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Improving Nitrogen Use Efficiency for Corn (Zea mays L.) Production

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Abstract

Nitrogen (N) fertilizer is one of the main expenses for crops in high-input agricultural systems. Insufficient use of N is not only responsible for higher cost of crop production, but also for environmental pollution. Corn is one of the most important crop in the world. Application of N is a primary method used to maintain soil nutrients and increase corn yield. economic and environmental challenges are driving increased interest in improving NUE. Opportunities abound for improving NUE through implementation of fundamental BMPs, including selection of genetics with high NUE, development of enhanced-efficiency fertilizer products (CRF and NI), precision nutrient application at optimum rate, timing and placement, and carefully water management.

Keywords

Nitrogen; Use Efficiency; Corn; Production.

1. Introduction

1.1. Nitrogen Use Efficiency

Nitrogen (N) fertilizer is one of the main expenses for crops in high-input agricultural systems. The determination of N use efficiency (NUE) is an important way to evaluate the role of applied N fertilizers in improving crop yield. Moll et al.[1] defined NUE as the yield of grain per unit of available N in the soil. This NUE can be further divided into two components: N uptake (the efficiency with which the soil N can be taken up by the plant) and N utilization efficiency (the seed dry weight per unit of absorbed N fertilizer). The world cereal grain NUE is estimated to be far less than 50%[2]. Insufficient use of N is not only responsible for higher cost of crop production, but also for environmental pollution.

1.2. Corn Production in the United States

The United States (U.S.) is the largest producer of corn in the world, accounting for 32% of the world's total corn production. Corn provides 80% of feed grain for livestock, poultry and fish production. Corn is also processed into various food and industrial products, for example, starch, sweeteners and fuel ethanol. A previous study showed that corn received about 50% of the N used in the U.S., and more than 90% of N fertilizers were applied to corn in the Corn Belt [3]. However, NUE for corn production is generally low. Cassman et al. [4] reported 37% N recovery for corn grown in the north central U.S. Therefore, improving NUE of corn is desirable to improve corn yield, reduce cost of production, and maintain environmental quality.

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2. Management Practices to Improve NUE for Corn

Improving corn NUE is a worthy goal and fundamental challenge for both fertilizer industry and agriculture. Many tools are available to accomplish this task.

2.1. Use of Nitrogen-efficient Genotypes

The development of corn cultivars that are superior in absorption and utilization of N is an important strategy in improving NUE. Studies indicate that high genetic variability exists for traits related to NUE in corn[5-7]. Many selection experiments treated with various N inputs have been performed on corn. Presterl et al. [8] showed that a direct selection in environment having low N status would be more effective than an indirect selection under high N fertilization input. However, a major challenge for corn breeders is obtaining satisfactory yield under low N conditions. Banziger and Lafitte[9]reported that heritability for grain yield is usually lower for plants grown under low N conditions. Research also showed that the genotypes selected under low N environment are not well adapted to high N soils[10]. Gallais and Coque[11] suggest that selection should be performed under N deficiency conditions as long as plant growth is not severely stunted and yield is not depressed more than 35-40% under low N input.

In recent years, molecular markers have been used to study the inheritance of complex traits such as NUE using corn as a model crop. Correlation studies between the different components of NUE and yield using different genotypes or populations of recombinant inbred lines (RILs) have been carried out. Bertin and Gallais[5] found that most of the chromosomal regions for yield and traits related to NUE detected at low N input corresponded to quantitative trait loci (QTLs) detected at high N input. In another study, a limited number of QTLs for yield was detected only at low N input [12]. These controversial results indicate that based on the RIL population, the response of yield to various levels of N fertilization is controlled by a different set of genes [13]. In order to use gene knowledge to improve NUE, a more complete understanding of how corn responds to different N conditions is necessary. Even though a few attempts have been made to identify possible genes involved in regulating NUE, there are still many challenges to overcome before marker-assisted selection (MAS) can be routinely used in breeding program.

2.2. Optimize Nutrient Management Practices

Adopting appropriate nutrient management practices is an important component of improving NUE, reducing cost of production and improving crop yields. The efficiency of fertilizer N can be improved by best management practices (BMP) such as source, rate, method of application, and split application of nutrients.

2.2.1. Source

Nitrogen fertilizers mainly contain N in the form of ammonia, ammonium, nitrate, or urea. Generally, urea and ammonium sulfate are the principal sources of N fertilizers [14]. Specialty products, such as controlled release fertilizer (CRF) or fertilizers containing nitrification inhibitor (NI) have also been developed. Shoji et al.[15]showed that the use of CRF instead of urea in a corn field markedly increased NUE from 21% to 65%, which was accompanied by a reduction in the N2O emission as well. However, CRF accounts for only 0.15% of the total fertilizer N used. The main reason for the limited use of CRF is the high cost, which may be 3 to 10 times the cost of traditional fertilizer. Adding a NI with the fertilizer could maintain the N in the soil as ammonium and thus prevent the loss of N by both nitrification and denitrification. Surveys of U.S. farmers indicate that about 9% of the national corn area is treated with NIs.

2.2.2. Timing and Rate

Studies that address the timing of N application are numerous in the literature. The general conclusion is that N application should coincide with crop need. Under field conditions, a single

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application of N fertilizer is generally applied at planting to attain optimal yield, and the amount ranges from 100 to 240 kg N ha-1 depending on the cultivar needs and the existing soil fertility [16]. While application of N in the fall may save time and labor, Randall et al. [17] found fall-applied N, especially without a NI, is 10%-15% less efficient than spring-applied N. Fall application also produced lower corn grain yields than spring pre-plant application regardless of N rate [18].

Multiple applications of N have demonstrated to be advantageous over single application. Splitting N applications according to crop demand enhanced NUE in irrigated corn[19]. In addition, Fernandez et al. [20] found that splitting a total of 170 kg N ha-1 applied into three applications was more efficient than a larger single pre-plant application of 500 kg N ha-1 in corn.

2.2.3. Application Methods

Application method has always been critical in ensuring efficient use of fertilizer nutrients. Determining the right placement is as important as determining the right application rate and timing. Havlin et al. compared different N fertilizer placement methods and reported a NUE of 42% for broadcast, 50% surface band, and 68% for subsurface band application of urea-ammonium nitrate (UAN) to no-till corn in Kansas. A similar result was also reported by Touchton and Hargrove[21].

2.3. Water Management

Adequate soil water during crop growth and development is fundamental to obtain high NUE. Water deficiency could limit N movement in soil and may reduce NUE. In contrast, excessive water may cause N leaching and runoff and consequently low NUE.

Eghball and Manville[22]noted that NUE generally parallels water use efficiency (WUE) in corn. Research in corn has shown that maximum NUE can be obtained with low N rates and with light, frequent irrigation [23]. Freney[24] indicated that supplying N in the irrigation water as well as foliar applications of N were useful for controlling losses of fertilizer N. Wienhold et al. [25] reported that supplemental irrigation appears to be an applicable technology for growing corn in the northern Great Plains if irrigation inputs are optimized to prevent nutrient leaching from the root zone. On sandy soils, N fertilizer placement and timing and effective irrigation management are important considerations in promoting NUE [26].

2.4. Balanced Fertilization

Adequate and balanced application of N fertilizer is one of the most common practices for improving the NUE and is equally effective in both developing and developed countries. In a review based on 241 site-years of experiments in China, India, and North America, balanced fertilization with N, P, and K increased first-year NUE to an average of 54%, compared to NUE of only 21% where N was applied alone.

3. Summary

Application of chemical fertilizers such as N is a primary method used to maintain soil nutrients and increase crop yield. Today, economic and environmental challenges are driving increased interest in improving NUE. Opportunities abound for improving NUE through implementation of fundamental BMPs, including selection of genetics with high NUE, development of enhanced-efficiency fertilizer products (CRF and NI), precision nutrient application at optimum rate, timing and placement, and carefully water management.

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References

[1] Moll, R. H., E. J. Kamprath, W. A. Jackson. Analysis and interpretation of factors which contribute to efficiency of nitrogen utilization[J]. Agron. J., 1982,74:562-568.

[2] Raun, W. R., G. V. Johnson. Improving nitrogen use efficiency for cereal production. Agron[J]. J. 1999, 91: 357–363.

[3] Stanford, G. Rationale for Optimum Nitrogen Fertilization in Corn Production[J]. J. Environ. Qual. 1973,2: 159-166.

[4] Cassman, K.G., A. Dobermann, D.T. Walters. Agroecosystems, nitrogen use efficiency, and nitrogen management[J]. Ambio.2002, 31: 132-140.

[5] Bertin, P., and A. Gallais. Genetic variation for nitrogen use efficiency in a set of recombinant inbred lines. I. agro-physiological results[J]. Maydica.2001, 45: 53-66.

[6] Lafitte, H. R., , G. O. Edmeades. Improvement for tolerance to low soil nitrogen in tropical maize[J]. I. selection criteria. Field crop res.1994, 39: 1-14.

[7] Wang, R.L., A. Stec, J. Hey, L. Lukens, etal. The limits of selection during maize domestication[J]. Nature. 1999, 398: 236–239.

[8] Presterl, T., G.Seitz, M. Landbeck, et al. Improving nitrogen use efficiency in European maize: estimation of quantitative parameters[J]. Crop Sci. 2003,43:1259–1265.

[9] Banziger, M., and H.R. Lafitte. Efficiency of secondary traits for improving maize for low nitrogen target environments [J]. Crop sci.1997, 37: 1110-1117.

[10] Muruli, B.I., , G.M. Paulsen. Improvement of nitrogen use efficiency and its relationship to other traits in maize[J]. Maydica. 1981,26: 63–73.

[11] Gallais, A., M. Coque. Genetic variation and selection for nitrogen use efficiency in maize: a synthesis[J]. Maydica.2005, 50: 531–537.

[12] Agrama, H.A.S., A.G. Zacharia, F.B. Said, etal. Identification of quantitative trait loci for nitrogen use efficiency in maize [J]. Mol. Breed, 1999,5,:187-195.

[13] Hirel, B., T. Tétu, P. J. Lea , F. Dubois. Improving Nitrogen Use Efficiency in Crops for Sustainable Agriculture[J]. Sustainability. 2011,3: 1452-1485.

[14] Fageria, N.K., V. C. Baligar. Enhancing Nitrogen Use Efficiency in Crop Plants[J], Adv. Agron. 2005, 88:97-185.

[15] Shoji , S., J. Delgado, A. Mosier, etal. Use of controlled release fertilizers and nitrification inhibitors to increase nitrogen use efficiency and to conserve air and water quality. Commun[J]. Soil. Sci. Plant Anal.2001, 32: 1051-1070.

[16] Plenet, D., , G. Lemaire. Relationships between dynamics of nitrogen uptake and dry matter accumulation in maize crops. Determination of critical N concentration[J]. Plant Soil.2000, 216:65-82.

[17] Randall, G. W., J. A. Vetsch,,J. R. Huffman. Corn production on a sub-surface drained mollisol as affected by time of nitrogen application and nitrapyrin[J]. Agron.J. 2003,95:1213-1219.

[18] Stevenson, C.K., C.S. Baldwin. Effect of time and method of nitrogen application and source of nitrogen on the yield and nitrogen content of corn[J]. Agron. J. 1969,61:381-384.

[19] Varvel, G. E., J. S. Schepers, D. D. Francis. Ability for in-season correction of nitrogen deficiency in corn using chlorophyll meter[J]. Soil Sci. Soc. Am. J. 1997,61:1233-1239.

[20] Fernandez, J., J. Murilo, F. Moreno, F. Cabrera, et al. Reducing fertilization for maize in southwest Spain[J]. Commun. Soil. Sci. Plant Anal. 1998, 29:2829-2840.

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[21] Touchton, J. T., W. L. Hargrove. Nitrogen source and methods of application for non-tillage corn production[J]. Agron. J. 1982,74: 823-826.

[22] Eghball, B., J.W. Maranville. Interactive effects of water and nitrogen stresses on nitrogen utilization efficiency, leaf water status and yield of corn genotypes[J]. Commun. Soil. Sci. 1991,Plant Anal. 22:1367-1382.

[23] Russelle, M. P., E.J. Deibert , R.D. Hauck, et al. Effects of Water and Nitrogen Management on Yield and 15N-Depleted Fertilizer Use Efficiency of Irrigated Corn[J]. Soil Sci. Soc. Am. J. 1981,45: 553-558.

[24] Freney, J.R.. Strategies to reduce gaseous emissions of nitrogen from irrigated agriculture[J]. Nutr. Cycling Agroecosyst.1997, 48:155-160.

[25] Wienhold, B. J., T.P. Trooien, G.A. Reichman. Yield and Nitrogen Use Efficiency of Irrigated Corn in the Northern Great Plains[J]. Agron. J. 1995,87:842-846.

[26] Oberle, S. L., D.R. Keeney. Factors influencing corn fertilizer N requirements in the northern U.S. Corn Belt[J]. J. Prod. Agric.1991,3: 527-534.