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RESEARCH ARTICLE

# Long-term Effect of Chemical Fertilizers and Soil Amendments on Sustainable Productivity and Sulphur Nutrition of Crops under Maize-Wheat Cropping System in an Acid Alfisol

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## Abstract

A study on long-term effect of chemical fertilizers and soil amendments on sulphur nutrition and crop productivity under maize-wheat cropping system was carried out in randomized block design with 11 treatments viz. 50% NPK ($T_1$), 100% NPK ($T_2$), 150% NPK ($T_3$), 100% NPK + hand weeding ($T_4$), 100% NPK + Zinc ($T_5$), 100% NP ($T_6$), 100% N ($T_7$), 100% NPK + FYM @ 10 t $ha^{-1}$ to maize only ($T_8$), 100% NPK without S ($T_9$), 100% NPK + lime ($T_{10}$) and Control ($T_{11}$). Treatments were replicated 3 times with the increase in rates of N and P fertilizers, there was an increase in sulphur supply and hence increased the sulphur content in wheat grain, maize grain and stover. The $T_9$ resulted in higher maize grain and stover yield over control. Application of FYM (Farm Yard Manure) along with recommended doses of fertilizers increased the maize grain and stover yields to the maximum level. Increased productivity of maize was found with balanced integrated nutrient management ($T_8$). Due to the application of N alone for the last 35 cropping cycles, the yield of wheat has become zero application of FYM along with 100% NPK resulted in significantly higher productivity levels of both grain and straw in wheat (33.66 and 65.90 q $ha^{-1}$, respectively) than 100% NPK and 150% NPK. The application of 150% NPK resulted in decline in grain yield (17.53 q $ha^{-1}$) compared to 100% NPK (18.23 q $ha^{-1}$). The sulphur uptake by the maize crop followed the trend of maize yield.

**Keywords:** Chemical fertilizers, sulphur nutrition, randomized block design, stover yields, cropping cycles.

## Introduction

Sulphur is one of the important secondary nutrient elements and its essentiality for plant growth has been recognized since the middle of $19^{th}$ century. Sulphur (S) has been rated as the $4^{th}$ major nutrient element after N, P and K (Sarkar *et al.,* 1994). Sulphur nutrition to crops has not been fully realized during the past mainly because, S deficiency was not a serious problem but due to high use, fertilizers containing little or no S along with intensive cropping have led to depletion of S in many soils. Sulphur in the arable land would be in the form of soluble sulphate in solution and in organic matter got adsorbed in the soil complex (Pandian, 2011). Sulphur is indispensable for plant growth and it is a constituent of three important amino acids viz. cystine, cysteine and methionine essential for protein formation. Sulphur is required for the synthesis of chlorophyll and formation of disulphide (S-S) linkages, which are associated with structural characteristics of protoplasm. It is involved in the formation of glucosides and glucosinolates (essential components of oils) and is required for synthesis of glutathione, coenzyme-A, vitamin $B_{1.}$ biotin and activation of papainases. Removal of sulphur by crops in India is about 1.26 mt whereas; its replenishment through fertilizers is only about 0.76 mt (Tiwari and Gupta, 2006). Further, the recovery of added sulphur through external sources is also very low, being only 8-10% (Hegde and Murthy, 2005). Continued depletion of native reserves of S during post green revolution period has led to its deficiency in many regions of the country and at present, it is one of the major constraints for sustainable growth and productivity of several field crops. The increasing demand and escalating cost of S fertilizers during the last decade have stimulated the increased interest in the development of technology for more efficient use of S fertilizers. In order to use S fertilizers more efficiently, an understanding of the S transformations in relation to its availability in soil for crops and interaction of sulphate with soil matrix is necessary. Sulphur can play its role as yield and quality driver nutrient in crop production when it is applied in the soil wisely. Its application to soil has been found to significantly increase the yield of crops and to improve baking quality of cereals very well. Its application to soil not only helps in sustaining high crop yields but it also improves quality of produce. Oil contents in oilseed crops can be increased by 3-9% due to sulphur application in soils deficient in sulphur. Keeping these advantages of sulphur application in soil in mind, the present investigation was undertaken to evaluate the long-term effect of chemical fertilizers and soil amendments on S nutrition and crop productivity under maize-wheat cropping system in an acid Alfisol of Western Himalayas of India.

## Materials and methods

*Experimental design:* The field experiment was conducted on a pre-established long term experiment which comprised of 10 treatments up to 1980-81. The 11th treatment, consisting of 100% NPK without S was introduced in summer 1981. The treatments were: 50% NPK ($T_1$), 100% NPK ($T_2$), 150% NPK ($T_3$), 100% NPK + hand weeding ($T_4$), 100% NPK + Zinc ($T_5$), 100% NP ($T_6$), 100% N ($T_7$), 100% NPK + FYM @ 10 t $ha^{-1}$ to maize only ($T_8$), 100% NPK without S ($T_9$), 100% NPK + lime ($T_{10}$) and Control ($T_{11}$). The treatments were replicated thrice in randomized block design (RBD). Half dose of N and full dose of P and K were applied at the time of sowing in both the crops. The remaining half of N was top dressed in two equal splits at knee high and pre-tasseling stages in maize. The sources of N, P and K were urea, single super phosphate (SSP) and muriate of potash (MOP) respectively. In 100% NPK without S treatment, P was applied through diammonium phosphate (DAP) to assess the effect of 'S' free high analysis P fertilizer in crop production. Zn was applied in $T_5$ as zinc sulphate @ 25 kg $ha^{-1}$ every year to both the crops. FYM application was made @ 10 t $ha^{-1}$ on fresh weight basis to maize crop only, which corresponds to the practice being followed by the farmers of the region. The FYM applied contained 60% moisture and its average nutrient content during the period of experimentation on dry weight basis was 1.01, 0.26 and 0.40% of N, P and K respectively. Thus, 10 t FYM $ha^{-1}$ in fresh weight basis contained 40 kg N, 10 kg P and 16 kg K $ha^{-1}$. Lime was added in $T_{10}$ @ 900 kg $ha^{-1}$ as marketable lime ($CaCO_3$) passed through 100 mesh sieve to maize crop only.

After the harvest of wheat (winter 2007-08) and maize (summer 2008), data on grain and straw/stover yields were recorded for the respective crops. The sulphur content in both grain and straw/stover of wheat and maize samples were analyzed by turbidimetric method after wet digestion with concentrated nitric ($HNO_3$) acid and perchloric ($HClO_4$) acid adding at 9:4 ratio as adapted from Chesnin and Yein (1950). The sulphur uptake was calculated by multiplying percent concentration of sulphur with grain and straw/stover yields of wheat and maize crops, respectively. The data generated during the course of the present investigation were subjected to analysis of variance (Gomez and Gomez 1984) through the requisite statistical computations so as to predict the cause and effect relationship of various treatments with the productivity of crop and S uptake.

## Results and discussion

*Response of crops to chemical fertilizers and amendments on productivity of maize:* Grain and stover yields of maize crop were affected differently with the application of sulphur at different rates (Table 1). The lowest grain and stover yields of maize were obtained in unfertilized control plots followed by 100% NPK without sulphur treatment which may be due to no application of sulphur. About 100% NPK without sulphur treatment resulted in higher grain and stover yield over control which may be attributed to the application of nitrogen, phosphorus and potash which had greater implication on nutrition of the crops and their vital role in metabolism as reported by Matsushima (1964). The application of P along with N (100% NP) significantly increased the grain and stover yield as compared to unfertilized control plot. These results are in conformity with the findings of Brar *et al.* (2001). The increasing rates of sulphur fertilizer from sub-optimal to optimum dose increased the grain and stover yield of maize. Sakal *et al.* (2000) also reported that with the increase in the rates of sulphur fertilization, maize yield increased significantly. Application of K along with N and P (100% NPK) resulted in higher grain and stover yields of maize over 100% NP only. Similar results were reported by Mahajan *et al.* (1997) in case of maize. Application of FYM along with recommended doses of fertilizers increased the maize grain and stover yields to the maximum level which is due to the release of organic acids that can complex Al and Fe, thereby, reducing P retention and inducing greater P availability (Singh and Jones 1976). Increased productivity of maize with balanced integrated nutrient management (100% NPK + FYM) might also be due to addition of sulphur through FYM as the application of FYM @ 10 t $ha^{-1}$ $yr^{-1}$ added 30 kg S $ha^{-1}$. The continuous use of 100% NPK + 10 t FYM $ha^{-1}$ maximized the productivity of maize crop (Pillai *et al.,* 2006). About 100% NPK + lime also increased grain and stover yields of maize which might be attributed to ameliorating effect of lime in reducing the soil acidity by increasing the pH value to 6.38 from its initial value of 5.8, thereby, increasing the availability of nutrients to plants.

*Response of crops to chemical fertilizers and amendments on productivity of wheat:* Wheat crop responded well to differential rates of fertilizers and amendments (Table 1). Due to the application of N alone for the last 35 cropping cycles, the yield of wheat has become zero. This might be due to increased soil acidity and deteriorated soil quality with the continuous use of N over a period of 35 years. Increase in grain and straw yields of wheat in 100% NP over 100% NPK without sulphur treatment may be due to the supply of sulphur through SSP in 100% NP treated plot. Akbari *et al*. (1999) and Varavipour *et al*. (1999) reported that wheat yield increased significantly with the application of P through SSP over the plots that received phosphorus through non-sulphur bearing fertilizers. The increase in wheat yield may also be attributed to the addition of sulphur through SSP as it contains 12% sulphur in addition to 16% phosphorus.

Table 1. Effect of long-term use of chemical fertilizers and amendments on grain and stover/straw yield of maize and wheat crops.

| Treatment | Maize (q $ha^{-1}$) | | Total biological yield (q $ha^{-1}$) | Wheat (q $ha^{-1}$) | | Total biological yield (q $ha^{-1}$) |
|---|---|---|---|---|---|---|
| | Grain | Stover | | Grain | Straw | |
| | | | Without sulphur | | | |
| Control | 4.94 | 12.89 | 17.83 | 5.77 | 14.26 | 20.03 |
| 100% N | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 100% NPK (-S) | 9.11 | 21.78 | 30.89 | 9.43 | 22.80 | 32.23 |
| | | | With sulphur | | | |
| 100% NP | 10.94 | 25.57 | 36.51 | 11.57 | 25.77 | 37.33 |
| 100% NPK + Zinc | 24.60 | 58.22 | 82.82 | 17.90 | 37.90 | 55.80 |
| 100% NPK + HW | 28.12 | 64.22 | 92.34 | 20.60 | 51.60 | 72.23 |
| 100% NPK + lime | 39.99 | 92.44 | 132.43 | 28.10 | 64.53 | 92.63 |
| 50% NPK | 16.04 | 38.00 | 54.04 | 13.37 | 31.70 | 45.07 |
| 100% NPK | 27.27 | 57.78 | 85.05 | 18.23 | 41.77 | 60.00 |
| 100% NPK + FYM | 43.38 | 95.57 | 138.95 | 33.66 | 65.90 | 99.56 |
| 150% NPK | 25.58 | 56.67 | 82.25 | 17.53 | 43.13 | 60.66 |
| CD at ≤ 0.05 | 3.62 | 8.42 | - | 3.35 | 9.23 | - |

Table 2. Sulphur concentration (%) in maize and wheat as affected by long-term use of chemical fertilizers and amendments.

| Treatment | Maize | | Wheat | |
|---|---|---|---|---|
| | Grain | Stover | Grain | Straw |
| | | Without sulphur | | |
| Control | 0.045 | 0.034 | 0.176 | 0.012 |
| 100% N | 0.000 | 0.000 | 0.000 | 0.000 |
| 100% NPK (-S) | 0.074 | 0.069 | 0.186 | 0.013 |
| | | With sulphur | | |
| 100% NP | 0.192 | 0.108 | 0.163 | 0.014 |
| 100% NPK + Zinc | 0.175 | 0.113 | 0.203 | 0.020 |
| 100% NPK + HW | 0.174 | 0.108 | 0.186 | 0.019 |
| 100% NPK + lime | 0.196 | 0.106 | 0.176 | 0.019 |
| 50% NPK | 0.130 | 0.089 | 0.156 | 0.017 |
| 100% NPK | 0.175 | 0.103 | 0.186 | 0.019 |
| 100% NPK + FYM | 0.199 | 0.117 | 0.236 | 0.017 |
| 150% NPK | 0.171 | 0.096 | 0.187 | 0.016 |
| Mean | 0.139 | 0.086 | 0.169 | 0.015 |

Table 3. Long-term effects of chemical fertilizers and amendments on sulphur uptake by maize and wheat crop.

| Treatment | Maize (kg $ha^{-1}$) | | | Wheat (kg $ha^{-1}$) | | |
|---|---|---|---|---|---|---|
| | Grain | Stover | Total | Grain | Straw | Total |
| | | Without sulphur | | | | |
| Control | 0.22 | 0.45 | 0.67 | 1.01 | 0.17 | 1.18 |
| 100% N | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 100% NPK (-S) | 0.66 | 1.66 | 2.32 | 1.77 | 0.30 | 2.07 |
| | | With sulphur | | | | |
| 100% NP | 2.11 | 2.78 | 4.89 | 1.90 | 0.35 | 2.25 |
| 100% NPK + Zinc | 4.30 | 6.64 | 10.94 | 3.60 | 0.74 | 4.34 |
| 100% NPK + HW | 4.92 | 7.31 | 12.23 | 3.86 | 1.00 | 4.86 |
| 100% NPK + lime | 7.82 | 9.88 | 17.70 | 4.96 | 1.24 | 6.20 |
| 50% NPK | 2.09 | 3.48 | 5.57 | 2.10 | 0.54 | 2.64 |
| 100% NPK | 4.79 | 5.99 | 10.78 | 3.42 | 0.81 | 4.23 |
| 100% NPK + FYM | 8.82 | 11.17 | 19.99 | 7.95 | 1.11 | 9.06 |
| 150% NPK | 4.38 | 5.48 | 9.86 | 3.28 | 0.69 | 3.97 |
| CD at ≤ 0.05 | 0.82 | 1.36 | - | 0.86 | 0.25 | - |

Varavipour *et al*. (1999), Sakal *et al*. (2000) and Sharma and Manohar (2002) also reported increase in the yield of wheat crop due to addition of sulphur fertilizers. Increasing rates of fertilization from sub-optimal to optimum level resulted in increase in yield of wheat crop which might be attributed to the balanced fertilization with nitrogen, phosphorus, potash and sulphur. These results corroborated with the findings of Singh and Singh (1979), Kumar *et al*. (1986), Sachidanand *et al*. (1988), Chandel *et al*. (1989) and Chowdhary *et al*. (1995). Application of FYM along with recommended doses of fertilizers resulted in highest yield of wheat grain and straw. This increase may be due to addition of FYM which besides supplying all the essential nutrients might have also improved the physico-chemical properties of the soil. Singh and Agarwal (2005) also reported the similar results. Mundra *et al*. (2003) also reported higher yield of wheat with 125% of recommended N, P and K application along with 10 t $ha^{-1}$ FYM. Wheat yield also increased with addition of lime. Increase in wheat grain and straw yields in 100% NPK + lime treated plots might be ascribed to the higher nutrient availability due to ameliorating effect of liming on soil acidity as the pH value increased to 6.38 from its initial value of 5.80.

*Effect of chemical fertilizers and amendments on sulphur concentration in maize and wheat crops:* Sulphur concentration in grain and straw samples of wheat and maize varied with different treatments being lowest in 50% NPK which might be due to the application of sub-optimal dose of sulphur fertilizers through single super phosphate which was not sufficient to meet out the crop sulphur requirements. The treatment 100% NPK without sulphur showed relatively higher concentration of sulphur in wheat grains which may be due to the lower dry matter yield in that plot over 100% NP and control (Table 2). In the treatment, where N was applied alone (100% N), yield recorded was zero hence, sulphur content could not be recorded. Maximum concentration of sulphur in grain samples of wheat and maize was recorded in 100% NPK + FYM treated plots which may be due to higher availability of sulphur as FYM also contributed to the sulphur pool in the soil. With the increase in rates of N and P fertilizers through urea and single super phosphate, there was an increase in sulphur supply and hence, the sulphur content in wheat grain, maize grain and stover also increased with the maximum value in 100% NPK + FYM treated plot (Table 2) which was in line with the findings of Setia and Sharma (2004), who also reported significant increase in the sulphur content in plants due to combined effect of N and P. The lowest concentration of sulphur in wheat straw, maize grain and stover samples was in unfertilized control plot followed by 100% NPK without sulphur treatment which may be due to non-application of sulphur fertilizers and low content of available sulphur in the soils (Table 3).

Addition of P fertilizers along with N also resulted in an increase in sulphur concentration of grain and straw/stover of both the crops as compared to control, 100% N and 100% NPK without sulphur treatment which might due to addition of sulphur through SSP in the 100% NP treated plots. Setia and Sharma (2004) also reported that combined effect of N and P significantly increased the sulphur content in plants. The lower concentration of sulphur in both maize and wheat grain and straw samples at 150% NPK level may be due to less availability of sulphur because of the low pH value as compared to 100% NPK and 100% NPK + FYM treated plots as sulphur availability is high in the neutral pH range. K along with N and P (100% NPK) resulted in lower content of sulphur in maize grain as well as straw as compared to 100% NP which may be due to high dry matter yield and hence, the dilution effect.

*Effect of chemical fertilizers and amendments on uptake of sulphur by maize and wheat crops:* Uptake of sulphur by maize and wheat crop varied with different treatments (Table 3). Unfertilized control plot gave lowest uptake of sulphur by grain and stover/straw of both maize and wheat which may be attributed to lowest dry matter yield (Table 1). Reduction in sulphur uptake in 100% NPK without sulphur treated plots over other differently fertilized plots may also be due to lower dry matter yield. In the 100% N treated plot, there was no biological yield hence the uptake was zero. Addition of P along with N (100% NP) brought about an increase in the uptake of sulphur as compared to 100% NPK without sulphur treatment. Islam *et al*. (2006) reported similar findings and attributed this increase in uptake of sulphur in 100% NP to the synergistic interaction between P and S. With the increasing rates of fertilizers from 50 to 150% NPK, both wheat and maize crops showed increased sulphur uptake which may be due to application of increasing levels of sulphur through SSP and also due to increased crop yields. Increase in sulphur uptake with the addition of increasing rates of sulphur was also reported by Sharma (1991), Sinha and Sakal (1993), Rakesh (1999) and Teotia *et al.* (2000). Application of FYM with 100% NPK resulted in an increase in the sulphur uptake over 100% NPK. This increase may be attributed to addition of sulphur and other macro and micro nutrients through FYM, thus, increasing the availability of all the nutrients in soil. With the application of lime, the increase in sulphur uptake may be due to liming effect which raised the pH of soil to 6.38 from the initial value 5.8 and pH has a direct effect on nutrient availability in the soil.

## Conclusion

Continuous use of imbalanced inorganic fertilizers resulted in reduced crop yields. Application of 100% N alone caused complete crop failure and loss of productivity, while omission of K also reduced the yields significantly.

The addition of lime and FYM along with inorganic fertilizers resulted in the highest yield and thus, sustained productivity. Application of super-optimal (150% NPK) and sub-optimal (50% NPK) doses also reduced the yields in comparison to optimal dose. Use of DAP as P source resulted in sulphur deficiency and thus reduced yields. The sulphur uptake by the maize crop followed the trend of maize yield. In general, FYM and lime treatments resulted in highest sulphur uptake values. Lime addition raised the pH of soil and thus, increased the nutrient availability. The increase in sulphur uptake in FYM treated plots may be due to extra amount of nutrients supplied by FYM and due to the beneficial effect of organic matter on the sulphur availability and the physico-chemical properties of soil. Balanced application of NPK fertilizers with FYM and lime improved soil quality, sustained crop productivity and availability of sulphur. Application of N alone for 35 years had the most deleterious effect on soil properties and the crop productivity leading to complete failure of crops. Most strikingly, application of sulphur in soil increased the sulphur availability in soil solution for plant uptake.

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