**Management Options for Increasing Nutrient Use Efficiency**

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**Introduction**

The awareness of an interest in improved nutrient use efficiency has never been greater. Driven by a growing public belief that crop nutrients are excessive in the environment and farmer concerns about rising fertilizer prices and stagnant crop prices, the fertilizer industry is under increasing pressure to improve nutrient use efficiency (Dibb 2000). However, efficiency can be defined in many ways and is easily misunderstood and misrepresented. Definitions differ, depending on the perspective. Environmental nutrient use efficiency can be quite different than agronomic or economic efficiency and maximizing efficiency may not always be advisable or effective. Agronomic efficiency may be defined as the nutrients accumulated in the aboveground part of the plant or the nutrients recovered within the entire soil-crop-root system (Fageria *et al*. 2008). Economic efficiency occurs when farm income is maximized from the proper use of nutrient inputs, but it is not easily predicted or always achieved because future yield increases, nutrient costs, and crop prices are not known in advance of the growing season (Tilman 2000). Environmental efficiency is site-specific and can only be determined by studying local targets vulnerable to nutrient impact (Ghosh *et al.).* Nutrients not used by the crop are at risk of loss to the environment, but the susceptibility of loss varies with the nutrient, soil and climatic conditions, and landscape. In general, nutrient loss to the environment is only a concern when fertilizers or manures are applied at rates above agronomic need. Though the perspectives vary, agronomic nutrient use efficiency is the basis for economic and environmental efficiency. As agronomic efficiency improves, economic and environmental efficiency will also benefit. In the past decades, an increase in the consumption of nitrogen and phosphorus fertilizers has been observed globally. By 2050, nitrogen fertilization is expected to increase by 2.7 times and phosphorus by 2.4 times on a global scale (Tilman 2001). Nonetheless, increased fertilizer application rates exhibit diminishing marginal returns such that further increases in fertilizer were unlikely to be equally efficient in increasing grain yield as in the yesteryear. It is calculated that today only 30–50 % of applied nitrogen fertilizers (Samuel 2002; Ladha *et al*. 2005) and 45 % of phosphorus fertilizers (Smil 2000) are used for crops. For example, only 20–60 % of nitrogen fertilizers used in intensive wheat production is held up by the crop, 20–60 % remains in the filth, and approximately 20 % is lost to the environment (Pilbeam 1996). The phosphorus-use efficiency can be as high as 90 % for well-managed agroecosystems (Syers *et al*. 2008) or as low as 10–20 % in highly phosphorus-fixing soils (Bolland and Gilkes 1998).

**Nutrient Use Efficiency Terminology**

Nutrient use efficiency can be expressed in several ways. Mosier *et al*. (2004) described four agronomic indices commonly used to describe nutrient use efficiency: partial factor productivity (PFP, kg crop yield per kg nutrient applied); agronomic efficiency (AE, kg crop yield increase per kg nutrient applied); apparent recovery efficiency (RE, kg nutrient taken up per kg nutrient applied); and physiological efficiency (PE, kg yield increase per kg nutrient taken up). Crop removal efficiency (removal of nutrient in the harvested crop as a percent of nutrient applied) is also commonly used to explain nutrient efficiency. Available data and objectives determine which term best describes nutrient use efficiency. Fixen (2005) provides a good overview of these different terms with examples of how they might be applied. Understanding the nomenclature and the setting in which it is applied is critical to prevent misinterpretation and misunderstanding. Recovery of 37 % in the aboveground biomass of applied N is disturbingly low and suggests that N may pose an environmental risk. Simulating the grain contains 56 % of the aboveground N, a typical N harvest index; only 21 % of the fertilizer N applied is transferred in the texture. A recovery of 21 % as calculated from a single-year response, recovery in the grain or 100 % as estimated from the total uptake (soil N + fertilizer N) of N, assuming the land can carry on to supply N in the long term? The result cannot be recognized unless the long-term dynamics of N cycling are understood. Fertilizer nutrients applied, but not struck up by the crop, are vulnerable to losses from leaching, erosion, and denitrification or volatilization in the case of N, or they could be temporarily immobilized in soil organic matter to be published at a posterior time, all of which impact apparent use efficiency. Dobermann *et al*. (2005) preceded the term system-level efficiency to account for the contributions of added nutrients to both crop uptake and soil nutrient supply.

**Optimizing Nutrient Use Efficiency**

The plant food industry supports applying nutrients at the proper pace, right time, and in the right position as a best management practice (BMP) for achieving optimum nutrient efficiency.

**Right Rate**- Most crops are location and season-specific depending on cultivar, management practices, climate, and so on, and hence it is critical that realistic yield goals are made and that nutrients are used to match the target output. Over- or under-application will result in reduced nutrient use efficiency or losses in fruit and crop quality. Soil testing remains one of the most potent instruments available for defining the nutrient supplying capacity of the land, but to be useful for making appropriate fertilizer recommendations, good calibration data are likewise necessary. Alas, soil testing is not useable in all areas of the world because reliable laboratories using methodology appropriate to local soils and crops are inaccessible or calibration data relevant to current cropping systems and yields are lacking. Other techniques, such as omission plots, are proving useful in limiting the quantity of plant food required for achieving a return target (Witt and Dobermann 2002). In this method, N, P, and K are applied at sufficiently high rates to ensure that production is not determined by an insufficient supply of the added nutrients. Target yield can be determined from plots with unlimited NPK. One nutrient is omitted from the plots to determine a nutrient-limited production. For lesson, an N omission plot receives no N, but sufficient P and K fertilizer to insure that those nutrients are not limiting yield. The difference in grain yield between a fully fertilized plot and an N omission plot is the shortfall between the crop demand for N and indigenous supply of N, which must be met by fertilizers. Nutrients removed in crops are also a significant consideration. Unless nutrients removed in harvested grain and crop residues are replaced, soil fertility will be consumed.

**Right Time**- Greater synchrony between crop demand and nutrient supply is necessary to improve nutrient use efficiency, especially for N (Johnson *et al*. 1997). Split applications of N during the farming season, rather than a single, large application prior to embedding, are recognized to be efficient in increasing N use efficiency (Cassman *et al*. 2002). Tissue testing is a well-known method used to assess N status of producing crops, but other diagnostic instruments are too usable. Chlorophyll meters have proven useful in fine-tuning in-season N management (Francis and Piekielek 1999), and leaf color charts have been highly successful in guiding split N applications in rice and now maize production in Asia (Witt *et al*. 2005). Precision farming technologies have introduced, and now commercialized, on-the-go N sensors that can be coupled with variable rate fertilizer applicators to automatically correct crop N deficiencies on a site-specific basis. Some other approach to sync the release of N from fertilizers with crop demand is the use of N stabilizers and controlled-release plant foods. Nitrogen stabilizers (e.g., nitrapyrin, DCD [dicyandiamide], NBPT [n-butyl-thiophosphorictriamide]) inhibit nitrification or urease activity, thereby slowing the conversion of the fertilizer to nitrate (Havlin *et al*. 2005). When soil and environmental conditions are favorable for nitrate losses, treatment with a stabilizer will often increase fertilizer N efficiency. Controlled-release plant foods can be grouped into compounds of low solubility and coated water-soluble plant foods. Most slow-release plant foods are more expensive than water-soluble N fertilizers and have traditionally been used for high-value horticulture crops and turf grass. Nevertheless, technology advances have cut down manufacturing costs were controlled-release fertilizers are available for use in corn, wheat, and other commodity grains (Blaylock *et al*. 2005). The most promising for widespread agricultural use are polymer-coated products, which can be projected to release nutrients in a contained way. Nutrient release rates are kept in line by manipulating the attributes of the polymer coating and are generally predictable when average temperature and moisture conditions can be calculated.

**Right Place**- Application method has always been vital in ensuring fertilizer nutrients are utilized efficiently. Finding the proper position is equally important as finding the correct application rate. Numerous placements are available, but most generally involve surface or subsurface applications before or later embedding. Prior to planting, nutrients can be passed around (i.e., applied uniformly on the soil surface and may or may not be incorporated), employed as a band on the surface, or employed as a subsurface band, usually 5–20 cm deep. Applied at planting, nutrients can be rung with the seed, below the seed, or below and to the side of the source. After planting, the application is ordinarily restricted to N and placement can be a top dress or a subsurface sidedress. In general, nutrient recovery efficiency tends to be higher with banded applications because less contact with the soil lessens the opportunity for food loss due to leaching or fixation reactions. Placement decisions depend on the crop and soil conditions, which interact to determine the nutrient intake and availability. Plant nutrients rarely work in isolation. Interactions among nutrients are important because a deficiency of one restricts the uptake and use of another. Numerous studies have demonstrated those interactions between N and other nutrients, primarily P and K, impact crop yields, and N efficiency. Equal and balanced application of plant food nutrients is one of the most common exercises for improving the efficiency of N fertilizer and is every bit in force in both growing and developed nations. In a recent review based on 241 site-years of experiments in China, India, and North America, balanced fertilization with N, P, and K increased first-year recoveries an average of 54 % compared to recoveries of only 21 % where N was used alone (Fixen *et al*. 2005). An assortment of exercises and improvements are suggested in the scientific literature to increase nutrient utilization efficiency in farming, such as the acceptance of multiple cropping systems, improved crop rotations, or intercropping. Because of escalating prices of chemical plant foods, the nutrient uptake and utilization in field crops should be more efficient to make decreases in the price of production and achieve larger profit for resource-poor farmers. To get at these targets, it is important to realize and enhance nutrient utilization efficiency. Agroforestry, which includes trees in a cropping system, may improve pest control and increase nutrient- and water-use efficiency. Likewise, cover crops or reduced tillage can reduce nutrient leaching. Nutrient use efficiency is increased by appropriately applying fertilizers and by better matching temporal and spatial nutrient supply with plant uptake (Tilman *et al*. 2002). Applying fertilizers during periods of highest crop uptake, at or near the point of uptake (roots and leaves), as well as in smaller and more frequent applications have the potential to reduce losses while maintaining or improving crop yield quantity and quality (Cassman *et al*. 2002). However, controlled release of nitrogen (e.g., via using nitrogen inhibitors) or technologically advanced systems such as precision farming appear to be too expensive for many farmers in developing countries (Singh 2005). Many of the aforementioned management practices can be held up by targeting research (e.g., on improving efficiency and minimizing losses from both inorganic and organic nutrient sources; on improvements in timing, pacing, and splitting of fertilizer applications, as well as by judicious investments, for exemplar, in soil testing).

**Different Computation Methods**

**Nitrogen Fertilizer Use Efficiency**

In isotopic-aided fertilizer experiments, a labeled fertilizer is added to the soil and the amount of fertilizer nutrient that a plant has taken up is determined. In this way, different fertilizer practices (placement, timing, sources, and so forth) can be considered.

1.Percent nitrogen derived from fertilizer (Ndff):

The first parameter to be determined when studying the fertilizer consumption by a crop by means of the isotope techniques is the fraction of the nutrient in the plant derived from the (labeled) fertilizer, i.e., fdff (fraction derived from fertilizer).

Y= S/F× 100;

where Y = Amount of labeled fertilizer N in the sample (%Ndff)

S = Atom % 15N excess in sample

F = Atom % 15N excess in the labeled fertilizer

2. Uptake of nitrogen by plants: The grain and straw uptake of nitrogen is calculated as follows:

Uptake by grain or straw (kg/ha) = %N content in grain or straw grain or straw yield (kg/ha)/100

3. N use efficiency (NUE) = Total N uptake (kg/ha) ×% Ndff/ Rate of fertilizer N applied (kg/ha)

4. Residual fertilizer N in soil (kg ha-1) = Total N in soil (kg/ha) × % Ndff/100

5. Unaccounted fertilizer N (%) =100-[fertilizer - N recovery% + residual fertilizer - N in soil]

15N as tracer studies have yielded valuable information on the aspects of:

• Availability of native soil N to crops

• Influence of N carriers associated with the plant recovery studies

• Impact of immobilization in soil for plant consumption

• Studies of biological exchange in which mineralization and immobilization proceed simultaneously in the same organization

• Denitrification loss in or from soil

• Influence of added available N on mineralization

• The relative uptake of NH4 + and NO3 ions by crop plants and microorganisms

• Placement position in root zone on availability of N fertilizer to crops

• Balance studies as influenced by time and method of N application

**Phosphorus Fertilizer Use Efficiency**

Generally, phosphorus losses are largely from erosion and surface runoff (Shepherd and Withers 2001). Yet, P leaching can occur where soil P sorption is low, as in sandy soils and with the repeated P fertilizer application. The problem of P leaching is accelerated under high input P, and with frequent and heavy rain events (Sims *et al*. 1998). In a sandy loam soil with low P sorption saturation, P leaching was higher than from a clay (Djodjic *et al*. 2004). Phosphorus from inorganic fertilizer can be leached to beneath 1.1 m soil depth (Eghball *et al*. 1996).

**Nutrient Efficient Plants**

Soil Science Society of America (1997) defined a nutrient efficient plant as a plant that absorbs, translocates, or utilizes more of a specific nutrient than another plant under conditions of relatively low nutrient availability in the soil or growth media. In the twenty-first century, nutrient efficient plants will take on a major part in increasing crop yields compared to the twentieth century, primarily due to limited land and water resources available for crop yield, higher cost of inorganic fertilizer inputs, declining trends in crop yields globally, and increasing environmental concerns. Nutrient efficient plants are specified as those plants, which create higher returns per unit of nutrient, used or absorbed than other plants (standards) under similar agroecological conditions (Fageria *et al*. 2008). During the last three decades, much research has been directed to distinguish and/or breed nutrient efficient plant species or genotypes/cultivars within species and to further understand the mechanisms of nutrient efficiency in crop plants. Yet, success in releasing nutrient efficient cultivars has been fixed. The principal causes for limited success are that the genetics of plant responses to nutrients and plant interactions with environmental variables are not easily read. The complexity of genes involved in nutrient utilization efficiency for macro- and micronutrients and limited collaborative efforts between breeders, soil scientists, physiologists, and agronomists to evaluate nutrient efficiency issues on a holistic basis have hampered progress in this field. Hence, during the twenty-first century agricultural scientists have tremendous challenges, as well as opportunities, to develop nutrient efficient crop plants and to develop best management practices that increase the plant efficiency for utilization of applied fertilizers. During the twentieth century, breeding for nutritional traits has been suggested as a strategy to improve the efficiency of fertilizer use or to receive higher yields in low-input farming systems. This scheme should continue to get top priority during the twenty-first century for developing nutrient efficient crop genotypes (Fageria *et al*. 2008).

**Conclusion**

Improving nutrient efficiency is a desirable goal and fundamental challenge facing the fertilizer industry and farming in general. The opportunities are there and tools are available to achieve the job of ameliorating the efficiency of applied nutrients. Nevertheless, we must be cautious that improvements in efficiency do not occur at the expense of the farmers’ economic viability or the surroundings. Wise application of fertilizer BMPs, right rate, right time, right place, and right agronomic practice targeting both high yields and nutrient efficiency will benefit farmers, society, and the environment alike.

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