of these nutrients will be removed from the field in the harvested portion of the crop while the remainder will be recycled back into the system as crop residue. In some cases, nutrient uptake and nutrient removal values will be similar as in harvesting forage for hay where most of the aboveground biomass is removed. In other situations, such as cereal grain production, only a portion of the total nutrient uptake requirement is removed from the field. The total nutrient requirement of a crop depends on the type of crop and the yield potential of that crop. The higher the yield, the greater the nutrient requirement will be. Some of this requirement will be met through the soil nutrient supply, and the remainder will need to be provided as fertilizer inputs. However, determining fertilizer application rates based only on expected total nutrient removal by a crop is risky as it does not take into account the amount of crop nutrient supplied by the soil throughout the growing season or the reduced availability of some applied nutrients by the soil (for example, fixation of P by aluminum or K in the interlayer of 2:1 clays) and leads to decreased crop production efficiency.

Soil testing

Soil sampling and nutrient analysis are the foundation for many nutrient recommendations. The relatively soil-immobile nutrients such as P, K, Zn, Mg, and several others are best managed by implementing a long-term, sound soil-testing program. In lower-rainfall areas (e.g., the Great Plains and other western states), the more soil-mobile nutrients such as N, S, and Cl are also assessed and managed based on a preplant soil-testing program. However, N application rates are generally not based on soil testing in more humid climates because weather-induced variations in inorganic N concentrations greatly affect the ability of a soil test to accurately predict N availability to the crop in a given growing season. So, while a soil test is one of the best methods to determine the right rate of P, K, and several other nutrients in these higher-rainfall areas (e.g., Corn Belt, southern/southeastern states, etc.), pre-plant soil-testing programs are generally not used to develop N fertilization programs.

The soil testing process is based on: soil samples taken from representative areas in a field to a consistent and specified soil depth, analysis using an extraction technique 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. While much research has been directed toward the development of appropriate soil test procedures that help predict crop nutrient needs, these soil tests do not provide the final answer of what fertilizer rate needs to be applied to an individual field in a given year. As a result, two main approaches to utilizing soil test results for the development of fertility programs have resulted: (1) nutrient sufficiency and (2) build maintenance.

For the sufficiency approach, the goal is to apply, on average, just enough fertilizer to maximize profitability in the year of application without considering future soil test values. The recommended rate will be relative to a "critical" soil test level, at which the soil is capable of supplying nutrient amounts sufficient to achieve about 90 to 95% of maximum yield. The recommended rate will exceed crop removal at very low soil test levels and approach zero as the soil test value reaches the critical level—although a small amount of fertilizer (particularly P and/or K) is often suggested in starter applications. Over time, using this method will result in soil test levels equilibrating in the low, or deficient, category and nutrient applications will be required each year.

In the build-maintenance approach, fertilizer rate recommendations are made to meet the nutrient requirement of the immediate crop and to raise soil test values to the critical level over a specified time period. Once the soil test value is raised to the critical level, the soil is largely capable of meeting the crop nutrient requirement in a given year and only the amount of nutrients removed with the crop are applied to maintain the soil test levels in a target range slightly above the critical level. Once soil test values exceed this target range, no nutrient application will be recommended—except for the small amounts supplied in starter fertilizer applications.

Soil-testing laboratories differ in nutrient recommendation approaches. Some universities and commercial laboratories suggest using the nutrient sufficiency approach, others suggest following a build-maintenance approach, and others have adopted fertilizer rate recommendation systems that have attributes of both approaches. Kansas State University provides guidelines for both the sufficiency and the build-maintenance approaches depending on the fertility program objectives of the individual farmer. Build-maintenance approaches are impractical in some situations; for example, building soil test K in soils with low cation exchange capacity in high rainfall areas. But in general, sufficiency approaches are more common in the western USA while build-maintenance approaches are more common in the eastern USA. ▶

Determining nitrogen fertilizer rates

Making accurate N fertilizer recommendations is very challenging. Chief factors hindering accurate N recommendations are the difficulties associated with estimating inherent soil N supply and predicting variable losses of both soil and fertilizer N. Difficulty in predicting N availability of green manures, animal manures, composts, biosolids, and other N sources also increases the uncertainty of N recommendations. Nitrogen fertilizer rate recommendations are made in many crops on a per-unit-of-yield basis. One of the major challenges in using a yield-based approach for determining fertilizer rates is obtaining an accurate estimate of crop yield potential. Another problem with approaches based solely on yield potential is that they assume that crop responsiveness to fertilizer inputs is constant across locations and years. In other words, a high-yielding crop has a high N fertilizer requirement. Yield levels are known to vary widely in a given environment from year to year. However, crop responsiveness to N fertilizer also fluctuates as a result of the environment, independent of crop yield potential. Both yield potential and crop responsiveness affect the annual N fertilizer rate requirement.

Other alternatives to yield-based N recommendation systems include determining N fertilizer requirements based on cropping system, soil type, or productivity or based on crop to fertilizer price ratios. Equations and models that predict crop yield and thus N uptake and availability of soil and applied N are also being utilized to fine-tune N rate recommendations.

In-season methods for determining the right nutrient rate

Most fertilizer rate recommendations are made prior to establishing the crop or very early in the growing season. However, to be fully committed to matching nutrient supply with plant demand throughout the growing season, some in-season monitoring may be necessary. One of the more common in-season methods is plant tissue analysis.

Plant tissue analysis is the sampling of a diagnostic plant part and measuring of the nutrient concentration in the tissue or the sap from the tissue. Nutrient deficiencies identified by tissue testing can be corrected in some situations or direct corrective action for future crops. While a range of nutrient concentrations is often provided to help guide the plant nutrient analysis interpretation, adequate concentrations can vary with crop, variety, plant part sampled, growth stage when sampled, environment, geographic area, and other factors. Collecting tissue and soil samples from both "poor" and "good" areas of a field often helps to diagnosis nutrient deficiencies.

Other in-season tools used to assess nutrient status of plants employ "indirect" methods of determination. An indirect, or nondestructive, measurement of plant nutrient content can provide information that can help guide in-season fertilizer applications without needing to collect, process, and analyze plant or soil samples. One such tool is the leaf color chart (LCC). First developed for use in southeast Asian rice production systems, the LCC is a hand-held card that allows growers to make real-time decisions regarding N requirements on a site-specific basis by comparing their crop to colors on the card that range from N deficient to excessive leaf N content. One of two methods employing a LCC is typically used to determine in-season N rate requirements in rice. One involves a pre-determined program of N application rates and timings. Leaf color chart measurements are made at critical growth stages, and the pre-determined N rates are adjusted up- or downwards depending on leaf color. The other method employs a real-time approach. Using this approach, a fertilizer application is made whenever the LCC value falls below an established critical level. Leaf color charts have also been evaluated for making in-season fertilizer rate decisions in wheat, maize, and sugarcane.

Another indirect measurement-based tool for monitoring in-season nutrient status is the chlorophyll meter. A chlorophyll meter provides a quantitative measure of the "greenness" of the plant leaf, which is indicative of chlorophyll content. When clipped onto a leaf, the meter provides an indexed reading, which is correlated with leaf N content. These readings can then be compared with research-based critical levels, or in-field reference (non-nutrient limited) areas, to determine an N fertilizer requirement. The meters are much more sensitive to subtle changes in color than the eye, and deficiencies can be detected much earlier in the season.

A strategy for determining in-season N fertilizer application rates that is rapidly gaining popularity is the use of optical sensors. Most optical sensors currently being used for making N rate decisions are active sensors, meaning they have an internal light source, rather than using sunlight. The sensors emit light at specific wavelengths and measure the portion of the light reflected back to the sensor. The amount of reflected light is correlated with plant characteristics such as greenness (much like a chlorophyll meter) and biomass.

One type of sensor that has been used to make on-the-go adjustments in N rate is the GreenSeeker. This sensor measures reflected red and near-infrared light to calculate a vegetation index [Normalized Difference Vegetation Index (NDVI)], which has been correlated with leaf area index, leaf N content, and crop yield. The NDVI values measured by the sensors are entered into an algorithm using an on-board computer and an N rate requirement is calculated. Nutrient rate algorithm components vary by region, but most are fairly sophisticated, taking into consideration several factors. Some of the factors used in various N rate algorithms include in-field reference measurements that are usually collected from "nonlimiting" or "nutrient-rich" areas established earlier in the growing season to compare with the target measurements at the time of fertilization; consideration of spatial and temporal conditions that affect crop growth, soil nutrient availability, and overall yield potential; and estimates of crop responsiveness to applied fertilizer that account for other nutrient sources such as manures or early-season mineral fertilizer applications.

Conclusion

The best approach for determining fertilizer rate requirement will be site-specific and depend on several factors including soil, climate, economics, labor supply, and logistics. The specifics will be different for each site, crop, and grower, but the principles are the same for all. Selecting the "right" rate for the most efficient and effective use of fertilizer requires that several factors be considered including:

- Plant demand for nutrients
- Soil nutrient supply
- Other available sources of nutrients
- Season-to-season variability in nutrient demand
- In-season changes in nutrient demand

Just as this list is not all inclusive, the topics covered in this article are only some of the tools available for making fertilizer rate decisions. It is also important to state again that rate is only one component of 4R nutrient stewardship. It is linked completely with and dependent on the other fertilizer "rights"—source, time, and place. It is the interconnectivity of 4R nutrient stewardship that can help meet the economic, environmental, and social goals of sustainable agricultural systems. ■

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July–August 2009 Self-Study Quiz

Selecting the right fertilizer rate: A component of 4R nutrient stewardship (no. SS 03920)

This quiz is worth 1 CEU in Nutrient Management. A score of 70% or higher will earn CEU credit. The International CCA program has approved self-study CEUs for 20 of the 40 CEUs required in the two-year cycle. An electronic version of this test is also available at www.certifiedcropadviser.org. Click on "Self-Study Quizzes to Earn CEUs."

Directions

1. **After carefully reading the article, answer each question by clearly marking an "X" in the box next to the best answer.**
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1. When is it important to select an appropriate fertilizer application rate?

- ❑ a. When crop value is high.
- ❑ b. When potential environmental consequences of misapplication of nutrients are evident.
- ❑ c. When fertilizer price is high.
- ❑ d. It is always important.

2. Total crop nutrient requirement is

- ❑ a. the total amount of nutrients removed in the harvested crop.
- ❑ b. the same for all crops.
- ❑ c. the total amount of nutrients that will be taken up by the crop during the growing season.
- ❑ d. a good way to determine fertilizer application rate.

3. The soil-testing process is based on

- ❑ a. collecting a representative soil sample.
- ❑ b. appropriate extraction techniques.
- ❑ c. correlation of soil test values with plant nutrient uptake.
- ❑ d. all of the above.

4. Two main approaches to utilizing soil test results for the development of fertility programs are

- ❑ a. nutrient sufficiency and build maintenance.
- ❑ b. correlation and calibration.
- ❑ c. buildup and maintenance.
- ❑ d. nutrient sufficiency and critical levels.

5. The nutrient sufficiency approach does not consider

- ❑ a. future soil test values.
- ❑ b. profitability in the year of application.
- ❑ c. critical soil test levels.
- ❑ d. all of the above.

6. A major difficulty in making accurate N fertilizer recommendations is

- ❑ a. estimating soil N supply.
- ❑ b. predicting losses of soil and fertilizer N.
- ❑ c. determining N availability of animal manures and other N sources.
- ❑ d. all of the above.

Quiz continues next page

7. Which of the following statements is true?

- ❑ a. Crop yields are usually consistent from year to year in a given environment.
- ❑ b. Crop response to N fertilizer applications varies from year to year.
- ❑ c. A high-yielding crop always requires high N fertilizer rates.
- ❑ d. None of these statements are true.

8. Which of the following is an indirect method of determining plant nutrient content?

- ❑ a. Soil test.
- ❑ b. Leaf color chart.
- ❑ c. Tissue test.
- ❑ d. Petiole sap analysis.

9. Optical sensors measure

- ❑ a. reflected light.
- ❑ b. plant nutrient content.
- ❑ c. leaf area index.
- ❑ d. plant N requirement.

10. Which of the following statements is false?

- ❑ a. 4R nutrient stewardship can help meet sustainability goals.
- ❑ b. The right rate depends on the other fertilizer rights—source, time, and place.
- ❑ c. Fertilizer rate is the most important component of 4R nutrient stewardship.
- ❑ d. The best approach for determining the right fertilizer rate is site-specific and depends on several factors.

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