Selecting the Right Nutrient Rate: Basis for Managing Fertilization Programs

Bielinski M. Santos¹

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SUMMARY. Selecting the “right” nutrient rate for fertilization programs is one of the most important decisions growers face. On one hand, increasing fertilizer prices and environmental concerns have increased the awareness of accurately managing fertilization programs, thus reducing fertilizer amounts during cropping seasons. By contrast, many growers fear not obtaining the desired crop performance and economic returns, especially when fertilization is assumed as “inexpensive insurance” to improve yields, thus leading to overfertilization. The objective of this paper was to provide general principles for selecting and monitoring the right nutrient rate within the framework of the “4R” nutrient management concept (right rate, right source, right placement, and right timing) to protect environmental quality while maintaining productivity. Some methodologies to determine, apply, and adjust fertilization rates during the growing season were discussed, including in-season monitoring procedures, such as petiole sap testing, plant diagnostic analysis, leaf color evaluation, and plant growth index.

Nutrient rates: What is “right”?

Minimizing nutrient losses and increasing crop utilization is a desirable goal for the fertilizer industry, grower associations, and environmental groups throughout the world. One tool to achieve that goal is the use of fertilization best management practices that allow improving agricultural environmental and economic sustainability of crops (Roberts, 2007). The implementation of these best management practices is tightly linked to four aspects of nutrient management for crops, which are defined as the “4R” nutrient management concept: “right” rate, source, placement, and timing (Bruulsema et al., 2009; Roberts, 2007). Therefore, the objective of this paper was to provide general principles for selecting and monitoring the right nutrient rate within the framework of the “4R” of nutrient management concept to protect environmental quality while maintaining productivity (Bruulsema et al., 2009).

It is widely recognized that having a single nutrient rate recommendation

for a given crop is unrealistic and unpractical because of the relative nature of this practice across different locations, soils, seasons, cultivars, fertilization practices, and production techniques. Instead, the appropriateness of a given nutrient rate, and therefore a fertilization program, depends on factors within the farm (e.g., irrigation and available equipment), as well as exogenous conditions (e.g., fertilizer prices and environmental regulations). The “right” nutrient rate needed during a cropping season is the summation of the crop requirement and the nutrient losses in the environment and the soil. The crop nutrient requirement is defined as the amount of a given nutrient needed to achieve the desired growth and development. This requirement will depend intrinsically on the crop type and its yield potential (Phillips et al., 2009), and it could be supplied from three main sources of nutrients: 1) atmospheric deposition and inputs, 2) the natural soil supply, and 3) the applied fertilizers. The former is important in the case of the essential elements carbon (C), hydrogen, and oxygen, which are in most cases under non-limiting conditions, and for sulfur (S), deposition is in the form of acid rain (Ceccotti et al., 1998). Nevertheless, it is widely understood that the soil supply and fertilizers comprise the bulk of the amounts needed to satisfy the crop nutrient requirement.

The key for designing an effective fertilization program is to accurately determine the amounts of fertilizer needed to supplement the soil nutrient supply potential. However, in some cases, the amount of fertilizer applied could be higher than needed by the crop to replenish a share of the natural soil nutrient pool (Phillips et al., 2009). Obviously, the nature of a given soil will have a profound influence on the amounts of nutrient available for plant absorption. Soils with considerable organic matter content and cation exchange capacity will tend to be richer, acting as nutrient reservoirs, than highly weathered and degraded soils.

On the other hand, the determination of the “right” nutrient rate will depend heavily on the correct assessment of the possible nutrient losses. These losses refer to reduced nutrient availability because of biological and mineral immobilization, volatilization, leaching, and runoff. Biological and mineral immobilization occurs when soil microbes, including bacteria, use C atoms as an energy source or as a building block for their structures. A typical example of this process is nitrogen (N) fixation by microbes in the presence of a high C to N ratio (Bengtsson et al., 2002), whereas mineral immobilization takes place when nutrients become unavailable because of strong adsorption to the cation exchange capacity complex such as potassium (K) ions in expandable clay fields, or by forming insoluble compounds, such as phosphorus (P) combining with aluminum forming relatively insoluble aluminum phosphates. Volatilization of ammonia (NH₃) and nitrous oxide (N₂O) are two cases of N losses in soils because of microbial activity (Reddy et al., 1979; Snyder et al., 2007). Atmospheric concentrations of N₂O have risen steadily during the last century, and the proportion of cropland N₂O emissions directly induced by fertilizer is estimated at about 23% worldwide (Snyder et al., 2007). Nutrient leaching and runoff are two physically driven processes that could cause severe nutrient depletion in agricultural regions. Hong et al. (2007) indicated that application of N fertilizer has increased dramatically in recent decades, and it is projected to continue because of the pressure to produce more food in less land. The environmental

Gulf Coast Research and Education Center, IFAS, University of Florida, 14625 County Road 672, Wimauma, FL 33598

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¹Corresponding author. E-mail: bmsantos@ufl.edu.

consequences of this increase are high nitrate (NO_3) losses from soils to the environment (Matson et al., 1998). Heavy NO_3 leaching to groundwaters is one of the main causes for rivers and lakes eutrophication. In Florida, NO_3 levels in bodies of water have increased two- to threefold over the past 20 years, which impairs aquatic life ecosystems (Finkl and Charlier, 2003; Florida Department of Environmental Protection, 2008). In the midwestern United States and elsewhere in the world, NO_3 leaching has also been indicated as a source of well water contamination (Schlesinger et al., 2006). Runoff of P and S may occur from fertilized fields and have been reported as another source of pollution into groundwaters and lakes (Bates et al., 2002; Moore et al., 2000). Fertilizer management practices that enhance crop absorption of available and applied nutrients are the basis for sustainability production systems and the efficacy of fertilization programs. This is directly linked to the amount of nutrients applied for crop production.

Methodologies to assess nutrient rates and status in crops

There are several methodologies to assess nutrient rates and status in crops. These methods range from very simplistic to sophisticated approaches. Regardless of the chosen methodology, none provide a 100% accurate prediction or adjustment of the nutrient rate and, in many instances, a combination is preferred for different essential elements. Additionally, the nature and functions of each one of the 17 essential elements for crop production along with the specific conditions of the farm and crop will dictate the necessary adjustments of the applied nutrient rates, and thus the fertilization program. Furthermore, a clear knowledge of these conditions (e.g., drip vs. sprinkler irrigation, mulched vs. bare ground beds) also will be tightly related to the other components of “right nutrient stewardship”: nutrient placement, source, and timing.

There are two basic phases for assessment of “right” nutrient rates for specific locations and crops: 1) determination and 2) application and adjustment of the fertilization program.

During the determination phase, multiple studies in diverse locations must be conducted under somewhat similar conditions for the target crop. This procedure uses increasing rates of the given nutrient and evaluates crop performance over a wide range of fertilizer doses. The objective should be to determine an approximate fertilizer range needed to attain that desired crop performance. Once this range is obtained, then it should be sufficiently calibrated and verified under normal and large-scale growing conditions to consider it a “recommended” nutrient rate. The investigator should be careful on drawing conclusions too broad from combining data of multiple studies, which often are carried out by different researchers in other locations. A typical example of this misconception is the “relative yield” methodology, which equals the highest obtained yield to 100% and expresses the response to other rates proportionally to that value. This method is only useful when considering results of studies that are closely related.

The application and adjustment phase is based on two diverging approaches: the “one-size-fits-all” recommendation, and the “application-monitoring-adjustment” (AMA) method. The former recommends a simple rate or a range of rates to be applied in the crop under a certain set of conditions. It is easy to implement and inexpensive, whereas it lacks environmental sustainability and does not consider changing crop conditions. The AMA method relies on the application of recommended rates, followed by monitoring the nutrient status of the crop, and the adjustment of the fertilization practice if needed. This approach is the most accurate and environmentally friendly, but it requires intensive supervision and equipment investment for monitoring nutrient status. The most common methods to assess the nutritional situation of crops are: 1) leaf color evaluation, 2) growth index, 3) petiole sap concentration, and 4) diagnostic plant part analysis. These methods could be used alone or in conjunction with the others to manage programs for crops that have multiple moments of fertilizer application (e.g., drip-applied nutrients and split “side-dressing” applications). The leaf color comparison uses either a color chart or leaf greenness to determine deficiencies of nutrients,

especially N. The leaf color chart is a handheld card that allows making instantaneous decisions regarding N requirements by comparing crop leaf colors that range from deficient to excessive content (Alam et al., 2005; Phillips et al., 2009; Singh et al., 2002). This is especially useful in monocot crops, such as rice (*Oryza sativa*), wheat (*Triticum aestivum*), and corn (*Zea mays*). On the other hand, leaf greenness is measured with a handheld color meter, which provides a numerical soil plant analysis development value, usually ranging from 0 (white) to 80 (dark green). This measurement is well correlated to chlorophyll content or N status in certain crops (Azia and Stewart, 2001; Himelrick et al., 1993; Ruiz-Espinoza et al., 2010). Growth index is an indirect measurement of plant biomass production and performance and uses either plant canopy volume or stem elongation as basis for calculations (Latter and Harrison, 1988). It is widely used in forestry, ornamentals, and other perennial species. It may not be the most accurate procedure for vegetable crops because of their herbaceous nature.

Petiole sap concentration is a real-time measurement of ions flowing through the plant vascular system and serves as a quick diagnostic tool for determining deficiencies and adjusting fertilization programs, especially for NO_3 and K (Hochmuth, 1994). These tests are accurate and inexpensive, but sufficiency values must be determined and validated for each crop before analysis. Also, the considered species has to be herbaceous enough to allow easy squeezing of petioles for sap extraction. The use of diagnostic plant parts has been the most typical “in-season” diagnostic method for decades. The most recently opened mature leaf is often collected, dried, and ground for nutrient analysis, especially that of N, P, K, Mg, and micronutrients. Some of the advantages of this method are its accuracy and broad range of nutrients that can be detected with one sample. However, it needs to be performed before or when deficiencies are barely suspected because the samples need to be dried and may be sent to commercial laboratories for analysis. A potential limitation of this method is that the whole process could last from 5 to

15 d, which could be too late to correct deficiencies.

Final considerations

The application of the appropriate nutrient rate is critical to achieve the desired crop performance and to reduce environmental pollution risks. The recent increase of fertilizer prices has contributed to improve awareness of the need to design accurate nutritional programs. Education of growers is critical to improve management and adjustment of fertilization programs during the cropping season, regardless of the selected nutrient monitoring procedure. Additionally, the relationship of nutrient rates with nutrient sources, placement, and timing, as well as with other cultural practices such as irrigation, cannot be overlooked. Efficient water management directly improves nutrient absorption and plays a major role on the reduction of nutrient runoff and leaching.

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