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L Talukdar
Department of Agronomy,
Assam Agricultural University,
Jorhat, Assam, India

S Dutta
Department of Soil Science,
Assam Agricultural University,
Jorhat, Assam, India

P Dutta
Department of Agricultural
Economic & Farm Management.
Assam Agricultural University,
Jorhat, Assam, India

Jemima Hussain
Department of Agrometeorology,
Assam Agricultural University,
Jorhat, Assam, India

Corresponding Author:
L Talukdar
Department of Agronomy,
Assam Agricultural University,
Jorhat, Assam, India

Nitrogen and Sulphur interaction on nutrient use efficiency in field crops: A review

L Talukdar, S Dutta, P Dutta and Jemima Hussain

Abstract

Nitrogen is considered as the most yield-limiting nutrient in crop production around the world. Sulphur is also a key nutrient for plant growth, accounting for 9 to 15% of N uptake by plants. Sulphur metabolism in plants is intertwined with their nitrogen metabolism, as both are components of proteins. A deficiency of S in a plant hinders its N-metabolism, resulting in higher levels of N in amide and NO3- forms. The ideal N:S ratio for plant growth and metabolism is 15-16:1 in legumes and 11-12:1 in cereals, according to research. In the absence of adequate S in soils, utilization of NO_3^- can be impeded. Leaching of underutilized NO_3^- can create serious environmental problems. As a result, a lack of S in proportion to N leads to poor N fertilizer-use efficiency by crops. Because the efficacy of additional nitrogen is limited by a lack of S, S addition becomes necessary to obtain maximal nitrogenous fertiliser efficiency. It was found that Maize yield was raised more by nitrogen fertiliser than by sulphur fertilisation. Likewise, N fertilization increased S concentration and S uptake, but S addition did not affect variables associated with N status in maize. In case of wheat Plant N uptake increased linearly in response to N addition until rates of 80 kg N ha^{-1}. Sulfur addition showed no effect at the lowest N fertilizer rate, but N uptake was increased when S was applied at the highest N rate, revealing a synergism between both nutrients. The application of N in combination with S significantly affected the yield, yield components, N uptake, nitrogen use efficiency, and grain protein content of the rice crop. Synergetic effects on S and N make use of efficiencies at optimum rates of S and N inputs, while antagonistic effects occur when one of the two elements is used at excessive rates. Adjusting S and N fertilization may result in good seed yield and seed protein quality in a sustainable manner, especially when N inputs are reduced.

Keywords: Nitrogen, sulphur, quality, yield, nutrient use efficiency

Introduction

Nutrient interaction in plants is likely one of the most important variables influencing annual crop yields (Fageria 2014) [16]. On one hand, nutrient interaction at the root uptake level may be studied deterministically based on well-conditioned experiments; while on the other hand, it can be determined agronomically by studying nutrient availability and fertilizer effects on crop yield. The deterministic approach eliminates external influences such as other limiting nutrients, water limitation or water excess, temperature and pH, however the results are not always transferable to field conditions. Agronomic studies, on the other hand, have the drawback that external influences are uncontrollable, and the results can only be valid for the current conditions due to a slew of confounding variables.

According to Fageria (2014) [16], Interactions occur when the supply of one nutrient influences the absorption and utilisation of another nutrient. Plant growth and development are only affected by nutrient interactions when the supply of a specific nutrient is insufficient in comparison to the applied nutrients to put it another way, yield declines only when the supply of certain nutrients falls below a critical level. Plant growth will not be harmed if the soil or growth medium contains a sufficient supply of other important nutrients in comparison to the added one, even if the uptake of some nutrients may be limited. As a result, plant growth or yield is regarded as a more appropriate criterion for assessing nutrient interactions in crop plants. Nitrogen and sulphur are amongst the major macronutrients required for plant growth and development. They are available to plants mainly in the form of nitrate, ammonium and sulphate (Pate, 1973; Plessard *et al*., 1991; Rennenberg, 1984) [36, 37, 39] from the soil. Nitrate and sulphate reductions are compartmentalized and regulated to facilitate integration with other cellular metabolism.

Sulphur and Nitrogen Interaction in Soil

An intensive agriculture with use of improved cultivars and high analysis fertilization offers conditions of nutrients exhaustion resulting in nutrient imbalance in soils. According to Fazili *et al*., (2008) [17], a shortage of S reduces the efficacy of additional nitrogen, hence S supplementation is required to obtain optimal nitrogenous fertiliser efficiency. Kowalenko and Lowe (1975) [30] noticed that a high N:S ratio (produced by addition of N) resulted in a decrease in mineralization of S in the soil sample during incubation. Janzen and Bettany (1984) [28] indicated the optimum ratio of available N to available S to be 7:1. Ratios below 7 gave the reduced seed yields. A rapeseed and mustard crop under field conditions recovered 27-31% of added S without N, but 37-38% with 60 kg N ha-1 (Sachdev and Deb, 1990). Regression showed that S mineralization rates could be well predicted by taking into account soil organic N content positively. Rate of S mineralization was significantly and positively correlated to total N content of soil and it was weakly related to total S in soil (Gharmakher *et al*. 2009) [21].

Sulphur and Nitrogen Interaction in Plant

Because of central role of S and N in the synthesis of proteins, the supplies of these nutrients in plants are highly inter-related. Sulphur and nitrogen relationships were established in many studies (Ahmad *et al*., 1998; and Jamal *et al*., 2005; 2006a; 2010) [1, 24, 23, 27] in terms of dry matter and yield in several crops. While researching on tobacco plants, Barney and Bush (1985) [6] discovered that there was apparent buildup of one nutrient while the other was reduced, and that the stored nutrient was utilized in protein synthesis when the treatments were reversed. A shortage in the S supply to the crops lowers the utilization of the available soil nitrogen, thereby increasing nitrate leaching (Likkineni and Abrol, 1994). O'Connor and Vartha (1969) [34] observed that large dose of gypsum reduced the yield of hay when N status in soil was unsatisfactory. Likewise, large dose of N created S deficiency (Eppendorfer, 1971) [15].

It has been determined that there is one part of S for every 15 parts of N in protein, implying that the N:S ratio is fixed within a restricted range of 15:1. The N:S ratio in the whole plant in general is 20:1 (Cram, 1990) [12]. While researching on barley plants, Clarkson *et al*. (1989) [10] discovered that the apparent matching of supply to demand is accompanied by an apparent coupling of SO4 2- to NO3 - absorption at the whole plant level. Because both sulphur and nitrogen are necessary for protein synthesis, the ratio of total N to total S in plant tissue can represent N and S capabilities in protein synthesis (Brunold and Suter, 1984) [7]. Thus, a change in the ratio of reduced-N to reduced-S (NR/SR), which is a reflection of the amount of S amino acids, suggests that protein metabolism has been significantly altered and has important implications for protein quality (Friedrich and Schrader, 1978) [20]. Sulphur and nitrogen assimilation in plants are intimately linked. Being an essential component of S –containing amino acids which provide functional integrity to proteins, a central role and thus dependence upon each other has been documented for N and S. Sulphur assimilation is strongly influenced by nitrogen nutrition, and vice versa.

S in plant tissues is mainly present as amino compounds and protein-sulfur in the organic pool. Its metabolism is intertwined, and it so plays a key role in the production of a number of essential proteins. The supply of S is dependent on the supply of N, and nutritional imbalances result in lower yields due to reduced uptake and assimilation of both nutrients. Data showed that the nitrate-N content in the leaves of plants grown with N alone was significantly ($P< 0.05$) higher when compared to the plants grown with both S and N in both the genotypes studied.

This could be linked to these plants' lower potential for nitrate reduction, as seen by low NR activity. S-deficiency has long been recognized to result in accumulation of non-protein N, especially NO− 3 N in the leaves. Sulfur deficiency might cause an enrichment of non-protein nitrogenous compounds including nitrate in the plant tissue. Data showed that the nitrate-N content in the leaves of plants grown with N alone (OS+ lOON kg ha-I) was higher as compared to the plants grown with both S and N (40S+ lOON and 60S+ 150N kg ha'I), which may be associated with a reduced capacity of these plants for nitrate reduction as exhibited by low NR (Ahmad *et al*., 2001).

N:S Ratio In Relation To Sulphur and Nitrogen Interaction

A number of studies on S requirement of the crop in relation to N have been reported (Jamal *et al*., 2005; 2006a, 2006b, 2009, 2010) [24, 23, 25, 26, 27]. There is a significant positive S x N interaction in relation to the oil content and yield. Adequate N: S ratio has been found to be 7.5:1 in grains, above which deficiency of S can be observed (Aulakh *et al*., 1980) [5]. There is a strong relationship between S and N content in plants. The ratio of total N to total S and S in protein determine the degree of availability of S in protein. The N and S ratio is often preferred over concentration as a diagnostic criterion for S deficiency (Stewart and Whitefield, 1965). The total S content in plant tissues varies among plant species. Experiments with rapeseed showed that the N:S ratio of rapeseed tops sampled at the rosette stage was very sensitive and changes due to change in sites, year and seed varieties and these changes were sometimes greater than differences between S deficient and S sufficient rapeseed (Maynard *et al*., 1983) [32]. Dev and Saggar (1974) [14] observed that S application lowered total N: total S ratios in soybean. It was also observed that at the S levels where total N and total S ratios were consistent, one part of S was required for every 14 and 16 parts of N in protein production in various soybean varieties. Dev *et al*. (1981) [13] found that applying 20 kilograms S ha-1 reduced the N: S ratio in mustard seeds from 14:1-16:1 to 11:1-12:1, and that applying 40 kg S ha-1 reduced it even further to 10:1. Aulakh *et al*., (1977) [4] found N: S ratio of 15.5:1 in plant tissue of mustard to be critical, over which a lack of S might result in a severe drop in grain yield. Cate and Nelson, (1965) determined that the N:S ratio is not a suitable methodology for an early diagnostic of S deficiencies in wheat. For winter wheat, Blake-Kalff *et al*. (2004) reported 78% of correctly diagnosed samples. These data demonstrate that the N:S ratio is a reliable approach for detecting S shortages in advanced phases of the crop cycle with critical ratios of 16:1 for spring red wheat. (Calvo and colleagues, 2008) [8].

In assessing the nitrogen and sculpture relations as plant nutrients, sulphur mobility was studied in mustard plants, as influenced by concentration of nitrogen, using the tracer technique. The computed values for mobility of a constant level of ^{35}S-labeled sulphur against the increasing concentration of nitrogen in solution were significantly influenced and increased up to the level of 300ppm N (Nad *et al*., 2001) [33]. The application of N as well as S increased the content of N in grain of rice. The sequential rise in grain N content due to rising S levels was only significant up to 22.5 mg S kg1 at each N level.

In the case of rice straw, the application of N raised the N content invariably. In the absence of N fertilization, S application either decreased or failed to bring about a significant increase in the content of N. However, at other levels of N, raising S levels considerably enhanced the N content of straw compared to not applying S. In general, application of N as well as S increased the N content of rice grain.

In the absence of N fertilization, S application either decreased or failed to bring about a significant increase in the content of S. At other levels of N, an application of 15.0 mg S kg −1 and above increased the S content of grain significantly over no application of S. In case of rice straw, S content was not influenced by main effect of N or interaction effect of N × S. Application of S was found to invariably increase the S content of straw significantly as compared with no application of S. In general, application N as well as S increased the N:S ratio in grain of rice. In the absence of N fertilization or application of 15 mg N kg−1, S application above 7.5 mg S kg−1increased the N:S ratio significantly as compared with no application of S. However, with 15 mg N kg−1and at the highest S level (30.0 mg S kg−1) the N:S ratio was found to be significantly lower than ratio at 22.5 mg S kg−1 level. At 30 mg and 60 mg N kg−1, S application could bring a significant change in the N:S ratio of grains. At 45 mg N kg−1, a significant increase in N:S ratio was recorded at 7.5 mg S kg−1. In general, application of N increased the N:S ratio in straw of rice. A significant effect of N and S interaction on N:S ratio in rice straw indicated that only at 30 mg N kg−1 level, application of 22.5 mg and 30.0 mg S kg−1 brought a significant increase in N:S ratio of rice straw in comparison to no application of S (Srivastava and Singh, 2007) [42].

Impact on nutrient use efficiency and quality of crop

The most critical constraint for plant growth and development, and thus overall productivity, has been identified as the availability of nitrogen and sulphur in forms that are utilisable by plant systems. Inadequate application of N and S results in yield reduction. Increased productivity is the outcome of a positive interaction between sulphur and nitrogen. In addition to overall quality, sufficient N and S fertilisers are recorded in plants. Nitrogen is a fundamental component of proteins, and as the rate of nitrogen application increased, so did the nitrogen availability. Similarly increased sulphur supply, increases seed yield with higher protein content. Combined application of nitrogen and sulphur promote the uptake of sulphur and nitrogen and lead to significant enhancement in seed protein and oil content. This also improves total crop productivity tremendously. Nitrogen boosted sulphur uptake in plants.

Plant N uptake increased linearly in response to N addition until rates of around 80 kg N ha-1 were reached Ca. Sulfur addition had no effect at the lowest N fertilizer rate, but N uptake was increased when S was applied at the highest N rate, revealing a synergism between both nutrients (Salvagiotti *et al.*, 2009) [41]. Fertilization with nitrogen and sulphur increased maize yield without a significant N x S interaction Thus, N fertilisation had a bigger impact on grain yields than S fertilisation. NU dynamic was most greatly affected by N fertilization.

However, S fertilization tended to increase NU and NUE. A N x S interaction was observed on SU dynamic as S fertilization did not increase SU without N application. (Carciochi *et al.* 2020) [20]. The substantial improvement on the NUE components of the rice crop when N is fertilized with S could be due the synergistic effect of S on N uptake and utilization that facilitates the biosynthesis of proteins, a vital process that determines yield (Habtegebrial *et al.*, 2013) [22]. The interaction effect of nitrogen and sulphur was found to be highly significant on grain yield of rapeseed (Ojha *et al.* (2018) [18]. The results showed that the fertilization either with N alone or with N in addition with S resulted in significant increase in seed productions, but the complementary addition of S had no significant influence on seed yields and as expected, Significant effects of S applied on N uptake have been observed. Addition of sulphur to each nitrogen dose increases the yield of wheat grain and the content and uptake of the analyzed micronutrients, i.e., iron, manganese, zinc, and copper.

Obtained result shows the so-called sulphur additive effect. (Klikocka and Marks, 2018) [29]. A wider combination of N and S application rates are recommended in order to prove the interaction of S with higher N availability for the crop (Cordova *et al.* 2020) [11]. S and N fertilization may lead to high seed yield and seed protein quality in a sustainable manner, especially in the context of reductions in N inputs. (Poission *et al.*, 2019) [38]. Combined application of S and N (T2) increased the seed protein content. Less protein content in the seeds with the treatment T1. Combined applications of S and N (T2) increased the nitrogen harvest index. The role of S is linked to the function of nitrate reductase, the enzyme responsible for conversion of NO3−- N taken up by the crop into amino acids and subsequently into protein. Further, S is a constituent of the initiation amino acid methionine, which is essential for protein synthesis in eukaryotes. Nitrogen harvest index (NHI) reflects N-utilization efficiency of the crop during the reproductive phase of growth and the efficient partitioning of reduced nitrogen towards the economic sink (seed). Combined application of S and N increased the N-HI in rapeseed however, suggesting that S and N should be applied together in adequate and balanced doses for better partitioning of nitrogen towards economic sink resulting in to the increased protein in the seed (Fazili *et al.* 2008) [17]. Seed yield (kg ha-1) stover yield (kg ha^{-1}) were maximum in 150% RDF and was significantly superior over 100% RDF and was at par with 125%. Seed yield (kg ha-1) was maximum in 40 kg S ha-1 which was significantly superior over other treatments but found at par with 30 kg S ha-1 and 20 kg S ha-1. Supply of sulphur might have also promoted floral initiation, resulting in higher number of capsules plant-1, number of seeds plant-1 and ultimately enhanced seed yield. Oil yield was significantly differed due to different treatments. Maximum oil yield (kg ha-1) was recorded due to 40 kg ha-1 which was at par with 30 kg ha-1 and 20 kg ha-1 and significantly superior over treatment 10 kg ha-1 and control. (Thentu, T.L., 2014) [43]. The influence of N and S on the marketable yield of the onion bulb could be attributed to the important role of N and S in plant protein and some hormone formation; hence it helps to have a good marketable bulb. This might be due to the application of under sub-optimal supply of N and S that promotes poor bulb size formation. The combined application of N at the rate of 200kg ha-1and S at the rate of 45 kg ha-1resulted in the highest N uptake (243.33 Kg ha-1). However, the combined application N at the rate of 100 kg N/ha with no S application recorded the lowest value of N uptake (127.66 kg ha-1). The combined application of N at the rate of 200kg ha-1 and S at the rate of 45 kg ha-1 resulted in the highest S uptake (31.90 Kg ha-1). The combined application of N at the rate of 100 kg ha-1 with no S application recorded the lowest value of S uptake (13.20 kg ha-1). (Tilahun *et al.*, 2021) [44].

Conclusion

Nitrogen and Sulfur make diverse plant constituents involved in biogeochemical cycles and their combined integration in plants proves to be highly beneficial for increasing NUE. As a result of this, enhanced plant growth and development leading to one to all increase in the yield and productivity.

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