Biological and Synthetic Sources of Nitrogen – Can They be Complimentary?

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Abstract

The heavy use of chemical N fertilizers in agriculture imposes economic and environmental costs. About 52% of global synthetic N consumption has been used to produce the world's three major cereals, rice, maize, and wheat. Alternatives to N fertilizers must be researched. Biological nitrogen fixation is one such alternative. It is important to explore on the global scenarios and future projections of N balances in relation to relative importance of biological N fixation and fertilizer N in cereals with major emphasis on rice. To supply sufficient N to meet increased food demand and maintain a safe environment, fertilizer N must be used efficiently and prudently, that is, N-use efficiency (NUE) must be improved. N requirement and supply to rice needs to be synchronized similar to that in legumes. Although some of the main factors such as climate controlling crop needs for N are largely outside farmer control, there is significant potential to increase NUE in cereals.

Keywords: Chemical fertilizer, crop production, legume, nitrogen use efficiency

Introduction

The expansion and intensification of agricultural production to meet the needs of a burgeoning population have brought vast land areas under cultivation. Continued growth in cultivated area, however, is very unlikely since in the future there will be more competition for domestic and industrial uses. This means that crop productivity has to be increased, for which nitrogen, plays the most crucial role. The atmosphere contains a large, well-mixed, biologically unavailable pool of N, of which a relatively small part is converted to biologically available or reactive pool of N. Biological N fixation is the primary natural source of reactive N. In recent years, however, industrial N fixation has become equally important in agriculture, as meeting the growing demand for food has forced large increases in the use of synthetic N fertilizer. The global demand for N fertilizer is increasing day by day, driven mainly by cereal production. The world presently uses around 100 million tonnes of synthetic N annually, which is about a 100-fold increase over the last 100 years. About 52% of global synthetic N consumption has been used to produce the world's three major cereals, rice, maize, and wheat. The projections are that up to 110% increase in food production would be required by 2050 to feed 9.3 billion people (Tilman et al 2011). This will require an increased use of N fertilizer of a similar magnitude if the efficiency is not increased. Moreover, there will be enormous environmental penalties for the use of such a large amount of inorganic, reactive N. The continuing increase in the use of N has altered the global cycle of N. In the pre-industrial era, all global N (90 to 130 Tg) (1 Tg = 10^{12}g) was in the biotic pool. In the industrial era (1800-2000), another 130 to 150 Tg of N, which constitutes the reactive pool, is believed to have accumulated on land, causing serious problems to the environment (Vitousek et al 2010). Therefore, to supply sufficient N to meet increased food demand and maintain a safe environment, fertilizer N must be used efficiently and prudently, that is, N-use efficiency (NUE) must be improved.

Fertilizer N-use efficiency

Fertilizer N-use efficiency is a complex term with many components (Ladha et al 1998). To quantify NUE, the term most widely used is a ratio with output (biological yield or economic yield in terms of biomass or N content) as the numerator and input (N supply from soil, fertilizer, or soil plus fertilizer) as the denominator. Three widely used efficiency ratios are agronomic [AE_N], recovery [RE_N], and physiological [PE_N] N-use efficiency. Based on an average of a large number of studies conducted in research fields involving 300 to 700 data points from across the globe in a wide diversity of agroecologies, 44 and 55% (by ^{15}N and N-difference methods, respectively) of the applied fertilizer N was recovered (RE_{NT}) in the first crop (Ladha et al 2005). When fertilizer-N recovery in plant and soil during succeeding seasons was considered, an additional recovery of about 7% was estimated. Based on the best available information, it is likely that on-farm RE_{NT}

values range from 20 to 30% in rainfed and 30 to 40% in irrigated conditions, across three major cereals. An N recovery efficiency of 40% or more, however, has been obtained with improved N management practices. These findings beg a question regarding importance to future food security needs: What is the maximum RE_N value attainable in cereal production?

Of course, very high efficiency (close to 100%) similar to that of symbiotic N-fixing systems such as legume-rhizobium is possible. In symbiotic N_2-fixing systems, however, the N requirement and supply are highly synchronized. As a result, almost no leakage (excluding N leakage through root exudation and NH_3 volatilization from leaves) of N occurs. Absolute synchrony similar to that of legumes will not be attainable in fertilizer-dependent cereal production systems. Nonetheless, efficiency levels close to 70–90% obtained in several well-managed controlled experiments can be targeted, at least in well-managed irrigated cereal systems (Ladha et al 2005).

Fertilizer NUE is governed by three major factors: N uptake by the crop, N supply from soil and fertilizer, and N losses from soil-plant systems. The crop N requirement is the most important factor influencing NUE. Much research has been conducted during the past 50 years to improve NUE by trying to develop better fertilizers or improved N management practices, mainly based on a better synchronization between the supply and the uptake of N by the crop. There is significant potential to increase NUE in cereals. Many of the strategies needed to achieve such increases have already been developed (Table 1).

The use of the best available management strategies comprising optimal soil, water, and crop management together with good climatic conditions would attain greater efficiencies. In addition, cereal genotypes with a large harvest index must be used to obtain high RE_N and PE_N because the harvest index is tightly linked to NUE (Ladha et al 1998).

Table 1. Comparative evaluation of tolls or tactics of enhancing fertilizer N-use efficiency

Tools/tactics	Benefit: Cost	Agencies involved[a]	Limitations
Site-specific N management	High	Research, extension, farmer	Has to be developed for every site, infrastructure required
Chlorophyll meter	High	Extension, farmers	Initial high cost
Leaf color chart	Very high	Extension, farmers	None
Plant analysis	High	Research, extension, farmers,	Facilities need to be developed
Controlled-release fertilizer	Low	Research, farmers, industry	Low profitability and lack of interest by industry
Nitrification inhibitors	Low	Research, farmers, industry	Low profitability and lack of interest by industry
Fertilizer placement	High	Extension, farmers	Lack of equipment, labor-intensive
Foliar N application	High	Extension, farmers	Lack of equipment, risk involved
Breeding strategy	Very high	Research	Varieties yet to be developed
N-fixation in non-legumes	High	Research	Technology yet to be developed for field scale
Models and decisions support systems	Medium	Research, extension	Tools are available
Remote-sensing tools	Low	Research, extension, industry	Technology needs to be fine-tuned
Geographic information systems	Low	Research, extension, industry	Technology needs to be fine-tuned
Precision farming technology	High	Research, extension, farmers, industry	Technology needs to be fine-tuned
Resource-conserving technologies	High	Research, extension, farmers, industry	Technology needs to be evaluated for long-term impacts
Integrated crop management	High	Research, extension, farmers, industry	Technology needs to be evaluated for long-term impacts

Approaches to increase N-use efficiency

Many approaches have been suggested for increasing NUE, for example, optimal time, rate, and methods of application for matching N supply with crop demand; the use of specially formulated forms of fertilizer, including those with urease and nitrification inhibitors; the integrated use of fertilizer, manures, and/or crop residues; and optimizing irrigation management. In addition, some modern tools such as precision farming technologies, simulation modeling, decision support systems, and resource-conserving technologies also help to improve NUE. Importantly, some of these techniques are being adopted on a large scale by many farmers. Two success stories based on crop demand-based N management warrant a mention.

In large-scale agriculture practiced in developed countries, precision farming studies have demonstrated that variable-rate N-fertilizer application has the potential to significantly reduce the N rate required to achieve yields similar to those obtained with standard uniform management practices. In agriculture with small to medium farm size in developing countries, the use of a simple and inexpensive leaf color chart assists farmers in applying N when the plant needs it. The use of this simple tool, currently practiced by about 350,000 farmers globally, has reduced fertilizer N use by about 25%.

Conclusions

Because some of the main factors such as climate controlling crop needs for N are largely outside farmer control, it will remain difficult to predict the amount of N to apply for optimum growth. Along similar lines, the amount of N that becomes available for crop uptake through net soil N mineralization varies across the landscape and is difficult to predict. Therefore, because of those uncertainties related to the demand for and supply of N to the crop, it will always remain a daunting task to achieve significantly higher fertilizer N-use efficiencies. However, our recent global analysis on long-term changes in soil N (Ladha et al 2011) and N balances (unpublished) in three cereals indicated that a substantial part of N input comes from the sources other than synthetic N, a large part of which includes non-symbiotic N fixation. This strongly suggests that the two sources of N are complimentary and therefore should be managed accordingly. Undoubtedly, in the future scenario, the synthetic N fertilizer will continue to be the major source of N in agriculture. However our goal should be to ensure soil conditions which promote biological inputs of N and overall efficient use of all the sources of N.

REFERENCES

Ladha JK, Kirk GJD, Bennett J, Reddy CK, Reddy PM and Singh U. 1998. Opportunities for increased nitrogen use efficiency from improved lowland rice germplasm. *Field Crops Res* 56: 41–71.

Ladha JK, Pathak HP, Krupnik TJ, Six J and van Kessel C. 2005. Efficiency of fertilizer nitrogen in cereal production: retrospect and prospect. *Advan Agron* 87: 86-156.

Ladha JK, Reddy CK, Padre AT and van Kessel C. 2011. Role of nitrogen fertilization in sustaining organic matter in cultivated soils. *J Environ Quality* 40:1756-1766.

Tilman D, Balzer Christian, Hill J, Befort B. 2011. Global food demand and sustainable intensification of agriculture. *Proc Natl Acad Sci* 108: 20260-20264.

Vitousek PM, Naylor R, Crews T, David MB, Drinkwater LE, Holland E, Johnes PJ, Katzenberger J, Martinelli LA, Matson PA, Nziguheba G, Ojima D, Palm CA, Robertson GP, Sanchez PA, Townsend AR and Zhang FS. 2010. Nutrient imbalances in agricultural development. *Science* 324:1519–1520.

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