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*Full Length Research Paper*

# Effects of sulphur and zinc applications on growth and nutrition of bread wheat in calcareous clay loam soil

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**The objective of this study was to evaluate the effects of sulphur (S) and zinc (Zn) on soil pH and electrical conductivity (EC), nitrogen (N), S, iron (Fe), Zn, N:S ratio; and straw and grain dry weight of wheat grown in a calcareous clay loam soil. For this purpose, a pot experiment was conducted in greenhouse conditions. Sulphur was applied at 0, 10, 50, 250 mg Skg$^{-1}$ (as $CaSO_4.2H_2O$) and zinc at 0, 5 mg Znkg$^{-1}$ (as $ZnSO_4.7H_2O$) to the soil. The soil pH decreased by S alone. The soil EC increased due to increase in sulphur with zinc. The straw S concentration increased by sulphur alone. In the 250 mg Skg$^{-1}$ application to soil, the straw S concentration increased by 28.13% when compared with 0 mg Skg$^{-1}$ treatment. The concentrations of grain S and Fe, straw Zn, straw and grain N and N:S ratios were not significantly affected by sulphur and zinc. The grain Zn concentration was significantly increased by sulphur with zinc. In the 250 mg Skg$^{-1}$ with 5 mg Znkg$^{-1}$ application to the soil, the grain Zn concentration increased 38.47% when compared with no sulphur and zinc treatment to soil. The zinc treatment led to a significantly reduced straw Fe concentration. The straw dry weight was significantly affected by sulphur alone and it increased from 2.53 to 3.86%. The grain dry weight was significantly affected by zinc alone and it decreased by 12.18%. But, the grain zinc concentration increased 25% by increasing the zinc. The results suggest that application of sulphur and zinc could be a good approach for the nutrition of wheat plants. However, the generated salinity was high for sulphur applications, which means that plants might be faced high salinity problems. Also, with the application of high sulphur to plants, it should be considered that an N:S imbalance can occur. On the other hand, N:S imbalance can occur in crops grown in high N fertility in especially, S-deficient soils. Therefore, the levels of electrical conductivity, pH, texture, $CaCO_3$, organic matter, sulphur and nitrogen of soils and cultivated plant species should be taken into consideration when recommending sulphur and zinc application to soils.**

**Key words:** Sulphur, zinc, soil pH, soil salinity, calcareous soil, wheat, N, Fe, Zn, N:S ratio.

## INTRODUCTION

Sulphur (S) and zinc (Zn) are important elements in wheat nutrition. S deficiency can exert a large influence on the technological properties of wheat (Randall and Wrigley, 1986; Zhao et al., 1999a). Sulphur deficiency has been reported to produce doughs that are less extensible and more resistant to extension and loaves of smaller volume and of poorer texture (Moss et al., 1981, 1983; MacRitchie and Gupta, 1993; Zhao et al., 1999b, c). Zhao et al. (1999c) reported that while the grain yield of wheat was increased by increasing the rate of S to 20 kg Sha$^{-1}$, loaf volume was increased by increasing the rate of S to 100 kg S ha$^{-1}$ to soil. Also, loaf volume increased 6% in application of 46 kg Sha$^{-1}$ to soil compared to control (Schnug et al., 1993). These results are an indication that there is still need to apply S fertilizer to wheat in many areas to maintain breadmaking quality (Zhao et al., 1999b, c). As in all plants, the interaction between the nitrogen and sulfur nutrition is very important in wheat plant. The sulphur contents are influenced not only by sulphur fertilizers, but nitrogen

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fertilizers as well and due to the strong N-S relationships, fluctuations in protein contents also caused decreases/increases in the S contents of the wheat grain (Gyori, 2005). Cakmak et al., (2009) reported that higher amounts of the applied sulphur to calcareous chernozem soil caused a decline in the yield of wheat grain and a decrease of nitrogen content. Therefore, in the application of S to plants, it should be considered that an N:S imbalance can occur. The N:S imbalance occurs at ratios greater than 14.8 according to Bergmann (1992); 16 according to Zhao et al. (1999 c) and 13.1 according to Reussi et al. (2011) in wheat grains.

Zn and iron (Fe) deficiencies are the most common micronutrient deficiencies in human populations affecting the health of over three billion people worldwide (Welch and Graham, 2004; Cakmak et al., 2010). Welch (2001) indicated that the grains of 384 wheat genotype ranged from 27 to 85 mg $kg^{-1}$ of Zn concentrations and 30 to 73 mg $kg^{-1}$ of Fe concentrations. In Turkey, the grain Zn concentrations ranged from 20 to 30 mg $kg^{-1}$ in applied Zn or adequate Zn conditions, but the values ranged from 5 to 12 mg $kg^{-1}$ in Zn deficient conditions (Kalaycı et al., 1999; Erdal et al., 2002). Improving the concentration of the Zn and Fe in the grain of cereal crops to enhance their nutritive value and improve human health, or biofortification, has been a focus of much research over the past decade (Graham et al., 1999; Grusak, 2002; Cakmak, 2008). Analyses of grain mineral nutrient concentrations often show that the concentrations of Zn (and Fe) are significant correlated with grain S concentrations (McDonald and Mousavvi, 2009). Also, S is biologically oxidized to $H_2SO_4$ in soil under aerobic conditions. The oxidation of S to $H_2SO_4$ is particularly beneficial in alkaline soils to reduce pH, supply $SO_4^{2-}$ to plants, make phosphorus (P) and micronutrients more available, and reclaim soils (Burns, 1967). The use of S to decrease soil pH and increase the solubility of metals in soils has been suggested (Kayser et al., 2000; Seidel et al., 1998; Tichý et al., 1994). It is important to find a sustainable, long-term solution to increased availability of Zn and Fe in soils in order to correct plant Zn and Fe deficiency and their accumulation in crops grown for human consumption.

The aim of this study was to clarify the role of S and Zn treatments on soil pH and electrical conductivity (EC), S, N, Zn and Fe nutrition and N:S ratio of bread wheat in calcareous clay loam soil.

## MATERIALS AND METHODS

A total of 5 kg of sieved soil was placed in pots with holes at the bottom. Before sowing the seeds, the following nutrients were homogeneously incorporated into the soil; sulphur as $CaSO_4.2H_2O$ (16.8% S) at four levels 0 ($S_0$), 10 ($S_{10}$), 50 ($S_{50}$), 250 ($S_{250}$) mg $kg^{-1}$ and zinc as $ZnSO_4.7H_2O$ (22% Zn) at two levels 0 ($Zn_0$), 5 ($Zn_5$) mg $kg^{-1}$ according to completely randomized design factorial with 4 replicates. Also, 40 kg $da^{-1}$ 15.15.15 (15% N, 15% $P_2O_5$ and 15% $K_2O$) as basal fertilizers was applied to each pot. Twenty seeds were sown in each pot and the wheat plants were grown during 100 days in greenhouse conditions. The pots were equally watered. After 100 days, the plant shoots were harvested. The term “shoot” was used to refer to all above-ground parts of wheat plants including the grains; and the term “straw” was used to refer to the shoot excluding the grains. The grains and straws were washed with deionized water and then dried at 60°C for 72 h. They were weighed in order to determine their dry matter. All samples were ground and analyzed for S, N, Zn and Fe concentrations. Also, at the end of the experiment, the soil samples were taken from all pots for the determination of pH and EC levels.

In the straw and grain samples, total N was determined by a modified Kjeldahl procedure (Kacar and İnal, 2008). Total S, Fe, and Zn concentrations of dried samples (after wet digestions) were determined by using ICP-OES (Kacar and İnal, 2008).

The soil pH and EC was measured in water (1 : 2.5, soils : deionized water). The soil particle-size analysis was done by using the hydrometer method (Bouyoucos, 1955) and the $CaCO_3$ content was determined by using a Scheibler calcimeter. Organic matter was determined by using modified Walkley-Black Procedure (Black, 1965). The total N of soil was done by using modified Kjeldahl Procedure (Kacar, 2009). The extractable $SO_4^{2-}$-S of soil was extracted by 0.025 M KCl and determined by using ICP-OES (Bloem et al., 2002). The concentrations of DTPA-extractable Fe and Zn (by using ICP-OES) of soil were made according to Lindsay and Norvell (1978).

A calcareous clay loam soil was used in the experiment. Selected soil chemical and physical properties are given in Table 1.

### Statistical analyses

The data were analyzed by standard ANOVA procedures and their significances were based on $P<0.05$ level using the LSD tests.

## RESULTS AND DISCUSSION

The effects of applications of sulphur and zinc on soil pH are given in Table 2. Soil pH decreased significantly with the supply of S to the soil. However, Zn supply did not significantly affect soil pH. The highest pH decreased occurred in the 250 mg $kg^{-1}$ S treatment. Soil pH declined by 0.20 unit of the S level. Elemental S and S containing materials were biologically oxidized to $H_2SO_4$ in the soil, under aerobic conditions and this led to soil acidification (Richards, 1954). Kaplan and Orman (1998) reported that with time, the decrease in soil pH was from 0.07 to 0.35 units due to increasing elemental sulphur treatments to calcareous soil and the soil pH decreased up to the 5th week after which the pH started to increase. Lucas (1982) indicated that applied 1120 kg S $ha^{-1}$ in 0.4 unit decreased in soil pH and the decrease was important in practice. Orman and Kaplan (2011) reported that 3 weeks after application of 200 ppm elemental S to calcareous sandy loam soil, it resulted in 0.18 unit decrease in soil pH, according to control soil. Cui and Wang (2005) indicated that soil pH decreased significantly due to elemental S applications to soil, however, Zn supply did not induce soil pH change at the rate of sulphur ($S_0$).

Soil EC significantly increased by both S and Zn treatments (Table 2). This effect was particularly

**Table 1.** Physical and chemical properties of soil used.

| Parameter | Soil |
|---|---|
| Sand (%) | 25 |
| Clay (%) | 32 |
| Silt (%) | 43 |
| Texture | Clay loam |
| pH | 8.05 |
| $CaCO_3$ (%) | 17.71 |
| EC (dS $m^{-1}$) | 0.26 |
| Organic matter (%) | 1.50 |
| Total N (%) | 0.09 |
| Extractable $SO_4$-S (mg $kg^{-1}$) | 16.50 |
| Extractable Fe (mg $kg^{-1}$) | 4.47 |
| Extractable Zn (mg $kg^{-1}$) | 0.16 |

**Table 2.** Effects of sulphur and zinc treatments on soil pH and EC values.

| Sulphur treatment | Soil pH[a] | | | Soil EC (dS $m^{-1}$)[a] | | |
|---|---|---|---|---|---|---|
| | $Zn_0$ | $Zn_5$ | Means | $Zn_0$ | $Zn_5$ | Means |
| $S_0$ | 8.32 | 8.29 | 8.31 A | 0.31 C, a | 0.33 C, a | 0.32 |
| $S_{10}$ | 8.30 | 8.32 | 8.31 A | 0.34 C, a | 0.32 C, a | 0.33 |
| $S_{50}$ | 8.24 | 8.25 | 8.25 B | 0.45 B, a | 0.43 B, a | 0.44 |
| $S_{250}$ | 8.12 | 8.09 | 8.11 C | 0.99 A, b | 1.22 A, a | 1.11 |
| Means | 8.25 | 8.24 | | 0.52 | 0.58 | |
| ANOVA[b] | | | | | | |
| S | | ** | | | ** | |
| Zn | | N.S. | | | ** | |
| S*Zn | | N.S. | | | ** | |

[a], Values are means of four independent replicates. Mean values in a column followed by different uppercase letters and mean values in a row followed by different lowercase letters are significantly different by LSD test at the 5% level; [b], significance levels; ** ,P< 0.01; N.S, not significant.

significant in the highest S with Zn. It is known that $SO_4^{2-}$ anions cause an increase in salt content of soils. In this present study, because S was applied to soil as $CaSO_4.2H_2O$ and zinc as $ZnSO_4.7H_2O$, electrical conductivity of the experimental soil increased. Therefore, soil EC should be determined before the application of S to soils. High rates of S should be avoided, especially in soils with high EC level. The plants growing in such soils may face high salinity problems due to the generated salinity. Our previous studies indicated that while the soil pH was decreased, soil EC was increased in both calcareous clay soil and calcareous sandy loam soil by the elemental S applications (Kaplan and Orman, 1998; Orman and Kaplan, 2011). Also, Orman and Kaplan (2009) reported that a significant positive correlation was found between the $SO_4^{2-}$-S content and electrical conductivity (EC) of tomato greenhouse soils in the West Mediterranean region in Turkey. Ulgen et al. (1989) determined a significant positive correlation between the total salt content of the soils and S contents. They have also reported that the increase in salinity of the soils causes an increase in the available S contents. Soaud et al. (2011) reported that soil pH decreased, soil EC and S concentration increased with the addition of elemental S to calcareous soils.

The effects of applications of S and Zn on concentrations of N, S, and N:S ratio are presented in Table 3 for straw and in Table 4 for grain of wheat. There were no significant differences in the concentrations of straw N and grain N of wheat due to S and Zn treatments. However, grain N concentration increased by S with Zn treatments up to 50 mg S $kg^{-1}$ level. Reussi Calvo et al. (2008) reported that applied S (0, 5, 10 and 20 kg S $ha^{-1}$ as calcium sulphate) to four soil types did not increase N concentration in wheat plant. Kutman et al. (2010) indicated that N and Zn fertilization had a synergistic effect on grain Zn concentration of durum wheat.

**Table 3.** Effects of sulphur and zinc on N and S concentrations; and N:S ratio of wheat straw.

| Sulphur treatment | N (%)[a] | | | S (%)[a] | | | N:S [a] | | |
|---|---|---|---|---|---|---|---|---|---|
| | $Zn_0$ | $Zn_5$ | Means | $Zn_0$ | $Zn_5$ | Means | $Zn_0$ | $Zn_5$ | Means |
| $S_0$ | 0.47 | 0.41 | 0.44 | 0.23 | 0.23 | 0.23 B | 2.04 | 1.77 | 1.91 |
| $S_{10}$ | 0.48 | 0.44 | 0.46 | 0.27 | 0.24 | 0.26 BC | 1.83 | 1.88 | 1.86 |
| $S_{50}$ | 0.43 | 0.46 | 0.44 | 0.29 | 0.28 | 0.29 B | 1.50 | 1.58 | 1.54 |
| $S_{250}$ | 0.47 | 0.51 | 0.49 | 0.30 | 0.34 | 0.32 A | 1.57 | 1.51 | 1.54 |
| Means | 0.46 | 0.46 | | 0.27 | 0.27 | | 1.74 | 1.69 | |
| ANOVA[b] | | | | | | | | | |
| S | N.S. | | | ** | | | N.S. | | |
| Zn | N.S. | | | N.S. | | | N.S. | | |
| S*Zn | N.S. | | | N.S. | | | N.S. | | |

[a], Values are means of four independent replicates. Mean values in a column followed by different uppercase letters are significantly different by LSD test at the 5% level; [b], significance levels, **, P< 0.01; N.S, not significant.

**Table 4.** Effects of sulphur and zinc on N and S concentrations; and N:S ratio of wheat grain.

| Sulphur treatment | N (%)[a] | | | S (%)[a] | | | N:S [a] | | |
|---|---|---|---|---|---|---|---|---|---|
| | $Zn_0$ | $Zn_5$ | Means | $Zn_0$ | $Zn_5$ | Means | $Zn_0$ | $Zn_5$ | Means |
| $S_0$ | 2.32 | 2.46 | 2.39 | 0.20 | 0.20 | 0.20 | 11.80 | 12.22 | 12.01 |
| $S_{10}$ | 2.42 | 2.44 | 2.43 | 0.21 | 0.22 | 0.22 | 12.03 | 11.38 | 11.70 |
| $S_{50}$ | 2.37 | 2.47 | 2.42 | 0.21 | 0.21 | 0.21 | 11.42 | 11.74 | 11.58 |
| $S_{250}$ | 2.34 | 2.30 | 2.32 | 0.21 | 0.22 | 0.22 | 11.29 | 10.35 | 10.82 |
| Means | 2.36 | 2.42 | | 0.21 | 0.21 | | 11.63 | 11.42 | |
| ANOVA[b] | | | | | | | | | |
| S | N.S. | | | N.S. | | | N.S. | | |
| Zn | N.S. | | | N.S. | | | N.S. | | |
| S*Zn | N.S. | | | N.S. | | | N.S. | | |

[a], Values are means of four independent replicates; [b], significance levels; N.S; not significant.

The straw S concentration was increased by S alone. High level of applied S (250 mg $Skg^{-1}$) increased S concentrations significantly from 0.23 to 0.32% in wheat straw when compared with $S_0$ treatments. De Ruither and Martin (2001) reported that higher remobilization or excessive S retention in wheat stems may also be a plausible explanation, as the concentration and level of S in non-grain fractions were responsive to S fertilizer treatment, at both anthesis and maturity harvests. Inal et al. (2003) reported that straw S concentrations of the samples collected from in Ankara/Turkey ranged from 0.03 to 0.31% with an average value of 0.11%.

The S concentration of grain increased with increase in S levels, but increases in grain S was found not to be statistically significant. While the grain S concentration was 0.20% in $S_0$ (0 mg $Skg^{-1}$) treatment, this value increased by 0.22% as the average of other three S treatments. According to Martin (1997), S concentration should range from 0.18 to 0.25% in wheat grains. Grain S concentration values in excess of 0.20% are considered higher than the requirement for high quality bread flour (Moss et al., 1981; 1983). Inal et al. (2003) reported that shoot S concentrations of bread and durum wheat was significantly increased by S applications in greenhouse conditions. The same researchers indicated that S concentrations in the shoot and grain were increased by S applications, but in the grain, S was found not to be statistically significant in field conditions.

The N:S ratio in both straw and grain was not significantly affected by S and Zn treatments to soil. However, straw N:S and grain N:S ratios decreased due to S and Zn treatments. Inal et al. (2003) reported that the ratio of N:S in shoot and grain of wheat decreased by the addition of S. De Reutier and Martin (2001) found that application of S fertilizer significantly reduced the N:S ratio of wheat grain at maturity. The wheat plant generative organs more sensitive to the lack of S compared to vegetative organs and grain size decreases

**Table 5.** Effects of sulphur and zinc on Zn and Fe concentrations; and dry weight of wheat straw.

| Sulphur treatment | Zn (mg kg$^{-1}$) [a] | | | Fe (mg kg$^{-1}$)[a] | | | Straw dry weight (g pot$^{-1}$) [a] | | |
|---|---|---|---|---|---|---|---|---|---|
| | $Zn_0$ | $Zn_5$ | Means | $Zn_0$ | $Zn_5$ | Means | $Zn_0$ | $Zn_5$ | Means |
| $S_0$ | 20.45 | 21.18 | 20.82 | 35.78 | 33.53 | 34.65 | 12.92 | 12.46 | 12.69 AB |
| $S_{10}$ | 19.03 | 20.10 | 19.57 | 39.23 | 24.03 | 31.63 | 12.39 | 12.28 | 12.34 B |
| $S_{50}$ | 23.48 | 28.58 | 26.03 | 44.45 | 25.63 | 35.04 | 12.72 | 13.67 | 13.20 A |
| $S_{250}$ | 20.33 | 19.00 | 19.67 | 47.50 | 34.73 | 41.11 | 12.86 | 13.18 | 13.02 A |
| Means | 20.82 | 22.22 | | 41.74 a | 29.48 b | | 12.72 | 12.90 | |
| ANOVA[b] | | | | | | | | | |
| S | | N.S. | | | N.S. | | | * | |
| Zn | | N.S. | | | ** | | | N.S. | |
| S*Zn | | N.S. | | | N.S. | | | N.S. | |

[a], Values are means of four independent replicates. Mean values in a column followed by different uppercase letters and mean values in a row followed by different lowercase letters are significantly different by LSD test at the 5% level; [b], significance levels; *, P<0.05; **, P< 0.01; N.S, not Significant.

**Table 6.** Effects of sulphur and zinc on Zn and Fe concentrations; and dry weight of wheat grain.

| Sulphur treatment | Zn (mg kg$^{-1}$) [a] | | | Fe (mg kg$^{-1}$)[a] | | | Grain dry weight (g pot$^{-1}$) [a] | | |
|---|---|---|---|---|---|---|---|---|---|
| | $Zn_0$ | $Zn_5$ | Means | $Zn_0$ | $Zn_5$ | Means | $Zn_0$ | $Zn_5$ | Means |
| $S_0$ | 15.18 B, b | 23.98 A, a | 19.58 | 28.98 | 28.78 | 28.88 | 4.56 | 4.30 | 4.43 |
| $S_{10}$ | 17.96 A, b | 22.63 A, a | 20.29 | 28.22 | 34.73 | 31.48 | 4.21 | 3.55 | 3.88 |
| $S_{50}$ | 17.78 A, b | 23.44 A, a | 20.61 | 36.78 | 34.33 | 35.55 | 4.44 | 3.59 | 4.02 |
| $S_{250}$ | 20.13 A, b | 24.67 A, a | 22.40 | 33.99 | 34.22 | 34.10 | 4.21 | 3.84 | 4.03 |
| Means | 17.76 | 23.68 | | 31.99 | 33.01 | | 4.35 a | 3.82 b | |
| ANOVA[b] | | | | | | | | | |
| S | | * | | | N.S. | | | N.S. | |
| Zn | | ** | | | N.S. | | | ** | |
| S*Zn | | * | | | N.S. | | | N.S. | |

[a], Values are means four independent replicates. Mean values in a column followed by different uppercase letters and mean values in a row followed by different lowercase letters are significantly different by LSD test at the 5% level; [b] significance levels; *, P<0.05; **, P< 0.01; N.S, not significant.

in the S deficient conditions (Zhao et al., 1999c). The ratio of N:S, which is a reliable indicator of S deficiency, changed greatly in favor of N in the case of S deficiency. Reussi et al. (2011) indicated that spring red wheat grains with S deficiency were determined as those with a total S concentration lower than 0.15% and a total N:S ratio higher than 13.1:1. Wheat grown in England rarely has N:S ratios exceeding 16 (Zhao et al., 1999c) and there is an indication that an N:S imbalance occurs at ratios greater than 16. In our study, while the N:S ratio of wheat grain was 12.01 in the $S_0$ (0 mg Skg$^{-1}$) treatment, the value decreased to 10.82 in the $S_{250}$ ( 250 mg Skg$^{-1}$) treatment. Therefore, with the application of S to plants, it should be considered that an N:S imbalance can occur. Janzen and Bettany (1984) found that maximum rapeseed yield was obtained only when the availability of N and S were in approximate balance. When the optimum ratio of available N to available S in the soil was estimated to be 7:1, they found that excessive S application relative to N availability produced excessive accumulation of S in plant tissue and reduced seed yields.

The effects of applications of S and Zn on concentrations of Zn, Fe, and dry weight are given in Table 5 for straw and in Table 6 for grain of wheat. The effects of S and Zn treatments were not significant on straw Zn concentration. However, the highest Zn concentration of straw (26.03 mg Znkg$^{-1}$) was obtained by the level of 50 mg kg$^{-1}$ S application. Also, while the Zn concentration of straw was 20.82 mg Znkg$^{-1}$ in 0 mg kg$^{-1}$ Zn treatment, the value was 22.22 mg Znkg$^{-1}$ in 5 mg kg$^{-1}$ Zn treatment. The straw Fe concentration was not significantly affected by S alone and sulphur and zinc interactions, but the highest Fe concentration of straw was obtained from 250 mg kg$^{-1}$ S treatment. While the straw Fe concentration was 34.65 mg Fekg$^{-1}$ in 0 mg kg$^{-1}$ S treatment, the value was 41.11 mg Fekg$^{-1}$ in 250 mg kg$^{-1}$ S treatment. Gunes et al. (2008) reported that applied S (as gypsum) increased Fe concentration of silage corn. The straw Fe concentration was significantly affected by Zn treatment. The straw Fe concentration was sharply decreased due to Zn treatment. While the straw Fe concentration was 41.74 mg Fekg$^{-1}$ in 0 mg kg$^{-1}$ Zn treatment, the value was 29.48 mg Fekg$^{-1}$ in 5 mg kg$^{-1}$ Zn treatment. Ghasemi-Fasaei and Ronaghi (2008) reported that Fe application to calcareous soil increased Fe uptake, but decreased Zn uptake in wheat plant. In our study, Zn application to soil decreased Fe concentrations of wheat straw. Therefore, Zn application might cause nutritional disorder due to the antagonistic effect of Fe and Zn.

The effects of S and Zn treatment were not significant on grain Fe concentration. However, the highest Fe concentration of grain was determined in the 50 mg Skg$^{-1}$ treatment to soil. Also, while the Fe concentration of grain was 28.88 mg Fekg$^{-1}$ in 0 mg kg$^{-1}$ S treatment, the value was 35.55 mg Fekg$^{-1}$ in 50 mg kg$^{-1}$ S treatments. McDonald and Mousavvi (2009) reported that wheat grain Fe concentration was enhanced by about 30% with additional S (15, 35 and 55 mg S kg$^{-1}$ as $K_2SO_4$ to soil). In this study, increasing S from 0 to 50 mg kg$^{-1}$ raised grain Fe concentration by about 18.76%.

The grain Zn concentration was significantly affected by both S and Zn treatments. While the grain Zn concentration in $S_0Zn_0$ treatment was 15.18 mg Znkg$^{-1}$, the value was 24.67 mg Znkg$^{-1}$ in $S_{250}Zn_5$ treatment and it increased by 38.47%. McDonald and Mousavvi (2009) reported that increasing S from 15 to 55 mg kg$^{-1}$ raised wheat grain Zn concentration by 40-50%. There are various physiological steps in plant tissues where N (and also S) nutrition can act positively to promote high grain accumulation of Zn and Fe (Cakmak et al., 2010).

The straw dry weight was significantly affected by the S treatments alone. The highest straw dry weight was obtained by the level of 50 mg kg$^{-1}$ S. While the straw dry weight was 12.69 g pot$^{-1}$ in 0 mg kg$^{-1}$ S treatment, the value was 13.20 g pot$^{-1}$ in 50 mg kg$^{-1}$ S treatment and it increased by 3.86%. Wheat yield increase of 2.9% over the control was recorded with 25 kg S ha$^{-1}$ as gypsum (Kharub and Dhillon, 2007). The grain dry weight was significantly affected by the zinc treatments alone. The grain dry weight of wheat was decreased 12.18% by increasing Zn treatment. In our study, the grain Zn concentration increased, but the grain dry weight decreased due to increasing Zn treatment. Gomez-Becerra et al. (2010) indicated that higher grain Zn concentration is not attributable to smaller seed size or seed weight which may result in “concentration effects”.

## Conclusion

Application of S may decrease soil pH and increase soil EC. It is known that $SO_4^{2-}$ anion in soils increases soil salinity and salt load of drainage water. The generated salinity was high of S applications, which means that plants might be faced with high salinity problems. Also, with the application of high S to plants, it should be considered that an N:S imbalance can occur. The N:S imbalance can occur in crops grown in high fertility N in, especially, S-deficient soils.

Sulphur and zinc fertilization may increase concentration of Zn in grain of cereal crops to enhance their nutritive value and improve human health, or biofortification. However, the Zn application to soil may cause nutritional disorder due to the antagonistic effect of Fe and Zn. The results suggest that application of S and Zn could be a good approach for the nutrition of wheat plants. However, the levels of electrical conductivity, pH, texture, $CaCO_3$, organic matter, S and N of soils and cultivated plant species should be taken into consideration when recommending S and Zn application to soils.

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