The price of nitrogen (N) fertilizer was increased by 5 fold during the last decade. This has led to a significant decline in net returns. However, the increase in cereal grain price for the same period of time was negligible compared to that of N fertilizer price. Thus, improving N uptake efficiency in crop production is important to maintain economic and environmental sustainability. We have presented different strategies on efficient use of N and phosphorus (P) via optimizing soil conditions such as oxygen fertilization. Our recent research results has shown that at a given N rate and soil temperature, N loss by ammonia (NH_3) emission was greater when soil water content was maintained at 20% than that at 80% of field capacity (FC). Flooded corn (genotype: FR27 × FRMO17) seedlings with oxygen fertilization absorbed N 8-fold greater than those without oxygen fertilization. Nitrogen use efficiency of wheat (genotype: Yanzhong 144) seedlings grown in complete nutrient solution was 10-fold greater than that of the seedlings under low-phosphorus stress (P-imbalanced nutrient solution). These results indicate that appropriate soil water management, oxygen fertilization, and supply of well-balanced nutrients significantly reduced N loss and enhanced N uptake and use efficiencies of corn and wheat.

Two loam soils were collected from Florida (Krome Gravelly Loam, KGL) and Washington State (Warden Silt Loam, WSL). Ammonium sulfate [$(NH_4)_2SO_4$] was applied equivalent to 75 kg N ha^{-1}. Soil water content was adjusted to either 20% or 80% field capacity (FC) at 20 or 29^{o}C (Liu et al., 2007). There were 1.3% to 19.4% differences in N loss between the two water regimes on the same soil at the same temperature. For example, N loss from the KGL soil at 20% FC was 17.1 to 19.4% of applied N greater than that at 20% FC. Actually, moisture quotient analysis showed that the ammonia (NH_3) emission rate at 20% FC was as much as 110 times greater than that at 80% FC in the same soil condition. Moisture quotient was defined as a ratio of NH_3 emission rate at 20% FC to that at 80% FC at the same soil under the same temperature. Therefore, adequate water availability is important to minimize NH_3 emission, thus, enhances N use efficiency. The effect of soil temperature on NH_3 emission was soil dependant. Thus, N loss from the KGL soil had no difference between the two soil temperatures but that from the WSL soil had 5 to 11-fold difference between the two soil temperatures. Temperature quotients of NH_3 emission were significantly different. Additionally, the KGL soil always had greater N loss than the WSL soil at each soil water regime or temperature. Further analyses of the data using principal component analysis (PCA) showed that soil type was the major factor influencing N loss via NH_3 emission (Liu et al., 2009). Therefore, the data in Table 1 reveal that water management can contribute to reduction of N loss via NH_3 emission and improve N use efficiency.

Plants are subject to hypoxic or even anoxic stress when grown in flooded conditions or on hydric soils. Growth and development of crop plants are impacted along with reduction in nutrient uptake. Our proton micro-measurements with a self-referencing ion selective (SRIS) microelectrode has shown that hydroponic corn seedlings without aeration or oxygen fertilization extruded only 20 picomol H^+ cm^{-2} s^{-1} around 5000 microns from the root tip as compared to 150 picomol H^+ cm^{-2} s^{-1} with oxygen fertilization (Liu et al., 2005). Hypoxic seedlings could not make sufficient ATP (Nicholls and Ferguson, 2002) to absorb ammonium (NH_4^+) from the hypoxic growth medium. Oxygen fertilization ensured adequate production of ATP which is required for NH_4^+ "uphill" transportation against the electrical potential gradient across the plasma membrane into the cytoplasm in counter-transport (or antiport) with H^+ or in symport with OH^- or HCO_3^- (Marschner, 1995). Ammonium transport across the plasma membrane into the cytoplasm via antiport or symport had the same net result: the proton concentration in the growth medium increases. Therefore, SRIS indirectly measured NH_4^+ uptake via determining the proton concentration in the growth medium. This indicated that oxygen fertilization greatly increased NH_4^+ uptake of flooded corn seedlings and hence enhanced N use efficiency.

Balanced nutrient supply is a key factor to enhance nutrient use efficiencies. Our split-root experiment we have shown that N use efficiency of wheat plants grown in P-balanced growing medium was up to 10 fold greater than that of P-imbalanced plants (Liu et al., 2007b). Furthermore, P bioavailability of insoluble phosphates depended upon the placement of phosphates. For example, insoluble phosphates had much greater P bioavailability when they were placed with the other nutrients together than they were separated with the other nutrients. This suggested that application of complex fertilizers was advantageous both in improving nutrient-use efficiencies and in mobilizing insoluble phosphates over that of single nutrient fertilizers in crop productions.

Based on the data presented above, we can conclude as follows (i) Optimal water management is a key to reduce N loss via NH_3 emission and hence improves N use efficiency, (ii) Oxygen fertilization significantly improved NH_4^+ influx of hypoxic corn plants and thus can significantly enhance N use efficiency, and (iii) N-use efficiency of wheat plants was 10 fold greater when grown in a nutrient balanced medium than in an imbalanced medium.

References

Liu, G.D., J. Dunlop, T. Phung, D.M Porterfield, and Y.C. Li. 2005. Effects of hypoxic and low-P stresses on proton extrusions on corn and wheat roots probed in SRIS. *In: Plant Nutrition: for Food Security, Human Health and Environmental Protection* (edited by C. J. Li et al) The XV International Plant Nutrition Colloquium, Beijing, China, September 15-19, 2005 Tsinghua University Press. 1110-1111. ISBN 7-302-11786-1

Liu, G.D., Y.C. Li, and A. Alva. 2007a. High water regime can reduce ammonia volatilization from soils. *Communications in Soil Science and Plant Analysis*. 38: 1203-1220.

Liu, G.D., J. Dunlop, T. Phung, and Y. C. Li. 2007b. Physiological Responses of Wheat Phosphorus-efficient and -inefficient Genotypes in Field and Effects of Mixing Other Nutrients on Mobilization of Insoluble Phosphates in Hydroponics. *Communications in Soil Science and Plant Analysis*. 38: 2239-2256.

Liu, G.D., Y.C. Li, and A. Alva. 2009. Geometric Classification and Principal Component Analysis of Ammonia Emission from Fertilized Soils. *Water, Air & Soil Pollution*. (in review).

Marschner, H. 1995. Mineral Nutrition of Higher Plants. 2nd ed. Academic Press, London.

Nicholls, D.G., S.J. Ferguson. 2002. *Bioenergetics 3*. Academic Press, San Diego, CA 92101-4495, USA. ISBN 978-0125181211.