IMPROVED MANAGEMENT OF NITROGEN TO RAISE PRODUCTIVITY OF FOOD CROPS

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Abstract

Increased nitrogen use efficiency, raising yield potential and closing existing yield gaps to avoid yield stagnation are pivotal components of a sustainable agriculture that meets human needs and protects natural resources. The better the yield determination is understood the more likely the breeding or management strategies designed to raise productivity will efficiently apply. Improved efficiency of nutrient use at a field and farm scale, both aiming at increasing crop yield and reducing losses, is dependent upon the magnitude of matching nutrient supply and demand of the crop. Matching nitrogen and water supply to the demand of the crop requires knowledge of crop growth processes and critical phenological stages in crop development.

Two cases are presented: one on N use in irrigated lowland rice and another on nitrogen use efficiency in wheat under abiotic stress. Irrigated lowland rice cropping systems show low ANR-values of about 0.30. The agronomic nitrogen use efficiency, derived from apparent nitrogen recovery (ANR) and physiological nitrogen use efficiency (PNUE), amounts to 0.50 on average for crops under temperate conditions. Water availability strongly affects N uptake and recovery. A quantitative systems approach is needed to identify the prospects for improving the agronomic N-use efficiency.

Keywords: wheat, rice, N uptake, N use efficiency (NUE), apparent N recovery (ANR).

Introduction

It was found that at the global level the industrial N fertilizer input exceeded the total crop N uptake around 1980 (Goudriaan *et al.*, 2001). In the developed countries the consumption of Nfertilizers declined from about 1985 onwards; however the N-consumption in developing countries continues to increase (Eickhout *et al.*, 2006). More than 60 % of the food supply for the human population currently depends on chemical N fertilizers. With the change to a more protein-rich diet in countries with emerging economies and a growing population, the dependence on N-fertilizers will increase strongly. Sylvester-Bradley & Kindred (2009) reported that yields of winter wheat in England increased strongly, but NUE only slightly from 20 to 24 kg DM. kg^{-1} N over the last three decades. They concluded that NUE improved more through better resource capture than physiological conversion. Thus, improvements were more depending on agronomic measures than breeding.

A comprehensive overview of opportunities to improve fertilizer N management is presented by Zebarth *et al.* (2009). They listed several research areas providing opportunities to improve fertilizer N use in cropping systems, such as: breeding for improved NUE in association with heat and drought tolerance, development of gene expression profiling to identify crop N stress, practical soil N mineralization tests, development of decision support systems and refinement of the decision-making process for variable rate fertilizer N application, use of controlled-release fertilizer N, capturing and recycling nutrients from drainage water. Successfully addressing the complex problem of the low agronomic NUE requires a more integrated approach than is currently used in most on-going monodisciplinary and sometimes scattered research activities (Neeteson *et al.*, 2002). Various stakeholders should be involved in this development process: researchers, farmers, consumers, policymakers, etc.

An integrated and interactive approach will be the most cost-effective approach for improving resource-use efficiency and profitability of sustainable agricultural systems (Spiertz, 2009).

Increased N use efficiency, raising the yield potential and closing existing yield gaps to avoid yield stagnation are pivotal components of a sustainable agriculture that meets human needs and protects natural resources (Cassman *et al.*, 2003).

Crop growth and nitrogen utilization in wheat

Strategic research on growth, development and yield formation of cereals has contributed to research-based crop management with a time- and dose-specific approach for crop protection and N fertilization, which increases both yield and yield stability in Northwest Europe (Stockdale *et al.*, 1997). Combining the genetic potential of modern cultivars with best practices in N management and pest and disease control almost doubled the yield of winter wheat in the better endowed regions of Northwestern Europe in a time-span of 30 years. In the Netherlands, average wheat yields increased from 4,820 to 8,200 kg ha-1 (Spiertz, 2004). The progress in raising yields has even been more successful in winter wheat compared to spring wheat and barley. Commercial grain yields (ca. 15% moisture) of winter wheat in regions with long days and a mild climate, e.g. Northern Germany and Scotland, currently average about 9,000 kg ha^{-1} with top yields up to 11,000 kg ha^{-1} under conditions with optimal fertilization and chemical control of pests and diseases.

Given the change in market demands, N management should become more directed to quality traits. A shift to split-dressing with an additional late N application around flowering has proven to increase the protein content of the grain in both rainfed (Ellen and Spiertz, 1980) and irrigated wheat (Wuest and Cassman, 1992). Decision support systems based on the N status of the leaves may be an option to improve the synchrony between N supply and crop demand. Wang *et al.* (2004) reported a good relationship between plant pigment ratio (R550 - R450)/(R550 + R450) measured at anthesis and grain protein content in winter wheat. This ratio is obtained from the reflectance's (R) measured at wavelengths of 450 and 550 nm.

<u>Nitrogen utilization in aerobic and flooded rice production</u>

In quantifying N response and NUE in *rice-wheat* (RW) cropping systems Jing *et al.* (2009) found lower apparent N recoveries (ANR) in wheat (0.27-0.34) than in rice (0.32-0.49). Lower ANRs may have been caused by higher N losses by denitrification and ammonia volatilization due to the change from anaerobic to aerobic soil conditions in RW systems. Aiming at saving water and N use, the *aerobic rice* concept was developed to produce high-yielding rice grown in non-puddled soils just like upland crops. Bouman *et al.* (2005) reported that the highest yields under aerobic conditions were realized with an improved upland cultivar (5.7 t ha^{-1}) and a lowland hybrid rice cultivar (6.0 t ha^{-1}). Total water input (irrigation and rainfall) was 1,240-1880 mm per season in flooded fields and 790-1,430 mm in aerobic fields. However, the consequences of transforming a flooded soils into an aerobic soil for N-use on the long term are still poorly understood. In flooded rice with saturated soils, ammonium is the dominant form of available N. Since nitrate is barely present in flooded rice soils, very little nitrate-N is leached to the groundwater. The intermittent application of irrigation water will create soil moisture conditions close to saturation during short spells. These alternating wet-dry soil conditions may stimulate denitrification/nitrification processes, resulting in gaseous losses of N through N_2 and N_2O. In addition, nitrate is prone to leaching. The differences in soil N dynamics and magnitude and pathway of N losses between flooded and aerobic systems may result in different fertilizer-N recoveries. Thus, water availability strongly affects N-uptake and Nrecovery (Belder *et al.*, 2005). Agronomically, farmers should aim at the minimum input of each production resource required to allow maximum utilisation of all other resources (de Wit, 1992).

<u>A system approach in nutrient management</u>

In N management, the goal is to make predictions of crop N demand based on the expected growth and yield while taking into account the soil N reserves and net N-mineralization during the growing season. However, there are many uncertainties in predicting the yield and mineralization due to weather extremes and the incidence of pests and diseases. In reality, the N-demand of a crop can be explored by measuring on site the dynamics in soil N availability and N-concentrations in the leaves. A more advanced method is using validated crop growth models and actual weather records to support Decision Support Systems. Crop diagnostics, like a leaf colour chart or imaging methods, can be used to increase the specific nature of recommendations during the growing season. The progress made by site-specific nutrient management (SSNM) in irrigated rice is relatively small compared to split-dressings of N taking into account crop N demand (Wang *et al.*, 2001). A greater use of SSNM in dynamic optimization of N management would be possible when phenology of the crop is taken into account.

Mathematical modeling has begun to integrate our understanding of the soil-plant N cycle and the soil, plant, environmental factors that govern it. Various models of crop growth, the soil N cycle and plant - soil models have been developed. Good examples are ORYZA2000 (Bouman *et al.*, 2001) and APSIM-Nwheat (Asseng *et al.*, 2000). However the complexity of the cycle and the large number of interactive factors that control it implies that the models do not closely approach reality.

Environmental concerns are focused on N losses from soils that may pollute the environment. Leaching is the major route by which nitrate enters the ground and surface waters, while nitrification-denitrification results in significant sources of N_2O, an important greenhouse gas. In irrigated rice-based cropping systems, N-losses from nitrate leaching are very low; however, large N losses occur from volatilization of ammonium sources. Improved efficiency of N-use at the field and farm scale to increase crop yield and quality and reduce N losses depends on dynamic optimization to match supply of N and the N requirements of the crop at a field scale. This optimization requires measurement and prediction of soil N supply, crop uptake and their variability (Cassman *et al.*, 2002).

Differences between fields are in part due to historical differences in management. But the major cause of varying fertilizer use efficiency, particularly for N, is that the supply of nutrients from soil reserves and fertilizers is not well synchronized with the demands of the crops (Raun *et al.*, 2002). This mismatch will be greater when crops depend mainly on organic N-sources because the mineralization rate is governed by temperature and soil moisture and may not be closely matched to crop demand.

Conclusions

Improving N use efficiency depends on securing attainable yields and matching nutrient supply and demand. Attainable yields should be secured by applying best farming practices.
The optimisation of N management requires measurement and prediction of soil N supply, and alleviation of factors that limit N uptake and utilization. Knowledge of temporal and spatial variation in N demand and supply is needed to improve N use efficiency. Integrated system analyses of the economic, ecological and social performance of conventional and alternative agro-production systems are also needed to guide a sustainable development and to meet societal concerns. A multi-scale approach to evaluate the efficiency of nutrient management in cropping and farming systems is recommended.

References

Asseng S., Van Keulen H. and Stol W., 2000: Performance and application of the APSIM-Nwheat model in the Netherlands. Eur. J. Agron. 12, 37-54.

Belder P., Bouman B.A.M, Spiertz J.H.J., Peng, S., Castaneda, A.R., Visperas, R.M., 2005: Crop performance and nitrogen use in flooded and aerobic rice. Plant Soil 273: 167-182.

Bouman B.A.M., Kropff, M.J., Tuong, T.P., Wopereis, M.C.S., ten Berge, H.F.M. and Van Laar, H.H., 2001: ORYZA2000: modeling lowland rice. IRRI, Los Baños (Philippines) 235 p.

Bouman B.A.M., Peng S., Castaneda A.R. and Visperas R.M., 2005: Yield and water savings of irrigated tropical aerobic rice systems. Agric. Water Manag.74: 87-105.

Cassman K.G., Dobermann A. and Walters D. T., 2002: Agroecosystems, nitrogen-use efficiency, and nitrogen management. Ambio 31(2), 132-140.

Cassman K.G., Dobermann A., Walters D.T. and Yang H., 2003: Meeting cereal demand while protecting natural resources and improving environmental quality. Annu. Rev. Env.. Resour. 28: 10.1-10.44.

Eickhout B., Bouwman A.F. and Van Zeijts H., 2006: The role of nitrogen in world food production and environmental sustainability. Agric. Ecosys. Env. 116: 4-14.

Ellen J and Spiertz J.H.J., 1980: Effects of rate and timing of nitrogen dressings on grain yield formation of winter wheat (*Triticum aestivum* L.). Fertilizer Res. 1: 177-190.

Goudriaan J., Groot J.J. R. and Uithol P., 2001: Productivity of Agro-ecosystems. In: *Terrestrial Global Productivity* (eds.: J. Roy, B. Saugier, and H. A. Mooney). Academic Press, San Diego, USA. pp. 301-313.