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TRUSTED CROP NUTRITION EXPERTISE℠
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Adequate Sulfur is Essential for Optimizing Nitrogen Use Efficiency

- Adequate sulfur can increase plant nitrogen use efficiency
- Additional nitrogen may not cure N deficiencies when S is limiting

Nitrogen Use Efficiency (NUE) is one of the most widely studied topics in crop nutrition. Improving NUE has significant implications for reducing farmers operating costs and mitigating the environmental impacts associated with the loss of nitrogen (N) fertilizer into the environment[1]. Over 110 million tons of nitrogen fertilizer are applied globally in crop production systems; however, only 40-45% of the applied nitrogen is utilized by crops in the year of application[2]. The remaining nitrogen is either immobilized by soil microorganisms, leached into groundwater, transferred to surface water, or lost to the atmosphere as gaseous emissions which contribute to climate change[2,3].

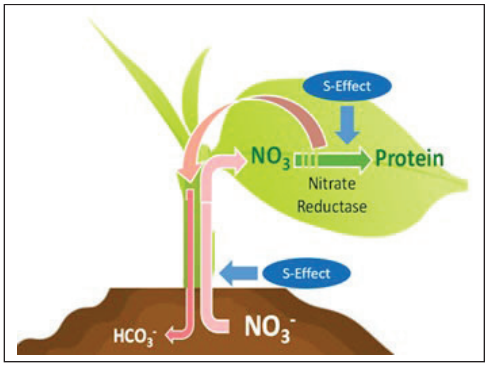

Figure 1: Illustration of root nitrate (NO_3^-) uptake and the assimilation of absorbed nitrate into proteins through the nitrate reductase enzyme, with both processes positively influenced by sulfur (S) nutrition (Developed by Dr. I. Cakmak and adapted from Imsande & Touraine, 1994)[6].

Improving nitrogen uptake from fertilizers, and the assimilation of N into proteins are key factors in influencing the NUE of plants. When N in the soil is not efficiently converted into proteins, the plant's ability to continue N uptake from the soil is diminished[4,5]. The processes of root N uptake (specifically nitrate-NO_3^-) and its conversion into protein within the plant are strongly influenced by sulfur (S) nutrition (Fig.1)[6]. The sulfate ion (SO_4^{2-}) is the primary form of sulfur taken up by plant roots. Protein synthesis in plant tissues relies on a continuous supply of sulfate from the soil. This suggests that the ability of plants to utilize nitrogen from soil depends on the presence of adequate sulfur in the soil as well. For example, short-term experiments have shown that wheat plants grown with adequate S supply take up nitrate (NO_3^-) more rapidly and in greater quantities relative to plants grown under marginal or low sulfur conditions[7].

Sulfur's Role in Converting Nitrogen to Protein

Sulfur is essential for synthesizing nitrogen containing amino acids such as methionine, cystine and linking together multiple cysteine molecules, the structural constituents to build proteins[8]. Nitrate reductase, a key enzyme that directly impacts the utilization of nitrate in protein biosynthesis (Fig. 1), shows reduced activity when sulfur is limiting[6,9]. As early as the 1930s, it was reported that sulfur-deficient plants were unable to effectively utilize nitrate for protein synthesis. Under such conditions, nitrate accumulates in the leaves due to the diminished activity of nitrate reductase. Those findings help explain why sulfur-deficient plants typically accumulate high levels of nitrate, amines, and amino acids (collectively referred to as **non-protein nitrogenous** compounds) while containing lower amounts of protein. The implication is that when the protein of plants grown under low sulfur conditions is compared to similar plants grown with adequate sulfur, the two types of plants do not contain the same amount of protein. In sulfur-sufficient plants, a majority of the nitrogen is present as protein, while in sulfur-deficient plants, non-protein nitrogenous compounds (such as nitrate and amino acids) predominate (Fig. 2)[9].

These findings indicate that crops grown on soils which cannot supply adequate S will have an impaired ability to convert N into protein and therefore decreased NUE. Consistent with these observations, field experiments have demonstrated that adequate S nutrition is required for better root N uptake and NUE in plants (Fig. 3)[10,11]. Salvagiotti et al. (2008) further demonstrated that grain production per unit of applied N fertilizer was about 50% higher in S-sufficient plants compared to those grown under low S supply[11].

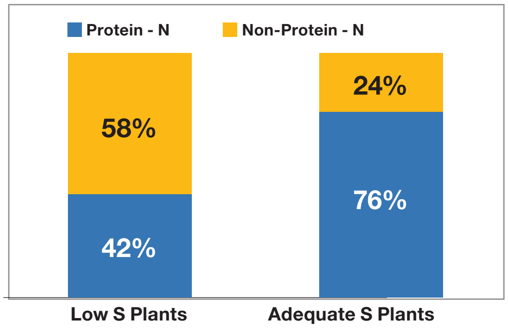

Figure 2: Distribution of non-protein-N and protein-N in young corn plants depending on S supply (Rendig et al. 1976, Plant and Soil)[9].

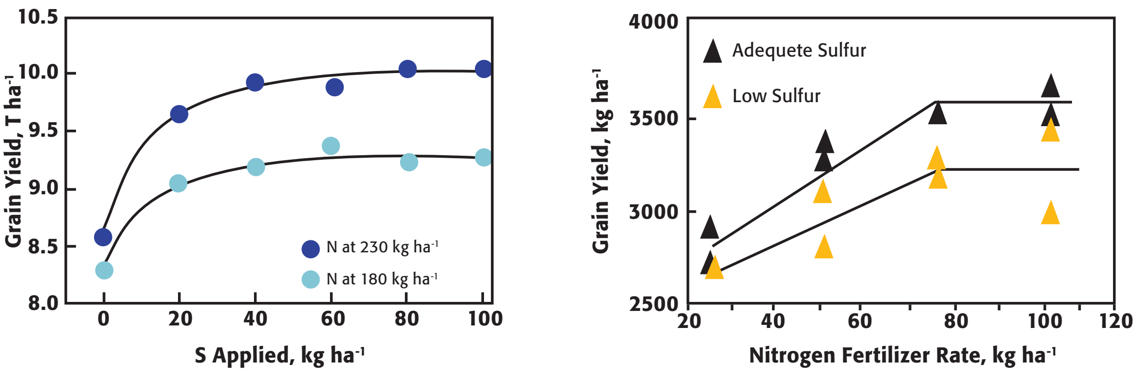

Figure 3: Effect of increasing S fertilization on wheat grain yield at low and high N supply in the UK (left)[10] and the effect of increasing N fertilization on wheat grain yield at low and adequate S fertilization in Argentina (right)[11].

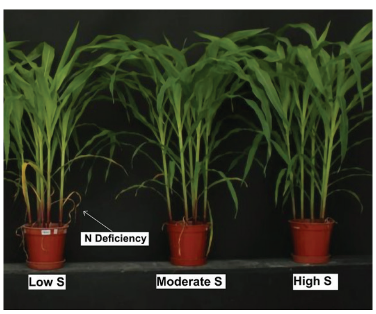

Figure 4: Even when nitrogen is supplied at a sufficient rate, plants that lack sulfur can show N deficiencies compared to plants that have adequate or high S supplied to the soil[7].

Conclusion

Evidence continues to support the role that proper sulfur nutrition has in enabling crops to improve NUE. Sulfur is known to be a critical mineral nutrient necessary for the proper function and activity of nitrate reductase, a key enzyme involved in converting nitrate into proteins. Consequently, S-deficient plants accumulate high amounts of unused nitrate, which then reduces the capacity of plants to utilize N from the soil. If nitrogen is not effectively incorporated into protein biosynthesis, plants lose their ability to take up N, even with sufficient N fertilization.

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