RESEARCH ARTICLE

IMPACT OF SULPHUR AND BORON ADDITION ON SOIL CHEMICAL PROPERTIES, ACTIVITY OF SOIL ENZYMES AND LENTIL PRODUCTION IN RED SOILS OF VINDHYAN REGION, UTTAR PRADESH

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Received-01.05.2021, Revised-18.05.2021, Accepted-30.05.2021

Abstract: In red soil, secondary nutrient deficiency, especially sulphur (S) and micronutrients (such as B), has resulted in low fertility. Due to the severe shortage of high-quality pulses, researchers have become increasingly interested in the availability of S and B in soils. Therefore, four levels of sulphur as gypsum ($CaSO_4.2H_2O$) and four levels of Boron as borax ($Na_2B_4O_7.10H_2O$) were applied to soil in different treatment combinations, along with recommended doses of NPK (40, 60, and 20 kg ha^{-1} N, P, and K, respectively) as urea, diammonium phosphate, and Muriate of potash. With a factorial completely randomised design, this experimental trial was performed in pots and repeated three times. The soil samples were collected and analysed after the harvest of the lentil crop to determine changes in soil pH, EC, organic carbon, availability of cationic DTPA - extractable micronutrient (Zn, Cu, Fe & Mn), urease and dehydrogenase activity. According to the findings, sulphur and boron application reduce soil pH and EC, increased organic carbon. Similarly, it also affects the available Cu and Mn but not significantly. Application of these treatments affects the Zn availability significantly both the years and available Fe in one season only. The lowest pH value (pH 5.74) was observed with the application of 45 kg S ha^{-1} with 3 kg B ha^{-1} and the lowest EC value (0.28 dSm^{-1}) was obtained different levels of boron fertilizers through borax along with RDF application. The soil organic carbon increased from 4.01 to 4.28 mg kg^{-1}. Soil application of sulphur and Boron along with RDF has significantly increased DTPA - extractable Zn (0.57 to 0.72 mg kg^{-1} and non-significantly decreased the soil available DTPA – extractable Cu (0.77 to 0.72 mg kg^{-1}) and increased in Fe (23.49 to 26.26 mg kg^{-1}) and Mn (5.38 to 5.67 mg kg^{-1}) status. The effect of or gypsum and boron on lentil yield found positive and it increased the grain yield 86.17 % as compared to the application of RDF of NPK only.Urease activity was increased from 35.08 to 52.57μg NH_4^+ $g^{-1}hr^{-1}$ and dehydrogenase activity from 113.39 to 141.87 μg TPF g^{-1} soil day^{-1}. The synergistic effect of S and B application along with RDF recorded in lentil yield also. Remarkably, 86.17 % increment was recorded in grain yield of lentil with combined application of S @ 45 kg ha^{-1} and B @ 2 kg ha^{-1}along with RDF (2.29 g $plant^{-1}$) as compared to treatment where only RDF applied (1.23 g $plant^{-1}$).The increasing doses of sulphur through gypsum improved result in crop growth and yield of lentil but a higher dose of boron through borax after 2 kg B ha^{-1} reduces the yield of the lentil crop.The study explains that the treatment combinations had a synergistic effect and it may be concluded that the combinations of sulphur + Boron with primary nutrients increased soil available micronutrient status, enzyme activity and yield of lentil.

Keywords: Gypsum, Borax, Physico-chemical properties, Micronutrients, Soil enzyme activity, Lentil yield

INTRODUCTION

To fulfil the need of a fast-rising population, roughly 250 mt of food grains will be required in the twenty-first century (Kakraliya et al, 2017) and pulses play pivotal role to meet the forecasted food grain demand. Lentil is a major global pulse crop that is cultivated during the winter season with mild winters and hot summers in many countries. Because of its protein-rich grains and straw, it is an essential food legume with a variety of uses as food and feed (Abbeddou *et al.*, 2011).It is grown as a rain-fed crop on 5.48 million hectares worldwide, 6.32 metric tonnes (mt) grain yield and average productivity of 1.15 tha^{-1}. Lentil is grown on around 1.42 million hectares in India, with a yield of 1.13 million tonnes and average productivity of 0.70 tha^{-1}(FAOSTAT 2016). Fertilizer application is a key component of agriculture intensification in India, as it helps to boost crop growth and food production. On the other hand, minerals have a variety of effectson soil properties, especially microbial properties and enzyme activity are unknown (Mandal *et al.*, 2007).

The Vindhyan area is situated in eastern Uttar Pradesh and encompasses Mirzapur, Sonbhadra, and parts of Allahabad and it makes up 5.1 percent of Uttar Pradesh's total territory. Due to a lack of nearly all major nutrients and a few micronutrients (B and Mo), including sulphur, crop production is poor in these soils.The deficiency of sulphur and Boron in acidic soils of the Vindhyan area is exacerbated by low organic matter content and coarse texture. The region is rainfed and about 50 % of the land is suitable for the cultivation of oilseeds and pulses due to its upland topography. Due to a lack of understanding of the function of nutrients, farmers, in general, do not apply fertilisers, especially micronutrients in pulses, and as a result, pulse productivity in this area is very poor.

After nitrogen, phosphorus and potassium, sulphur is the fourth most essential plant nutrient.It is becoming increasingly important in high-quality crop production. Sulphur deficiency has been identified

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across India, according to the TSI-FAI-IFA project study (1997-2006).In 18 states, 46 percent of samples were found to be sulphur deficient, while another 30 percent were found to be medium in available sulphur, indicating that they could be sulphur deficient. The available S in eastern UP soils was found to be deficient to the tune of 68 per cent (Tiwari *et al.*, 2003). In the Mirzapur district and Ballia district, most of the soils are prone to S deficiency. Red and lateritic, coastal sands and alluvial soils of Orissa are more prone to S deficiency to the extent of 88 % and this is growing due to farmers' ignorance of sulphur fertilisers.Sulphur deficiency is gradually becoming widespread in different soils of the country due to the continued use of high analysis sulphur-free fertilisers coupled with intensive cropping, higher crop harvest and higher sulphur removals. In India, crops remove about 1.26 million tonnes (Mt) of S, while fertiliser replenishment is only about 0.76 Mt. (Tiwari and Gupta, 2006). Furthermore, the use-efficiency of added S through external sources is also very low, being only 8–10% (Hegde and Murthy, 2005). Continued depletion of native reserves of S during the post-green revolution period has led to its deficiency in many regions of the country. At present sulphur deficiency is one of the major constraints for the sustainable growth and productivityof 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 fertilisers. External application of the nutrient by fertilisers has been shown to partially alleviate the problem of S deficiency, owing to the unequal supply of the nutrient. At the same time, there has been a lot of variation recorded in the ability of crops and varieties to withstand S deficiency stress (Hawkesford, 2000). Sulphur fertilisation is relatively inexpensive and it improves crop yield and quality significantly.

The amount of available B in Indian soils varies from traces to 8 mg/kg soil. It is deficient in acidic alluvial soils, red and lateritic soils in West Bengal, Orissa, Meghalaya, and Madhya Pradesh, calcareous, alluvial, and red-yellow soils in Bihar and Uttar Pradesh, acidic soils in Assamand to a lesser extent in other states.Boron (B) deficiency is one of the main constraints to agricultural production. In 1980, boron deficiency was recorded at 2% in India (Katyal and Vlek, 1985), but it has now risen to 52%. (Singh, 2012).Boron has a relatively narrow range between its phytotoxic and deficient limit in the soil. B deficiency is becoming more prevalent in large areas, especially in coarse-textured, calcareous soils with low organic matter content.On average, 33% of Indian soils are B-deficient (Tiwari, 2006). Indian soils, particularly eastern and north-eastern parts including Bihar, suffer from the B deficiency (Mondal *et al.*, 1991; Dwivedi *et al.*, 1993; Sarkar *et al.*, 2006). In the Mirzapur district of UP, around 61 % of soils have been found Boron deficient (Singh *et al.*, 2015). Boron is one of the trace elements essential for the vegetative growth and reproductive yield of many crops. Maintaining B in the soil solution is important for plant nutrition (Keren and Bingham, 1985a; Keren, Bingham, and Rhoades, 1985b). Boron affects the absorption of N, P, and K, and a lack of it has changed the proper equilibrium of these three macronutrients.

Enzymes are primarily produced by soil microorganisms and, despite their small quantities, are critical components in the dynamics of soil nutrient transformations (Masto *et al.*, 2006; Ge *et al.*, 2010). Enzymes including urease and dehydrogenase are essential in microbial activities and organic compound transformations (Sannino and Gianfreda, 2001).In the case of soil enzymes, recent findings have been conflicting and contradictory. Furthermore, the current patterns in Many of the short-term studies (Blaise *et al.*, 2005) have identified soil fertility changes from samples taken at the start or end of the cropping sequence. In comparison, information on biological processes that mediate and affect nutrient cycling, such as soil enzymatic action, is limited (Barnard *et al.*, 2006). For the majority of the data on soil enzymes, there was a lot of information available under the long-term application of organic and inorganic amendments. With these details in view, the present research was conducted to determine the impact of sulphur and boron addition on soil chemical properties, the activity of soil enzymes and lentil production in red soils of Vindhyan Region, Uttar Pradesh

MATERIALS AND METHODS

Experimental site and climate:

During the *Rabi* seasons of 2018-19 and2019-20, a pot experiment was carried out in the net house at the Department of Soil Science and Agricultural Chemistry, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi.Bulk soil (0-15 cm) for pot culture experiment was collected from the Agricultural Research Farm, Rajiv Gandhi South Campus, Banaras Hindu University, Barkachha, Mirzapur, Uttar Pradesh which is situated at 25º10′ latitude, 82º37′ longitude and an altitude of 427 m above mean sea levelin Vindhyan region.The Vindhyan region is situated in agro-climatic zone III-A (semi-arid eastern plain zone), with a rainfed climate and inevitably low soil fertility. The climate is semi-arid, with no rainfall and moderate humidity. The soil was analysed for initial soil chemical properties in both seasons, which are given in table 1.

Experimental details:

HUL-57, a popular variety of Lentil (*Lens culinaris*), was selected for this experiment as a test crop and four levels of sulphur and Boron applied with the recommended dose of NPK. The treatments detail is presented in table 2. The experiment was laid out in Factorial completely randomised design with three replications.

The soil samples were collected at the harvest and chemically analysed with the suitable method (table 1). The data on soil chemical parameters weresubjected to a factorial randomized block analysis of variance (ANOVA). The F-Test was used to determine the significance of treatment results. The treatment means were compared using the least significant difference (LSD) test method at a 5% level of significance where ANOVA indicated a difference.

RESULTS AND DISCUSSION

Soil pH

The sulphur and boron application along with RDF did not show a significant effect. During the first season, the soil pH did not improve substantially with different treatments, but S_3B_1 had marginally lower pH (5.72) values than S_0B_0(5.79),which received only RDF (Fig.1). In the season 2019-20 of the experiment, results were almost similar to season2018-19; the highest pH was noticed in S_0 combination with the B_1, B_2 and B_3, while the lowest was in treatment supplied with 30 kg ha^{-1} S with the recommended dose of NPK only. As shown in the two seasons' combined results, soil pH values followed an inverse trend with increasing sulphur doses, ranging from 5.82 to 5.74. (Fig.1). The oxidation of S compounds to sulphates is might be the possible reason for decreasing the pH of soil. Many scientists have reported similar trends, including Chouliaras and Tsadilas (1996) and Jamal *et al.* (2010).

Electrical conductivity

In the current experiment,different sulphur and boron levels decreased the EC but not significantly. In the season 2018-19, levels of sulphur and boron both showed a decrement in electrical conductivity in which sulphur shows significant effect but boron did not show a significant effect. Whereas in season 2019-20, both sulphur and boron levels show non-significant effect but the combination of both S and B slightly decrease the electrical conductivity. Two seasons' pooled data showed that electrical conductivity ranges in between 0.33 $dSm^{-1}$to 0.28 dSm^{-1} (Fig.2). In pooled data, maximum conductivity was observed in treatment S_0B_0supplied with RDF only (0.33 dS m^{-1}) which found similar to treatment S_0B_1, S_0B_2 while the minimum was noticed in treatment provided with 45 kg ha^{-1} and 2 kg B ha^{-1} along with the recommended dose of NPK (0.28 dSm^{-1}). Ram *et al.* (2014) found that the electrical conductivity of post-harvest soil was non-significantly affected by sulphur, zinc and boron application. Rathiya *et al.* (2018) also stated that there is no significant effect on electrical conductivity by the application of boron.

Organic carbon

The organic carbon content was found lowest in the S_0B_0(4.01 g kg^{-1}), which just received RDF of NPK (Fig.3), followed by S_0B_1 and S_0B_3. The highest organic carbon found in the S_3B_2 treatment (4.28 g kg^{-1}), was given 45 kg sulphur and 2 kg boron per hectare. The treatment effect was found statistically non-significant in both seasons of the study. However, 5.71% higher carbon content was recorded in treatment S_3B_1 in season 2018-19 and 7.71% in season 2019-20 where S was applied at 45 kg ha^{-1} with 2 kg ha^{-1} boron and recommended dose of NPK, as compare to S_0B_0 treatment (RDF only). The findings are similar to Vandana *et al.* (2009) and Yadav *et al.* (2010), who stated that N, P, K, and S application had a considerable effect on soil organic carbon content.

DTPA-extractable Zn

Significant effect of Sulphur and Boron application on DTPA extractable soil available Zn was recorded(fig.4). Available Zn varied from 0.58 to 0.72 and 0.56 to 0.73 mg kg^{-1} of soil in season 2018-19, season 2019-20, respectively. In season 2018-19, application of S @ 30 kg ha^{-1} as gypsum plus 2 kg ha^{-1} boron as borax along with RDF recorded the highest available Zn status of 0.72 mg kg $^{-1}$ of soil. Similarly, in the second season, the highest soil available Zn was recorded in S_3B_2 and S_3B_3(0.73 mg kg^{-1}) and the minimum found in treatment S_0B_0(0.56 mg kg^{-1}). This is mainly attributed to the sulphur application, which possibly decreased soil pH and increased the availability of macro and micronutrients in the soil. The results are following the findings of Ahmed (2013). Hepublished that oxidation of S to H_2SO_4 is particularly beneficial in reducing pH and supply of SO_4 to plants making P and micro-nutrients more available. Sulphur oxidising soil microorganisms transform sulphur into sulphuric acid in calcareous soils, lower soil pH, and increase micronutrient availability, especially cations (El-Eweddy *et al.*, 2005).Similarly, in an incubation study, Wang *et al.* (2008) reported that S application at 20 g kg^{-1} soil reduces pHby about 3 units and the solubility of Cu and Zn significantly increased after 64 days of incubation.

DTPA-extractable Cu

As per the experimental results, the DTPA extractable soil available Cu ranged from 0.74 to 0.83, 0.73 to 0.79 mg $kg^{-1}$of soil (Fig.5) inseason 2018-19 and season 2019-20, respectively. Application of sulphur and Boron did not bring significant changes in the available Cu; however, sulphur application through gypsum with or without B along with a recommended dose of NPK resulted in more variation in Cu availability as compare to boron treatments. In two seasons pooled data, maximum available copper (0.80 mg kg^{-1}) was found in treatment supplied with 15 kg ha^{-1} sulphur with 2 kg ha^{-1}boron and 2 kg B ha^{-1} without sulphur (along with RDF).

DTPA-extractable Fe

In the first season, the only sulphur application showed a significant effect on DTPA extractable soil available Fe and boron application showed a non-significant effect. But in the second season, the application of sulphur and boron both showed a non-significant effect. The availability of Fe ranged from 23.80 to 27.36, 23.19 to 26.15 mg kg^{-1} in season 2018-19 and season 2019-20, respectively (Fig.6). With the application of Sulphur @ 45 kg ha^{-1} as gypsum plus Boron @ 1 kg ha^{-1} as borax along with RDF registered the highest available Fe i.e. 27.36 mg kg^{-1} in season 2018-19 and treatment S_2B_1 with 26.15 mg kg^{-1} in season 2019-20 and the minimum was recorded in treatment S_0B_0 (applied RDF only) in both the season. It is well established that an acidic pH increases Fe availability; this is what transpired in the present investigation, where sulphur oxidation resulted in a decrease in pH of the soil, which induced iron solubility. These findings are in corroboration with the findings of Islam (2012), who explained that there is increased availability of micronutrient from the soil as a result of the temporary reduction in soil pH.

DTPA-extractable Mn

The DTPA extractable Mn was not influenced significantly by sulphur and boron application in lentil crop with various levels (Fig.7). It ranged from 5.39 to 5.75 and 5.38 to 5.67 mg kg^{-1} in season 2018-19 and season 2019-20, respectively. In season 2018-19, the maximum available Mn content of 5.75 mg kg^{-1} was reported while applying S @ 45 kg ha^{-1} as gypsum plus B @ 1 kg ha^{-1} as borax along with the prescribed dose of NPK.The lowest available Mn content was found in treatment S_0B_0 in both seasons(Fig.7). Application of sulphur and boron singly or in combination did not affect significantly the DTPA-extractable Mn content but it slightly increases with the S and B levels. This may be due to a transient decrease in soil pH and proton supply due to the sulphur oxidation process, and a rise in Mn availability due to Mn hydration. Further, this may be ascribed to the dissociation of the broken edges of the hydroxyl ions, which resulted in a higher protonated surface that retained more Mn. According to the results of Sabbagh *et al.* (2012), the higher proton output led to increased mobility of plant essential micronutrients and phosphorus in the soil, in addition to the release of cationic elements from organometallic compounds.

Urease activity

Enzyme activities varied widely among the treatments studied. In season 2018-19 urease activity was least in RDF fertilized soil (S_0B_0) which was 35.91µg NH_4^+ g^{-1} $hr^{-1}$and higher in soils treated with super 30 kg S plus 2 kg B ha^{-1} along with RDF (52.14 µg NH_4^+ g^{-1} hr^{-1}). Considering the S doses, the higher values were obtained with 30 kg S ha^{-1} through gypsum with different doses of B along with RDF. Urease activity did not follow a linear increase with the increase in sulphur and boron doses.The trend of urease activity was almost similar to the season 2019-20 also and it varied from 34.25 to 53.02µg NH_4^+ g^{-1} hr^{-1}. In season 2018-19, both S and B application along with RDF show significant effect but in season 2019-20, only S application showed a significant effect. Our results showed (fig.8) anincrease in urease activity by applicationof inorganic fertilizer sulphur and boron along with RDF. This finding shows that inorganic fertilizer can also increase urease activity which is similar to the finding of Bhatt *et al.*, (2016). Boron application also increases urease activity in soil with different doses but not in linear trend and this is also reported by Bilen *et al.*, 2011.

Dehydrogenase activity

Similarly, dehydrogenase enzyme activities of the soils also showed a significant difference with S application but not with different doses of boron (Fig.9). In season 2018-19 the highest dehydrogenase enzyme activity was observed at S_3B_3 treatment with 45 kg S and 3 kg B ha^{-1} along with RDF and the lowest dehydrogenase activity recorded in treatment S_0B_0. In the first season, it varied from 116.87 to 146.80µg TPF g^{-1} soil d^{-1}. In season 2019-20 highest dehydrogenase activity found in treatment S_3B_2 (45 kg S + 2 kg B ha^{-1} with RDF) which was at par with treatment S_2B_2 andS_3B_3, and in that season it varied from 109.91 to 137.51 µg TPF g^{-1} soil d^{-1}.The dehydrogenase enzyme activity increase with increasing sulphur doses but it increases with boron doses upto 2 kg B ha^{-1} and then slightly decrease except for treatment S_0B_3 in both seasons. These results are similar to the finding of Ram et al 2016 and Bilen et al 2011. Candida et al 2012 also reported that an increase in enzymatic activity is related to organic matter and amendments.

Lentil yield

Straw yield positively influences the yield of the crop by transfer the assimilates to the sink. Table 3. shows the data of straw yield collected at harvest. The minimum straw yield was observed in treatment S_0B_0 (2.61 g $plant^{-1}$) as compare to other sulphur and boron-containing treatments. In all the treatments, sulphur and boron combination along with RDF gave a higher yield as compared to the application of sulphur, boron or RDF alone. Pooled data of two season showed that the highest straw yield (4.25 g $plant^{-1}$) recorded in treatment S_3B_2 (45 kg S + 2 kg B along with RDF) due to more number of branches $plant^{-1}$ and plant height, which was statistically at par with treatment S_3B_3 (4.02 g $plant^{-1}$) and S_3B_1 (4.00 g $plant^{-1}$). Among all the sulphur boron combination, the minimum straw yield recorded in the treatment with 15 kg sulphur + 1 kg boron ha^{-1} along with RDF. Straw yield increases with sulphur and boron doses but not in a linear way. In season 2018-19, both S and B shows a significant effect in straw yield but in season 2019-20 only boron application showed a significant effect (B application also increase the straw yield but not significantly). In lentil, sulphur and boron increase the nitrogen fixation which boosts the nodulation and it supports plant growth. The straw yield plant^{-1} may be due to increasing the enzyme activity with sulphur and boron application along with RDF of NPK.

The grain yield plant^{-1} of lentil crop found higher in the treatments with sulphur and boron application along with RDF as compare to RDF alone. The pooled data of two season showed the maximum grain yield (2.29 g plant^{-1}) in the treatment S_3B_2 (45 kg S + 2 kg B ha^{-1} with RDF). After that, the maximum yield found in treatment S_3B_3 (2.16 g plant^{-1}) and S_3B_1 (2.16 g plant^{-1}) equally. According to the findings, increasing doses of sulphur fertilizer as gypsum increases the grain yield of lentil but in case of boron application as borax, up to 2 kg B ha^{-1} the grain yield increase after that some reduction found in lentil yield. The data of both the season showed that the grain yield of lentil more influenced by sulphur application as compare to boron. The combination of sulphur and boron with the level S_3B_2 gave a 16.24 % higher yield as compared to the application of 45 kg S ha^{-1} along with RDF without any dose of boron and 67.15 % more as compared to the application of 2 kg B ha^{-1} + RDF without Sulphur. The increment in plant height and the number of branches plant^{-1} increase the dry matter of lentil crop and according to several authors (Singh *et al.*, 2011; Biswas *et al.*, 2015), it may lead to an increase in grain yield also. The increment in crop yield due to sulphur and boron application maybe because of its important role in enzyme activation and carbohydrate metabolism (Davidian and Kopriva, 2010; Juszczuk and Ostaszewska, 2011).

CORRELATION

Figure 10. shows the pairwise scatter plots (lower half), histograms and corresponding correlation coefficients (upper half) among soil pH, electrical conductivity, organic carbon and available micronutrients. The soil pH showed Pearson's correlation coefficient strong positive relationship with EC (0.76) and strong negative relation with Fe with r value -0.82. Additionally, a moderate positive correlation of pH was reported with Cu (0.64) and negatively with Mn (0.64). Electrical conductivity was negatively correlated with all the micronutrients except Cu, which is positively correlated. Among micronutrients, Cu showed a negative correlation with all the three other micronutrients with varying level of r value. Zn and Mn are strongly correlated with an r-value of 0.80.

Table 1. Some physical and chemical properties of the initial experimental soil.

Soil Properties	Value	Method	Reference
pH	5.83	pH meter	Jackson, 1973
Electrical conductivity (dS m^{-1})	0.33	EC meter	Jackson, 1973
Organic carbon (g kg^{-1})	3.78	Wet oxidation	Walkey and Black (1934)
available N (Kg ha^{-1})	181.06	Alkaline $KMnO_4$	Subbiah and Asija (1956)
available P (Kg ha^{-1})	9.23	Bray's method	Bray and Kurtz (1945)
available K (Kg ha^{-1})	199.52	Ammonium Acetate	Hanyway and Heidal (1952)
Available S (mg kg^{-1})	8.52	Turbidimetric	Chesnin and Yien (1950)
Available B (mg kg^{-1})	0.36	Azomethine-H	Berger and Troug(1939)
Available Zn (mg kg^{-1})	0.56	DTPA solution by Atomic Absorption Spectrophotometer	Lindsay and Norvell (1978)
Available Cu (mg kg^{-1})	0.74		
Available Fe (mg kg^{-1})	23.57		
Available Mn (mg kg^{-1})	5.30		
Urease (μg NH_4^+g^{-1} hr^{-1})	14.21	Spectrophotometer	Douglas and Bremner (1971)
Dehydrogenase (μg TPF g^{-1} soil day^{-1})	55.94	Spectrophotometer	Casida (1964)

Table 2. Treatments detail

Sulphur (Source: Gypsum)		Boron (Source: Borax)		
Levels (kg/ha)	Notation	Levels (kg/ha)	Notation	All the sulphur and boron doses applied with RDF (40, 60 and 20 kg ha^{-1} N, P & K, respectively) through Urea, Diammonium phosphate and Muriate of potash
0	S_0	0	B_0	
15	S_1	1	B_1	
30	S_2	2	B_2	
45	S_3	3	B_3	

Table 3. Effect of sulphur and boron application on straw and grain yield of lentil crop

Straw Yield (g plant^{-1})															
Treatment	2018-19					2019-20					Pooled				
	B_0	**B_1**	**B_2**	**B_3**	**Mean**	**B_0**	**B_1**	**B_2**	**B_3**	**Mean**	**B_0**	**B_1**	**B_2**	**B_3**	**Mean**
S_0	2.56	2.63	2.71	2.68	**2.65**	2.65	2.74	2.88	2.83	**2.78**	2.61	2.69	2.80	2.76	**2.71**
S_1	2.86	2.84	3.00	2.98	**2.92**	3.12	3.16	3.33	3.30	**3.23**	2.99	3.00	3.17	3.14	**3.07**
S_2	3.20	3.32	3.63	3.63	**3.45**	3.59	3.69	3.84	3.82	**3.74**	3.40	3.50	3.74	3.73	**3.59**
S_3	3.54	3.82	4.18	3.92	**3.86**	3.90	4.19	4.32	4.12	**4.13**	3.72	4.00	4.25	4.02	**4.00**
Mean	**3.04**	**3.15**	**3.38**	**3.31**	-	**3.31**	**3.45**	**3.59**	**3.52**	-	**3.18**	**3.30**	**3.49**	**3.41**	-
CD (P = 0.05)	S				0.26	0.20					0.23				
	B				0.26	ns					0.23				
	S X B				ns	0.40					ns				
Grain Yield (g plant^{-1})															
S_0	1.21	1.28	1.33	1.32	**1.28**	1.26	1.34	1.41	1.39	**1.35**	1.23	1.31	1.37	1.35	**1.32**
S_1	1.43	1.44	1.54	1.52	**1.49**	1.56	1.61	1.71	1.68	**1.64**	1.50	1.53	1.62	1.60	**1.56**
S_2	1.64	1.72	1.88	1.89	**1.78**	1.84	1.90	2.01	1.99	**1.94**	1.74	1.81	1.95	1.94	**1.86**
S_3	1.87	2.06	2.24	2.10	**2.07**	2.07	2.26	2.33	2.22	**2.22**	1.97	2.16	2.29	2.16	**2.14**
Mean	**1.54**	**1.62**	**1.75**	**1.71**	-	**1.68**	**1.78**	**1.87**	**1.82**	-	**1.61**	**1.70**	**1.81**	**1.76**	-
CD (P = 0.05)	S				0.06	0.09					0.08				
	B				0.06	0.09					0.08				
	S X B				ns	ns					ns				

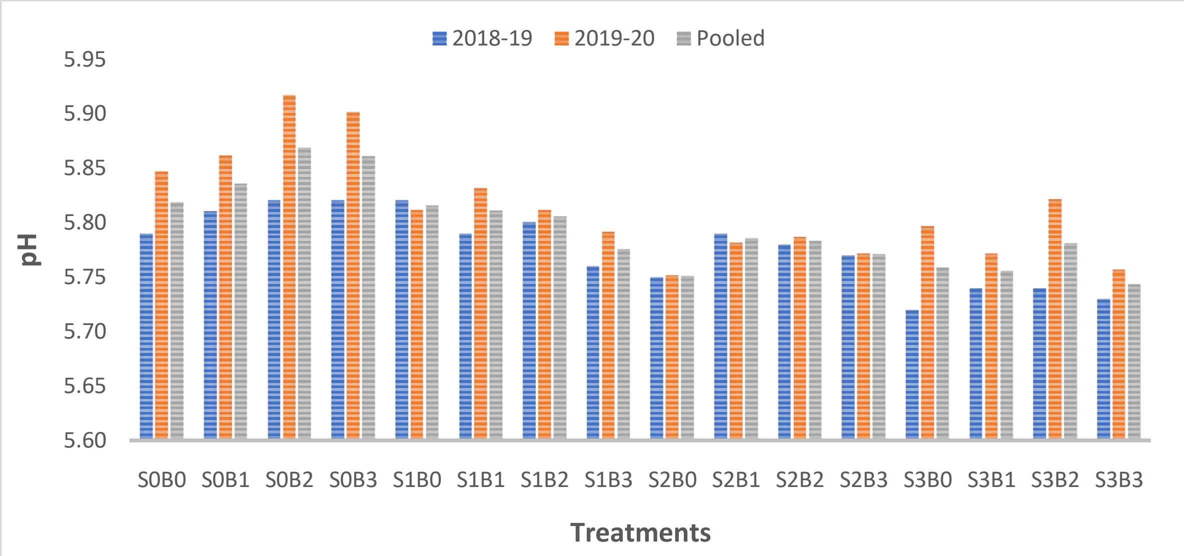

Fig. 1. Effect of sulphur and boron application on pH of post-harvest soil

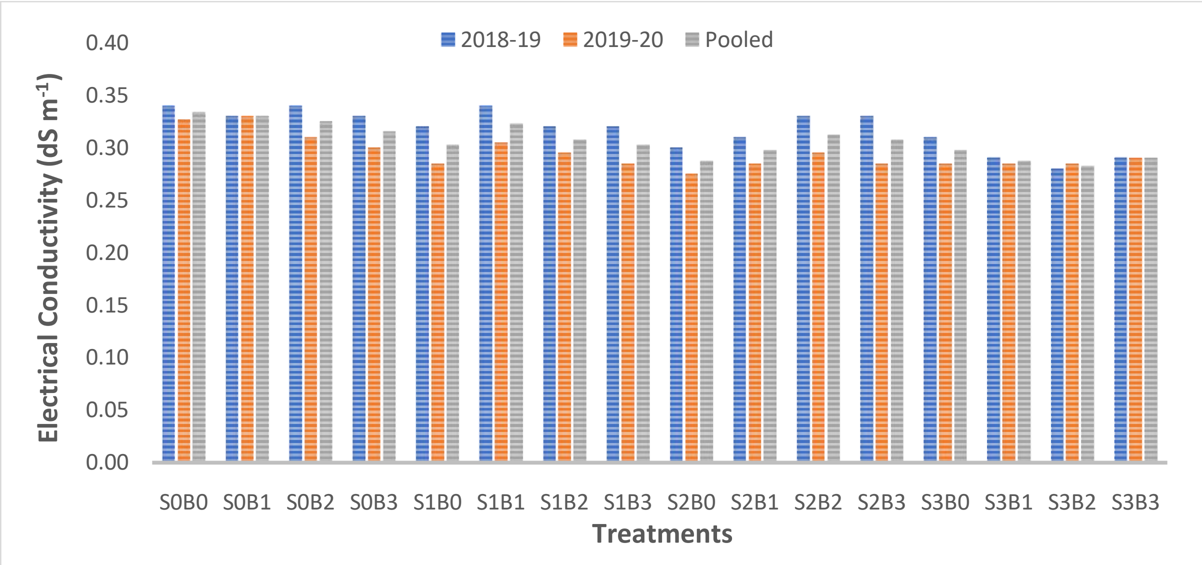

Fig. 2. Effect of sulphur and boron application on the electrical conductivity of post-harvest soil

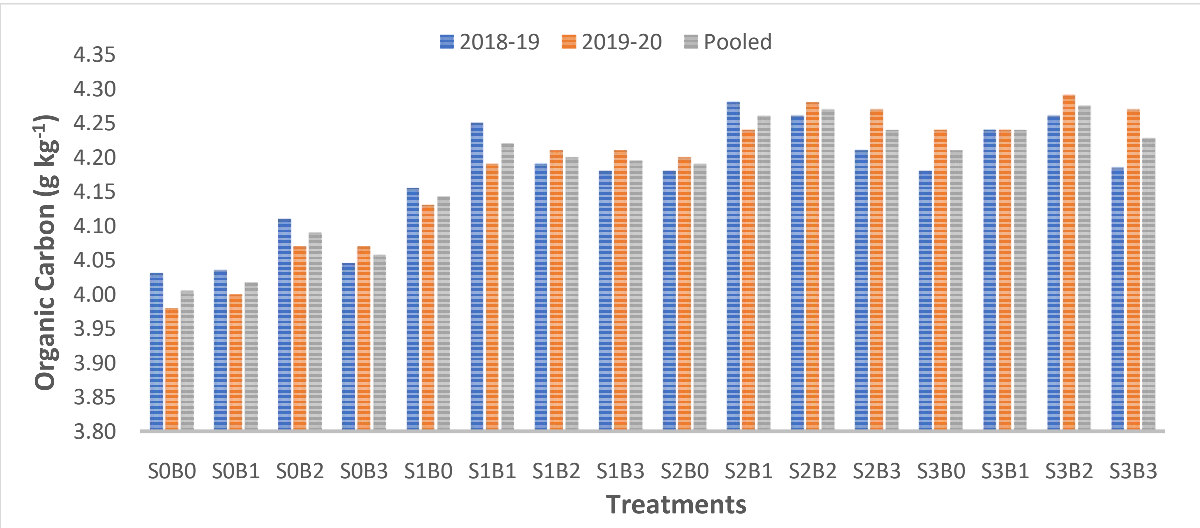

Fig. 3. Effect of sulphur and boron application on organic carbon of post-harvest soil

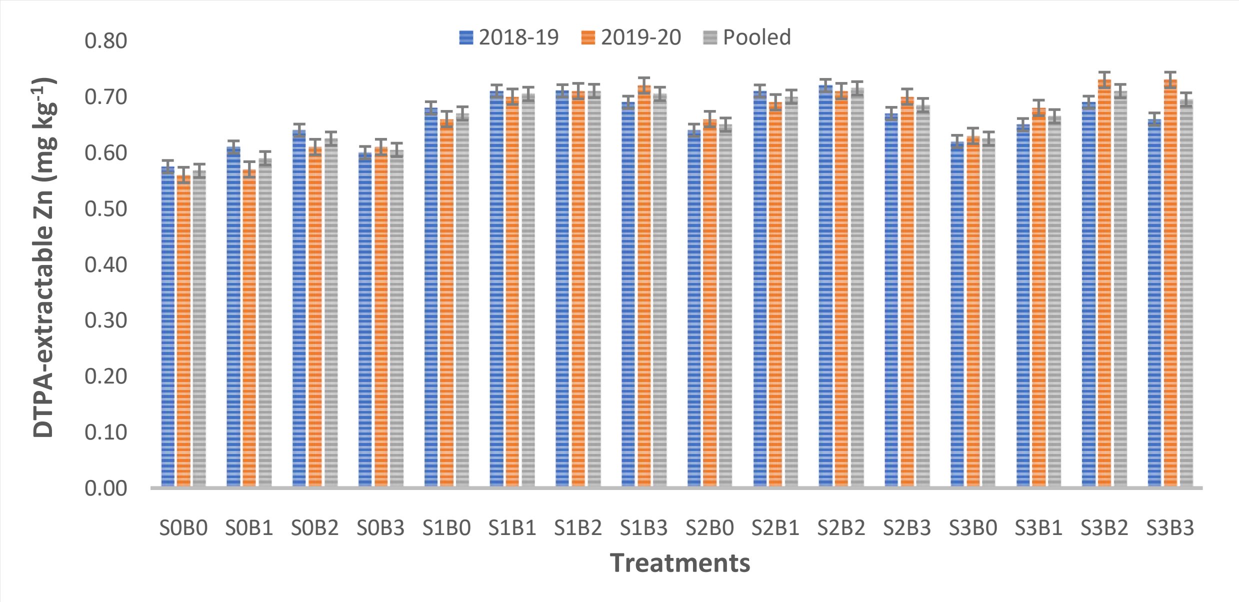

Fig. 4. Effect of sulphur and boron application on DTPA-extractable Zn of post-harvest soil

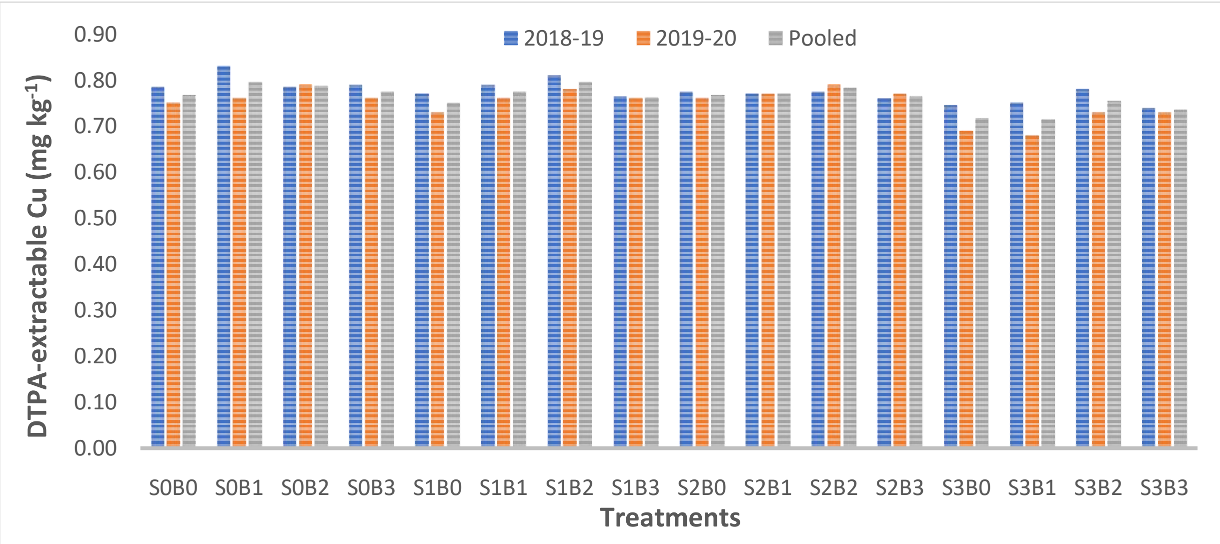

Fig. 5. Effect of sulphur and boron application on DTPA-extractable Cu of post-harvest soil

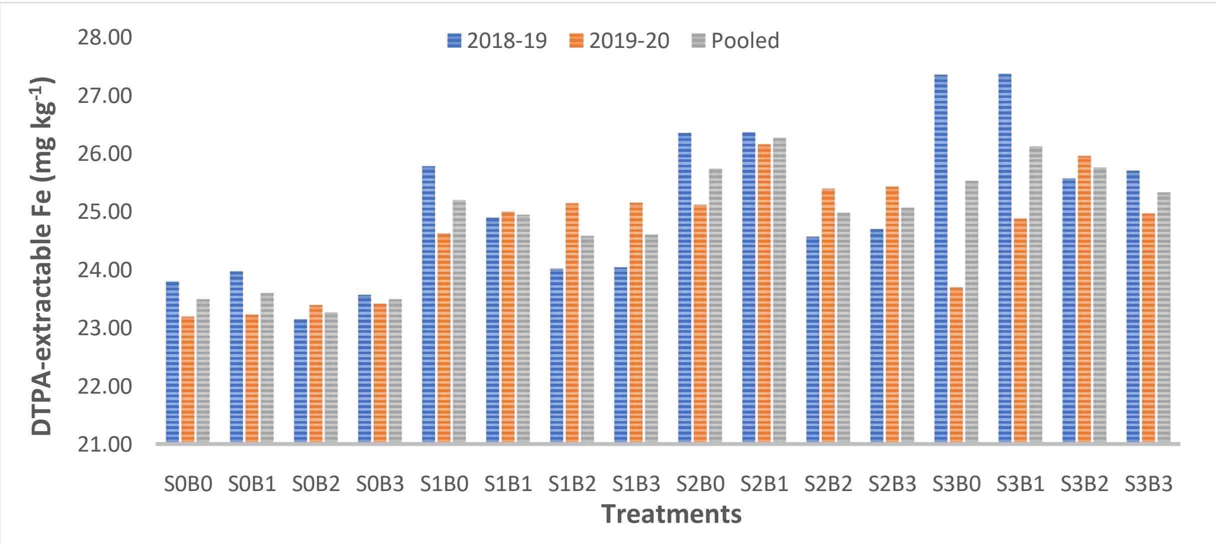

Fig. 6. Effect of sulphur and boron application on DTPA-extractable Fe of post-harvest soil

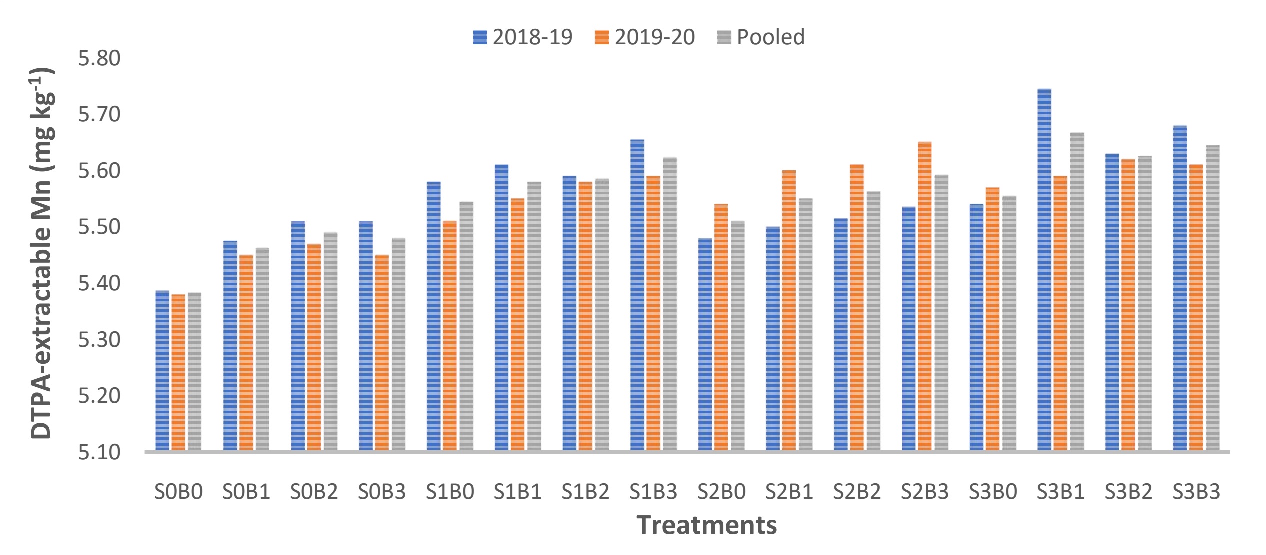

Fig. 7. Effect of sulphur and boron application on DTPA-extractable Mn of post-harvest soil

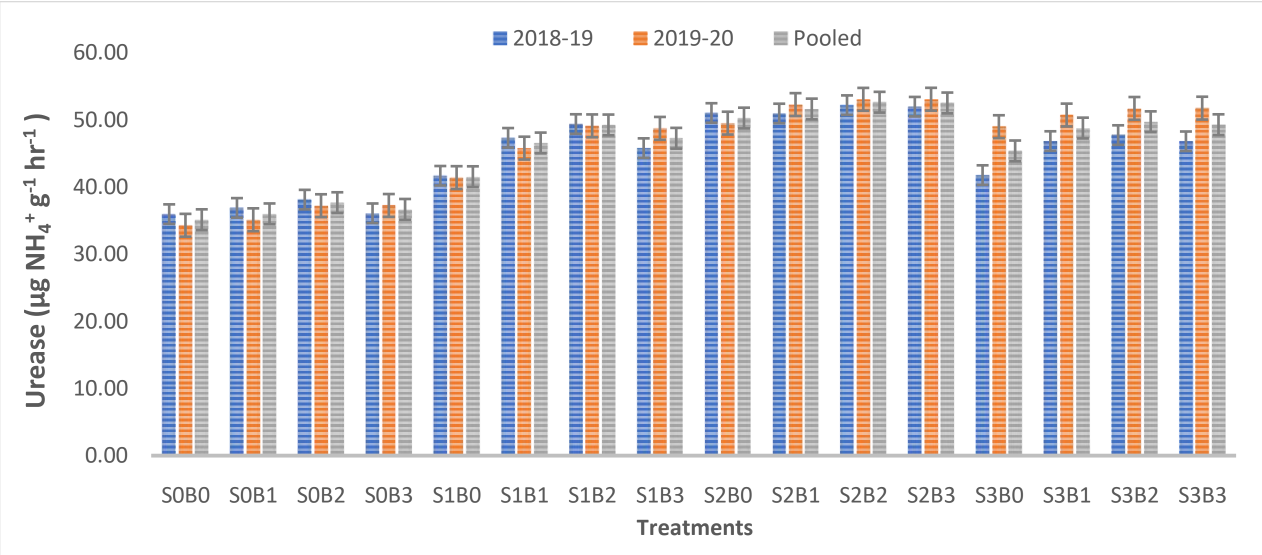

Fig. 8. Effect of sulphur and boron application on urease activity of post-harvest soil

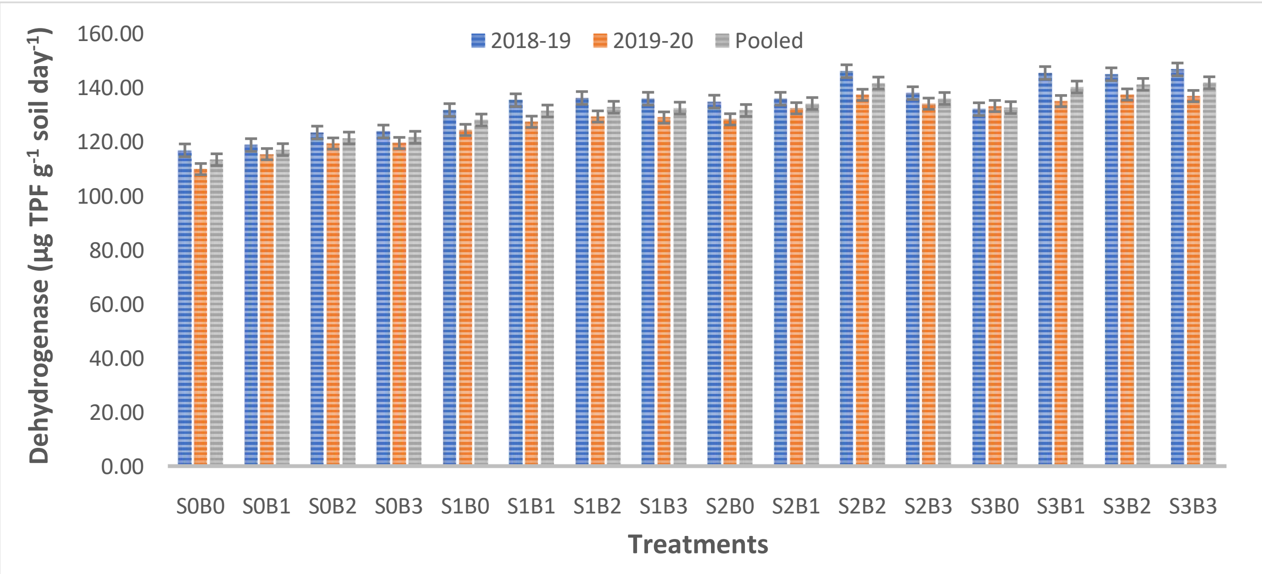

Fig. 9. Effect of sulphur and boron application on dehydrogenase activity of post-harvest soil

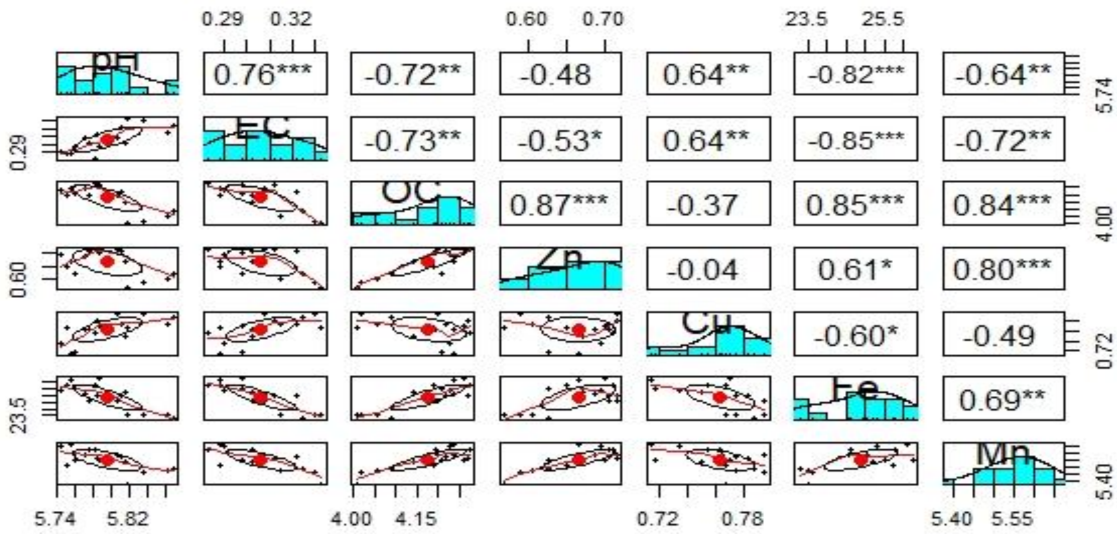

Fig. 10. Pairwise scatter plot matrix, histogram and correlation coefficient of soil chemical parameters. (Bivariate scatter plots are given below the diagonal, histograms on the diagonal and the Pearson correlation above the diagonal.) Note: EC: Electrical conductivity (dSm-1), OC: Organic carbon (%), Zn, Cu, Fe, and Mn are DTPA-extractable Available Zn, Cu, Fe and Mn (mg kg^{-1}), respectively.

CONCLUSION

The results from this study demonstrate that sulphur doses have a greater impact on the physicochemical properties of soil, cationic micronutrients, soil enzymes and lentil yield than boron doses. Soil pH, electrical conductivity and organic carbon were not affected significantly by the application of sulphur along with Boron; however, DTPA-extractable Zn was found to be significant in treatment with S and B addition along with RDF. Further, it could be concluded that application sulphur as gypsum and boron as borax with different doses led to increasing the soil enzymes activity but excessive use can reduce the soil enzyme activity as well as an available nutrient in soil and yield of the crop.

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