Soil and Input Management Options for Increasing Nutrient Use Efficiency

B.N. Ghosh, Raman Jeet Singh, and P.K. Mishra

Abstract

Public interest and awareness of the need for improving nutrient use efficiency is great, but nutrient use efficiency is easily misunderstood. Four indices of nutrient use efficiency are reviewed, and an example of different applications of the terminology shows that the same data set might be used to calculate a fertilizer N efficiency of 21 or 100 %. Fertilizer N recovery efficiencies from researcher-managed experiments for major grain crops range from 46 to 65 %, compared to on-farm N recovery efficiencies of 20–40 %. Fertilizer use efficiency can be optimized by fertilizer best management practices that apply nutrients at the right rate, time, and place and accompanied by the right agronomic practices. The highest nutrient use efficiency always occurs at the lower parts of the yield response curve, where fertilizer inputs are the lowest, but effectiveness of fertilizers in increasing crop yields and optimizing farmer profitability should not be sacrificed for the sake of efficiency alone. There must be a balance between optimal nutrient use efficiency and optimal crop productivity.

Keywords

Balanced fertilization • Fertilizer best management practices • Nitrogen efficiency • Right rate • Right time • Right place

1 Introduction

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

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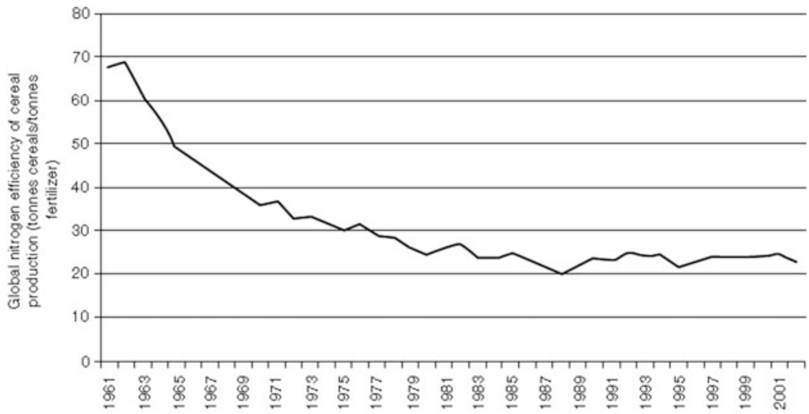

Fig. 1 Global nitrogen fertilizer efficiency of cereal production (annual global cereal production in tonnes divided by annual global nitrogen fertilizer production in tonnes for domestic use in agriculture) (*Source*: Tilman et al. 2002)

advisable or effective. Agronomic efficiency may be defined as the nutrients accumulated in the above-ground 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 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. 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 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). However, increased fertilizer application rates exhibit diminishing marginal returns such that further increases in fertilizer are unlikely to be as effective in increasing cereal yield as in the past. A declining trend in global nitrogen efficiency of crop production (annual global cereal production divided by annual global nitrogen application) is shown in Fig. 1 (Tilman et al. 2002). It is estimated that today only 30–50 % of applied nitrogen fertilizers (Smil 2002; Ladha et al. 2005) and 45 % of phosphorus fertilizers (Smil 2000) are used for crops. For example, only 20–60 % of nitrogen fertilizers applied in intensive wheat production is taken up by the crop, 20–60 % remains in the soil, 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).

2 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

Table 1 Fertilizer N efficiency of maize from 56 on-farm studies in north central USA

Average optimum N fertilizer rate, kg ha^{-1}	103
Fertilizer N recovered in the crop, kg ha^{-1}	38
Total N taken up by crop, kg ha^{-1}	184
N removed in the harvested grain, kg ha^{-1}	103
N returned to field in crop residue, kg ha^{-1}	81
Crop recovery efficiency (38 kg N recovered/ 103 kg N applied), %	37
Crop removal efficiency (103 kg N applied/103 kg N in grain), %	100

Cassman et al. (2002), source of data, Bruulsema et al. (2004), source of calculations

removal efficiency (removal of nutrient in harvested crop as 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 terminology and the context in which it is used is critical to prevent misinterpretation and misunderstanding. For example, Table 1 shows the same maize data from the north central USA can be used to estimate crop recovery efficiency of nitrogen (N) at 37 % (i.e., crop recovered 37 % of added N) or crop removal efficiency at 100 % (N removed in the grain was 100 % of applied N) (Bruulsema et al. 2004). Which estimate of nutrient use efficiency is correct? Recovery of 37 % in the above-ground biomass of applied N is disturbingly low and suggests that N may pose an environmental risk. Assuming the grain contains 56 % of the above-ground N, a typical N harvest index; only 21 % of the fertilizer N applied is removed in the grain. Such low recovery efficiency prompts the question – where is the rest of the fertilizer going and what does a recovery efficiency of 37 % really mean?

In the above data, application of N at the optimum rate of 103 kg ha^{-1} increased above-ground N uptake by 38 kg ha^{-1} (37 % of 103). Total N uptake by the fertilized maize was 184 kg ha^{-1}; 146 from the soil and 38 from the fertilizer. The N in the grain would be 56 % of 184, or 103 kg ha^{-1}: equal to the amount of N applied. Which is correct – a recovery of 21 % as estimated 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 soil can continue to supply N in long term? The answer cannot be known unless the long-term dynamics of N cycling are understood.

Fertilizer nutrients applied, but not taken 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 released at a later time, all of which impact apparent use efficiency. Dobermann et al. (2005) introduced the term system level efficiency to account for contributions of added nutrients to both crop uptake and soil nutrient supply.

3 Current Status of Nutrient Use Efficiency

A recent review of worldwide data on N use efficiency for cereal crops from researcher-managed experimental plots reported that single-year fertilizer N recovery efficiencies averaged 65 % for corn, 57 % for wheat, and 46 % for rice (Ladha et al. 2005). However, experimental plots do not accurately reflect the efficiencies obtainable on-farm. Differences in the scale of farming operations and management practices (i.e., tillage, seeding, weed and pest control, irrigation, harvesting) usually result in lower nutrient use efficiency. Nitrogen recovery in crops grown by farmers rarely exceeds 50 % and is often much lower. A review of best available information suggests average N recovery efficiency for fields managed by farmers ranging from about 20 to 30 % under rainfed conditions and 30 to 40 % under irrigated conditions.

Cassman et al. (2002) looked at N fertilizer recovery under different cropping systems and reported 37 % recovery for corn grown in the north central USA (Table 2). They found N recovery averaged 31 % for irrigated rice grown by Asian farmers and 40 % for rice under field-specific management. In India, N recovery

Table 2 Nitrogen fertilizer recovery efficiency by maize, rice, and wheat from on-farm measurements

Crop	Region	Number of farms	Average N rate, kg ha^{-1}	N recovery, %
Maize	North Central USA	56	103	37
Rice	Asia – farmer practice	179	117	31
	Asia – field-specific management	179	112	40
Wheat	India – unfavorable weather	23	145	18
	India – favorable weather	21	123	49

Cassman et al. (2002)

averaged 18 % for wheat grown under poor weather conditions, but 49 % when grown under good weather conditions. Fertilizer recovery is impacted by management, which can be controlled, but also by weather, which cannot be controlled. The above data illustrate that there is room to improve nutrient use efficiency at the farm level, especially for N.

While most of the focus on nutrient efficiency is on N, phosphorus (P) efficiency is also of interest because it is one of the least available and least mobile mineral nutrients. First-year recovery of applied fertilizer P ranges from less than 10 % to as high as 30 %. However, because fertilizer P is considered immobile in the soil and reaction (fixation and/or precipitation) with other soil minerals is relatively slow, long-term recovery of P by subsequent crops can be much higher. There is little information available about potassium (K) use efficiency. However, it is generally considered to have a higher use efficiency than N and P because it is immobile in most soils and is not subject to the gaseous losses that N is or the fixation reactions that affect P. First-year recovery of applied K can range from 20 to 60 %.

4 Optimizing Nutrient Use Efficiency

The fertilizer industry supports applying nutrients at the right rate, right time, and in the right place 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, etc., and so it is critical that realistic yield goals are established and that nutrients are applied to meet the target yield. Over- or under-application will result in reduced nutrient use efficiency or losses in yield and crop quality. Soil testing remains one of the most powerful tools available for determining the nutrient supplying capacity of the soil, but to be useful for making appropriate fertilizer recommendations, good calibration data is also necessary. Unfortunately, soil testing is not available in all regions 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 determining the amount of fertilizer required for attaining a yield target (Witt and Dobermann 2002). In this method, N, P, and K are applied at sufficiently high rates to ensure that yield is not limited 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 yield. For example, an N omission plot receives no N, but sufficient P and K fertilizer to ensure that those nutrients are not limiting yield. The difference in grain yield between a fully fertilized plot and an N omission plot is the deficit between the crop demand for N and indigenous supply of N, which must be met by fertilizers.

Nutrients removed in crops are also an important consideration. Unless nutrients removed in harvested grain and crop residues are replaced, soil fertility will be depleted.

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 growing season, rather than a single, large application prior to planting, are known to be effective in increasing N use efficiency (Cassman et al. 2002). Tissue testing is a well-known method used to assess N status of growing crops, but other diagnostic tools are also available. 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.

Another approach to synchronize release of N from fertilizers with crop need is the use of N stabilizers and controlled-release fertilizers. 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 fertilizers can be grouped into compounds of low solubility and coated water-soluble fertilizers.

Most slow-release fertilizers are more expensive than water-soluble N fertilizers and have traditionally been used for high-value horticulture crops and turf grass. However, technology improvements have reduced manufacturing costs where 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 designed to release nutrients in a controlled manner. Nutrient release rates are controlled by manipulating the properties of the polymer coating and are generally predictable when average temperature and moisture conditions can be estimated.

Right Place Application method has always been critical in ensuring fertilizer nutrients are used efficiently. Determining the right placement is as important as determining the right application rate. Numerous placements are available, but most generally involve surface or subsurface applications before or after planting. Prior to planting, nutrients can be broadcast (i.e., applied uniformly on the soil surface and may or may not be incorporated), applied as a band on the surface, or applied as a subsurface band, usually 5–20 cm deep. Applied at planting, nutrients can be banded with the seed, below the seed, or below and to the side of the seed. After planting, application is usually restricted to N and placement can be as a topdress 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 nutrient loss due to leaching or fixation reactions. Placement decisions depend on the crop and soil conditions, which interact to influence nutrient uptake 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. For example, data from a large number of multi-location on-farm field experiments conducted in India show the importance of balanced fertilization in increasing crop yield and improving N efficiency (Table 3).

Adequate and balanced application of fertilizer nutrients is one of the most common practices for improving the efficiency of N fertilizer and is equally effective in both developing and developed countries. 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

Table 3 Effect of balanced fertilization on yield and N agronomic efficiency

	Yield, t ha^{-1}			Agronomic efficiency, kg grain kg N^{-1}		
Crop	Control	N alone	+PK	N alone	+PK	Increase
Rice (wet season)	2.74	3.28	3.82	13.5	27.0	13.5
Rice (summer)	3.03	3.45	6.27	10.5	81.0	69.5
Wheat	1.45	1.88	2.25	10.8	20.0	9.2
Pearl millet	1.05	1.24	1.65	4.7	15.0	10.3
Maize	1.67	2.45	3.23	19.5	39.0	19.5
Sorghum	1.27	1.48	1.75	5.3	12.0	6.7
Sugarcane	47.2	59.0	81.4	78.7	227.7	150.0

Assumes a typical N harvest index of 56 %

Table 4 Effect of cropping system and fertility level on agronomic N use efficiency, physiological N use efficiency, apparent N recovery, N efficiency ratio, physiological efficiency index of N, and N harvest index in Bt cotton (mean data of 2 years)

Treatment	ANUE (kg seed cotton kg N^{-1})[a]	PNUE (kg seed cotton kg N^{-1})[b]	ANR (%)[c]	NER (kg DM kg N $uptake^{-1}$)[d]	PEIN (kg seed cotton kg N $uptake^{-1}$)[e]	NHI (%)[f]
Cropping system						
Sole cotton	–	–	–	46.25	17.0	38.0
Cotton + groundnut (1:3)	–	–	–	44.1	13.8	33.5
Fertility level (recommended dose of N: 150 kg ha^{-1})						
Control (0N)	–	–	–	55.8	15.1	35.3
100 % urea	8.2	11.8	69.3	41.7	13.7	32.9
75 % urea + 25 % FYM	9.5	11.44	83.3	40.0	13.4	37.6
50 % urea + 50 % FYM	5.27	13.17	40.0	50.0	14.5	42.6

[a](Yield in treatment plot-yield in control)/kg N applied
[b](Yield in treatment plot-yield in control)/(N uptake in treatment plot−N uptake in control)
[c](N uptake in treatment plot−N uptake in control)/kg N applied
[d](Dry matter yield/N accumulated at harvest)
[e](Seed cotton yield/N absorbed by biomass)
[f](N uptake by seed cotton/N uptake by whole plant)*100

recoveries of only 21 % where N was applied alone (Fixen et al. 2005).

A variety of practices and improvements are suggested in the scientific literature to increase nutrient use efficiency in agriculture, such as the adoption of multiple cropping systems, improved crop rotations, or intercropping. Because of escalating costs of chemical fertilizers, the nutrient uptake and utilization in field crops should be most efficient to cause reductions in the cost of production and achieve greater profit for resource-poor farmers. To arrive at these objectives, it is important to understand and enhance nutrient use efficiency. Singh and Ahlawat (2012) concluded that substitution of 25 % recommended dose of N (RDN) through FYM recorded the greatest Agronomic Use Efficiency (ANUE) and Apparent Nitrogen Recovery (ANR) followed by 100 % RDN through urea, whereas 50 % RDN substitution recorded the least ANUE and ANR (Table 4). Substitution of 50 % RDN followed by 25 % RDN substitution recorded the greatest Physiological Nitrogen Use Efficiency (PNUE), whereas 100 % RDN through urea recorded the least PNUE. Sole cotton maintained the greatest Nitrogen Efficiency Ratio (NER), Physiological Efficiency Index of Nitrogen (PEIN), and Nitrogen Harvest Index

(NHI) over cotton + groundnut. The greatest NER, PEIN, and NHI were recorded in the unfertilized control treatment followed by 50 % RDN substitution through FYM. The least NER, PEIN, and NHI were recorded with 25 % RDN substitution. The greatest ANUE and ANR by application of 25 % RDN substitution through FYM could be attributed to increase in seed cotton yield with combined application of inorganic and organic sources of N (Bandyopadhyay et al. 2009; Rao et al. 1991). Another reason might be that it improved N uptake of crop because of the increased humus content of soil, which would have slowed down release of ammoniacal N and its conversion to nitrates, thereby reducing the leaching loss of N (Silvertooth et al. 2001; Fritschi et al. 2004). High N availability in 25 % RDN substitution through FYM stimulated the development of larger plants and a more extensive root system capable of supplying the increased water and nutrients demanded by the larger plants. The cotton crop, therefore, drew from a larger pool of both added and indigenous N, which influenced the efficiency of fertilizer N (recovery vs. applied) as well overall N efficiency (Boquet and Breitenbeck 2000). The greatest NER, PEIN, and NHI were attributed to the better physical, chemical, and biological properties of soil that would have caused greater nutrient uptake and yield, leading to better fertilizer use efficiencies.

Mohanty et al. (1998) observed relatively higher NUE of rice with urea as compared with combined use of GM and urea up to 80 kg N ha^{-1} (Table 5). However, the trend was reverse at 120 kg N ha^{-1}.

Agroforestry, which includes trees in a cropping system, may improve pest control and increase nutrient- and water-use efficiency. Also, 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).

Table 5 Nitrogen use efficiency in rice through integrated nutrient management

Treatment	ANR(%) 1st rice	ANR(%) 2nd rice	AE 1st rice	PE 1st rice
		N0		
GM-N40 + N0	24.8	28.0	18.0	72.7
N40	43.3	44.9	23.5	54.5
GM-N40 + N40	35.6	35.7	15.5	43.5
N80	46.3	43.9	17.1	37.0
GM-N40 + N80	44.3	45.6	14.4	32.5
N120	31.8	30.8	10.3	31.4
GM-N40 + N120	34.4	38.7	9.7	28.2

Many of the aforementioned management practices can be supported by targeted research (e.g., on improving efficiency and minimizing losses from both inorganic and organic nutrient sources; on improvements in timing, placing, and splitting of fertilizer applications, as well as by judicious investments, for example, in soil testing).

4.1 Efficient Does Not Necessarily Mean Effective

Improving nutrient efficiency is an appropriate goal for all involved in agriculture, and the fertilizer industry, with the help of scientists and agronomists, is helping farmers work toward that end. However, effectiveness cannot be sacrificed for the sake of efficiency. Much higher nutrient efficiencies could be achieved simply by sacrificing yield, but that would not be economically effective or viable for the farmer, or the environment. This relationship between yield, nutrient efficiency, and the environment was ably described by Dibb (2000) using a theoretical example. For a typical yield response curve, the lower part of the curve is characterized by very low yields, because few nutrients are available or applied, but very high efficiency. Nutrient use efficiency is high at a low yield level, because any small amount of nutrient applied could give a large yield response. If nutrient use efficiency were the only goal, it would be achieved here in the lower part of the yield curve. However, environmental concerns would be significant because poor crop growth means less surface residues to protect the land from wind and water erosion and less root growth to build soil organic matter. As you move up the response curve, yields continue to increase, albeit at a slower rate, and nutrient use efficiency typically declines. However, the extent of the decline will be dictated by the BMPs employed (i.e., right rate, right time, right place, improved balance in nutrient inputs, etc.) as well as soil and climatic conditions.

The relationship between efficiency and effective was further explained when Fixen (2006) suggested that the value of improving nutrient use efficiency is dependent on the effectiveness in meeting the objectives of nutrient use, objectives such as providing economical optimum nourishment to the crop, minimizing nutrient losses from the field, and contributions to system sustainability through soil fertility or other soil quality components. He cited two examples. Saskatchewan data from a long-term wheat study where 3 initial soil test levels were established with initial P applications followed by annual additions of seed-placed P. Fertilizer P recovery efficiency, at the lowest P rate and at the lowest soil test level, was 30 %, an extremely high single-year efficiency. However, this practice would be ineffective because wheat yield was sacrificed.

The second example is from a maize study in Ohio that included a range of soil test K levels and N fertilizer rates. N recovery efficiency can be increased by reducing N rates below optimum yield that is sacrificed. Alternatively, yield and efficiency can be improved by applying an optimum N rate at an optimum soil test K level. Nitrogen efficiency was improved with both approaches but the latter option was most effective in meeting the yield objectives.

5 Different Computation Methods

5.1 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, etc.) can be studied.

1. ***Percent nitrogen derived from fertilizer (Ndff):***

   The first parameter to be determined when studying the fertilizer uptake 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).

$$Y = S/F \times 100,$$

where Y = Amount of labeled fertilizer N in sample (%Ndff)
S = Atom % ^{15}N excess in sample
F = Atom % ^{15}N excess in the labeled fertilizer

2. ***Uptake of nitrogen by plants:***

   The grain and straw uptake of nitrogen is calculated as follows:

$$\text{Uptake by grain or straw (kg/ha)} = \frac{\%\text{N content in grain or straw} \times \text{grain or straw yield (kg/ha)}}{100}$$

3. ***N use efficiency (NUE):***

$$= \frac{\text{Total N uptake (kg/ha)} \times \text{\% Ndff}}{\text{Rate of fertilizer N applied (kg/ha)}}$$

4. ***Residual fertilizer N in soil (kg ha^{-1}):***

$$= \frac{\text{Total N in soil (kg/ha)} \times \text{\% Ndff}}{100}$$

5. ***Unaccounted fertilizer N (%):***

$$= 100 - [\text{fertilizer} - \text{N recovery (\%)} + \text{residual fertilizer} - \text{N in soil}]$$

^{15}N 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 on plant uptake
- Studies of biological interchange in which mineralization and immobilization proceed simultaneously in the same system
- Denitrification loss in or from soil
- Influence of added available N on mineralization
- The relative uptake of NH_4^+ and NO_3^- 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

5.2 Phosphorus Fertilizer Use Efficiency

Generally phosphorus losses are largely from erosion and surface runoff (Shepherd and Withers 2001). However, P leaching can occur where soil P sorption is low as in sandy soils and with repeated P fertilizer application. The problem of P leaching is accelerated under high input P, and with frequent and heavy rainfall 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).

6 Nutrient Efficient Plants

Soil Science Society of America (1997) defined 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 play a major role in increasing crop yields compared to the twentieth century, mainly due to limited land and water resources available for crop production, higher cost of inorganic fertilizer inputs, declining trends in crop yields globally, and increasing environmental concerns. Nutrient efficient plants are defined as those plants, which produce higher yields per unit of nutrient, applied or absorbed than other plants (standards) under similar agro-ecological conditions (Fageria et al. 2008). During the last three decades, much research has been conducted to identify and/or breed nutrient efficient plant species or genotypes/cultivars within species and to further understand the mechanisms of nutrient efficiency in crop plants. However, success in releasing nutrient efficient cultivars has been limited. The main reasons for limited success are that the genetics of plant responses to nutrients and plant interactions with environmental variables are not well understood. Complexity of genes involved in nutrient use 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 area. 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 proposed as a strategy to improve the efficiency of fertilizer use or to obtain higher yields in low-input agricultural systems. This strategy should continue to receive top priority during the twenty-first century for developing nutrient efficient crop genotypes (Fageria et al. 2008).

Conclusion

Improving nutrient efficiency is a worthy goal and fundamental challenge facing the fertilizer industry and agriculture in general. The opportunities are there and tools are available to accomplish the task of improving the efficiency of applied nutrients. However, we must be cautious that improvements in efficiency do not come at the expense of the farmers' economic viability or the environment. Judicious 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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