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Effect of Different Sources and Levels of Sulfur on Wheat

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ABSTRACT

A field experiment was conducted during *rabi* season 2020-21. The experiment was laid out in factorial Random Block Design with 12 treatments and three replications viz. Three sources (Gypsum, Bentonite and Single super phosphate) and four levels of sulfur were combined to get 12 treatments. Plant height, tiller count, LAI, dry matter accumulation, chlorophyll, CGR and RGR and yield of wheat were significantly improved due to increasing levels of sulfur application. Application of sulfur fertilizers at 45 kg S ha^{-1} proved to be efficient in maximizing many parameters like plant height, tiller count, chlorophyll, LAI, dry matter accumulation and yield at most of the stages and showed maximum yield also. The least effective interaction on several growth parameters and yield was noted to be SSP at the rate of 0 kg S ha^{-1}.

Keywords Sulfur, Wheat, Sources, Levels.

INTRODUCTION

Wheat, which sparked the Indian subcontinent's green revolution, is an essential food grain that feeds nearly a third of the world's population. On a global scale, the crop is cultivated on 211.06 million hectares, yielding 566.8 million tonnes. India is the world's second-largest wheat producer, after only China and the crop has helped India's agriculture grow at the fastest rate in the world. Wheat will continue to grow in importance as a primary staple food in the coming years, both in terms of grain production and quality. Providing sufficient quantities of high-quality grains to an ever-increasing population is a never-ending challenge for researchers. By 2020, India will need 105 million tonnes of wheat production.

After nitrogen, phosphorus and potassium, sulfur (S) is the fourth most important nutrient for agricultural crop production. Sulfur is a structural component of organic compounds, some of which are synthesised exclusively by plants and provide essential amino acids to both humans and animals (methionine, cystine and cysteine). It is a component of the vitamins biotin and thiamine and is involved in the formation of chlorophyll and the activation of enzymes (B1) (Hegde and Sudhakara babu 2007). Because of its role in boosting crop production, not only of oil seeds, pulses, legumes and forages, but also of many cereals, sulfur's role in Indian agriculture is gaining importance (Singh *et al.* 2000). Sulfur deficiency in crops is becoming more common as a result of the

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extensive use of sulfur-free fertilizers, high-yielding crop varieties and intensive multiple-cropping systems with increased efficiency.

The shift from conventional internal input-based agriculture to today's external input-based agriculture has resulted in widespread sulfur deficiency. Farmers have moved from using organic to inorganic high analysis sulfur free fertilizers as a result of the adoption of intensive farming, resulting in more pervasive and severe sulfur deficiencies in Indian soils.

Sulfur requirements for one tonne of seeds range from 1-6 kg for cereals, 5-13 kg for legumes and 5- 20 kg for oilseed crops. S deficiency may result in a 50 % reduction in cereal yield (Zhao *et al.* 2001). Sulfur deficiency in the soil facilitates the accumulation of harmful nitrates and arnides, which delays protein formation and reduces the quality of protein in both grain and straw (Gupta and Schnug 2001). Sulfur deficiency results in decreased usage efficiency, cost-effective application of NPK fertilizers and the inability to achieve a consistent yield (Khan *et al.* 2006). Because of imbalances in the N/S and P/S ratios in plants, using high levels of other nutrients (N, P and K) in sulfur-deficient soil does not result in higher yields. Demand for S and other plant nutrients are projected to increase even further as global food demand increases (Tilman *et al.* 2011). This experiment was carried out in order to access the effect of sources and levels of sulfur on wheat crop and also to reiterate the importance of sulfur application.

MATERIALS AND METHODS

During the 2020-21 *rabi* season, A field experiment was conducted at Lovely Professional University's Research Farm, Jalandhar, Punjab which is located at 31°15′ N, 75°42′ E and 235 m above sea level. Bulk composite soil samples were collected from a depth of 0-15 cm prior to sowing from all the 36 plots of research area where the experiment was conducted. All 36 samples of the sieved soils were examined for different mechanical and physico-chemical properties after the air-dried soil was ground to pass through a 2.0-mm sieve. The experimental soil was loamy sand (sand-84.7%, silt-11.2% and clay-4.1%) in texture and low saline with pH 6.9 (Jackson 1973), EC 0.55 dsm^{-1} (Jackson 1967) and organic carbon 0.52% (Walkley and Black 1964), low in available N 260.3 kg ha^{-1} (Subbiah and Asjia 1965), available P 4.79 kg ha^{-1} (Olsen *et al.* 1954) medium in available K 180.5 kg ha^{-1} (Jackson 1967) and low in available S 3.9 ppm (Chesnin and Yien 1950).

The experimental design was laid out in factorial Random Block Design with three sources of sulfur viz. Gypsum, Bentonite and SSP and with 4 levels of sulfur (0,15, 30 and 45 kg S ha^{-1}). Therefore 12 treatment combinations were obtained viz., Gypsum+0 kg S ha^{-1} (T_1), Gpysum+15 kg S ha^{-1} (T_2), Gypsum+30 kg S ha^{-1} (T_3), Gypsum+45 kg S ha^{-1}(T_4), Bentonite+0 kg S ha^{-1} (T_5), Bentonite+15 kg S ha^{-1}(T_6), Bentonite +30 kg S ha^{-1}(T_7), Bentonite +45 kg S ha^{-1}(T_8), SSP +0 kg S ha^{-1}(T_9), SSP +15 kg S ha^{-1}(T_{10}), SSP +30 kg S ha^{-1}(T_{11}) and SSP+45 kg S ha^{-1} (T_{12}).

The variety used for this experiment was Unnat PBW 550 and it was sown on 30th of November. Spacing of 22.5 cm row to row was followed. One ploughing followed by one planking was carried out with the help of a tractor along with the required equipments. Plots of net size 15 sq m (5*3 m) were prepared along with irrigation channels before sowing. Soil had required moisture at the time of sowing for germination to occur. 4 timely irrigations were given at four growth stages. Chlorophyriphos 20EC was applied to control the termite attack. Recommended dose of nitrogen, phosphorus and potassium (N:P:K-125:62.5:0) kg ha^{-1} in the form of urea, di-ammonium phosphate was applied. Half dose of nitrogen, full dose of phosphorus were applied as basal dose and the other half of nitrogen was applied at the time of 1st irrigation. As potassium status was medium in the soil, the application was avoided. Sulfur in the form of Gypsum, Bentonite and SSP was applied according to the treatments as basal dose. All recommended practices were in accordance with PAU package of practices for *rabi* 2020-21.

Parameters recorded

Plant height, tillers per plant^{-1}, leaf area index (LAI), chlorophyll content, dry matter accumulation (t ha^{-1}) were noted for 30, 60 and 90 DAS. Crop growth rate (g m^{-2} day^{-1}) and relative growth rate (g g^{-1} day^{-1}) were calculated for 30-60 days and 60-90 days. Yield and yield attributes like test weight, grains per ear, seed yield (t ha^{-1}), straw yield (t ha^{-1}) and biological yield (t ha^{-1}) were recorded at the time of harvest.

RESULTS AND DISCUSSION

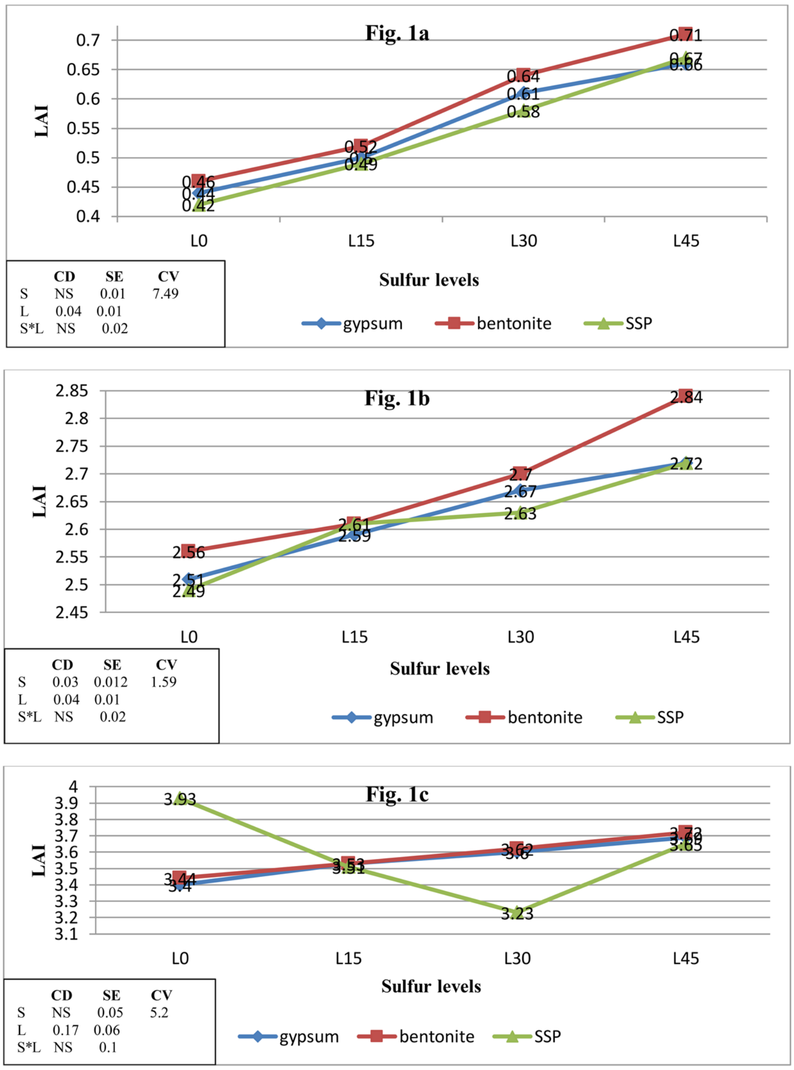
Plant height (cm) and tiller per plant^{-1}

The data (Table 1) indicates that changing the sulfur sources had no significant effect on plant height at 30, 60 and 90 DAS which might indicate that all the three sources applied had shown an equal effect on plant height. Increasing sulfur levels from 0 to 45 kg S ha^{-1} reported to have a non-significant effect (Table 1) at 30 DAS and executed significance at 60 and 90 DAS. Significantly the highest plant height (55.2, 83.7 cm) was obtained in 45 kg S ha^{-1} at 60 and 90 DAS and significantly the lowest plant height (46.7, 76.8 cm) was noted in 0 kg S ha^{-1}.The magnitude of increase in L4 i.e.45 kg S ha^{-1} was noted to be 18.2, 8.9 % over 0 kg S ha^{-1} at 30 and 90 DAS. The interaction of sulfur sources and levels was also reported to show no significant effect on plant height indicating that the differences among two plots across the experiment are not significant. Sulfur application might have increased the metabolic activity leading to increased photosynthesis thus showing a positive effect on plant height. Ram *et al.* (2014) reported similar results in rice-wheat cropping system where 60 kg S ha^{-1}, which was the highest dose of sulfur significantly improved plant height at harvest. There was an increase of 25.6% in plant height of wheat due to 25 kg potassium sulfate application (Safi *et al.* 2016). Singh *et al.*(2017) also noted significant results on plant height in rice due to increasing sulfur levels up to 45 kg S ha$^{-1.}$

No significant effect was observed on tiller count at 30, 60 and 90 DAS of wheat due to change in sources of sulfur indicating that the applied sources were equally effective over each other on tiller count. Tillers per plant were significantly increased with successive increment in levels of sulfur. Significantly the maximum number of tillers (2.6, 5.8 and 9.2) at 30, 60 and 90 DAS was recorded at 45 kg S ha^{-1} application and contradictorily, L0 i.e. 0 kg S ha^{-1} reported to show significantly the lowest number of tillers (1.4, 4.3 and 5.9). When compared with L0 i.e. 0 kg S ha^{-1}, magnitude of 34.8, 55.9 % increase

Table 1. Effect of different sources and levels of sulfur on plant height (cm) and tiller per plant.$^{-1}$

Treatments	Plant height (cm)			Number of tillers		
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
Sources						
S^1 Gypsum	21.4	52.1	81.1	1.9	5.1	7.8
S^2 Bentonite	20.4	52.8	80.8	2	5.3	8.3
S^3 SSP	21.2	49.9	80.2	2.04	5	7.2
CD ($p \leq 0.05$)	NS	NS	NS	NS	NS	NS
SE	0.43	0.97	0.4	0.06	0.19	0.37
Levels						
L1-0 kg S/ha	21.8	46.7	76.8	1.4	4.3	5.9
L2-15 kg S/ha	20.8	49.4	79.3	1.7	4.8	7.4
L3-30 kg S/ha	20.6	55.2	83.01	2.2	5.5	8.6
L4- 45 kg S/ha	20.9	55.2	83.7	2.6	5.8	9.2
CD ($p \leq 0.05$)	NS	3.3	1.37	0.21	0.67	1.27
SE	0.5	1.12	0.46	0.07	0.22	0.43
Interaction						
CD ($p \leq 0.05$)	NS	NS	NS	NS	NS	NS
SE	0.87	1.95	0.8	0.12	0.39	0.75
CV	7.22	6.54	1.73	10.7	13.2	16.6



	CD	SE	CV
S	NS	0.01	7.49
L	0.04	0.01	
S*L	NS	0.02	

	CD	SE	CV
S	0.03	0.012	1.59
L	0.04	0.01	
S*L	NS	0.02	

	CD	SE	CV
S	NS	0.05	5.2
L	0.17	0.06	
S*L	NS	0.1	

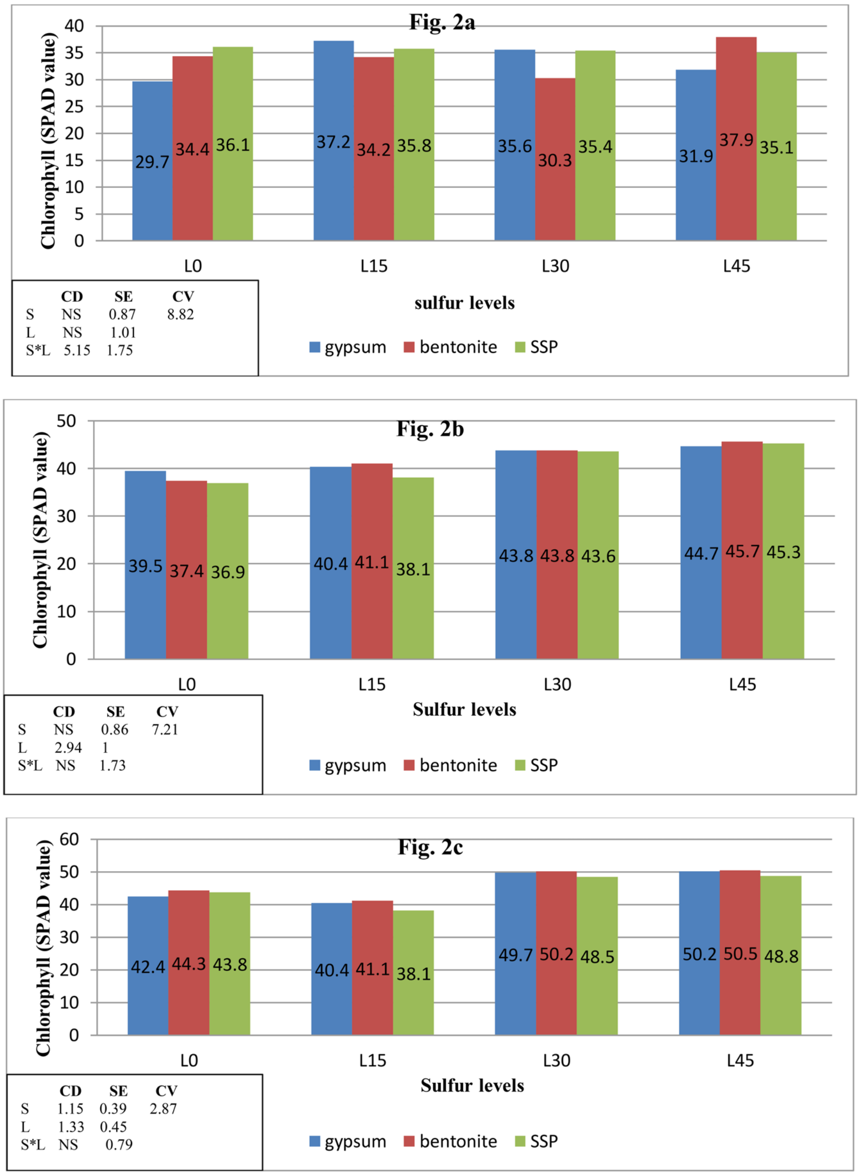
(S-Sources, L-levels, S*L-interaction)

Figs. 1 (a, b, c). Effect of sources and levels sulfur on leaf area index (LAI) at 30 (1a), 60 (1b) and 90 DAS (1c).

in tiller count was noted in L4 i.e. 45 kg S ha^{-1}. Along with sources the interaction was also reported to have no significant effect on tiller count which indicates there was no positive difference among the different plots across the experimental layout. Even though non-significant effect was observed in tiller count, the interaction effect showed highest values of tiller count (2.7, 6 and 9.4) at 30 and 90 DAS due to application of 45 kg S ha^{-1} in the form of Bentonite and at 60 DAS due to application of 45 kg S ha^{-1} in the form of Gypsum. Tillering is caused by expanding auxillary buds and is closely linked to the nutritional conditions of the main stem during its early growth cycle, which can be enhanced by sulfur application (Samaraweera 2009). Ram *et al*. (2014) also reported significant improvement in tiller count of rice over control due to sulfur application.

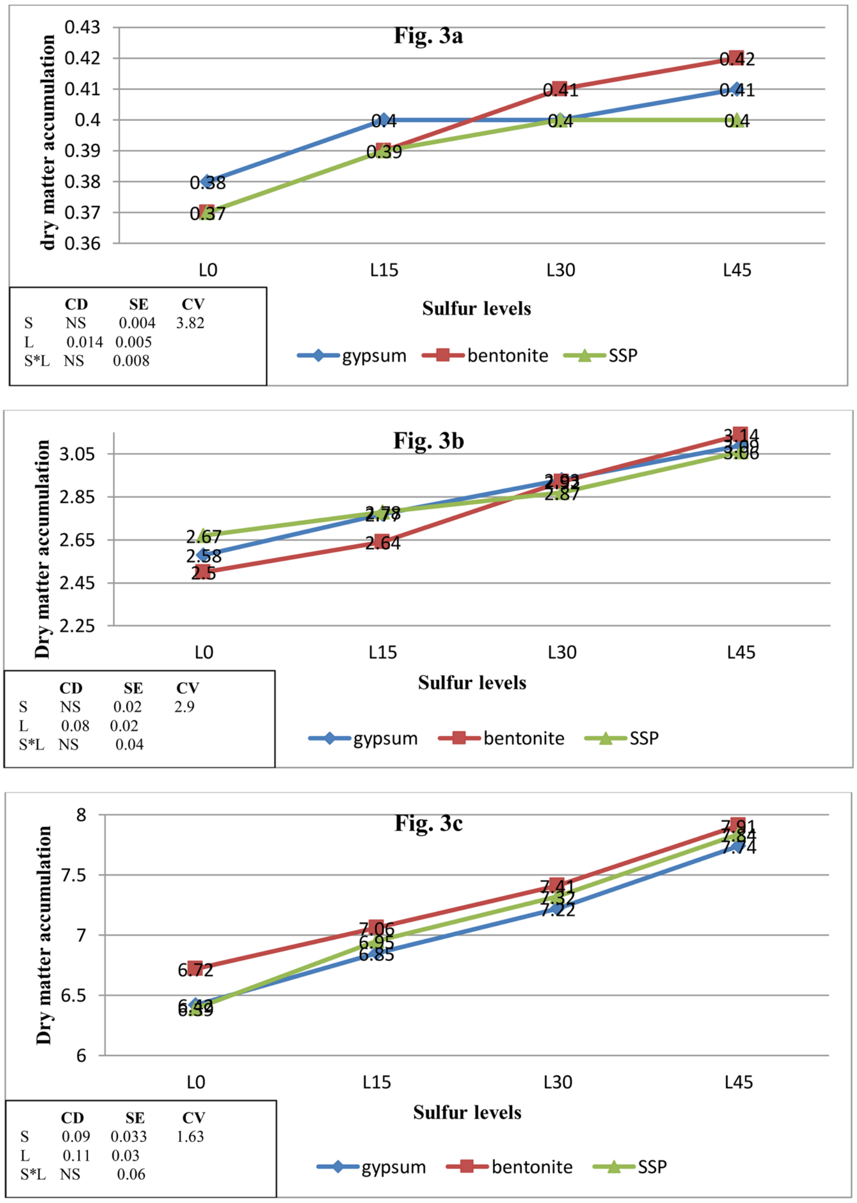
Leaf area index (LAI)

No significant results (Figs.1a, b, c) were obtained at 30 and 90 DAS by switching sulfur sources. This indicates that three sulfur sources applied were equally productive over one another. Significant results in LAI were seen at 60 DAS with Bentonite showing the highest LAI (2.67) at 60 DAS whereas SSP recorded the lowest (2.61). In terms of magnitude the increase in Bentonite was 2.29 % higher over SSP, which is a marginal increase. Increasing levels of sulfur from 0 to 45 kg S ha^{-1} substantially improved LAI at 30, 60 and 90 DAS (Figs. 1a, b, c). Among the levels highest LAI was obtained by application of 45 kg S ha^{-1} and the lowest was noted be of 0 kg S ha^{-1}. The magnitude of increase in LAI due to 45 kg S ha^{-1} application was 54.5, 9.5 and 8.2 % over 0 kg S ha^{-1}. The interaction effect i.e. sulfur sources combined with levels executed no significant effect on LAI which indicates that the difference between two plots across



Figs. 2 (a, b, c). Effect of sources and levels of sulfur on chlorophyll content at 30 (2a), 60 (2b) and 90 DAS (2c).

the experimental layout is not significant. The rise in leaf-area index with increasing sulfur levels may be attributed to a more balanced and sufficient nutrient supply, resulting in better carbohydrate utilization and the formation of more protoplasm. Adequate sulfur application may have helped plants in attaining vigorous growth of foliage thus increasing the LAI (Prasad 1999). LAI was significantly influenced due to sulfur application; plots receiving 20 kg sulfur ha^{-1} reported significantly higher LAI in rice when compared to control (Singh *et al*. 2012). Increasing levels of sulfur up to 60 kg ha^{-1} significantly improved LAI of maize (Thirupathi *et al*. 2016).



	CD	SE	CV
S	NS	0.004	3.82
L	0.014	0.005	
S*L	NS	0.008	

	CD	SE	CV
S	NS	0.02	2.9
L	0.08	0.02	
S*L	NS	0.04	

	CD	SE	CV
S	0.09	0.033	1.63
L	0.11	0.03	
S*L	NS	0.06	

Figs. 3 (a, b, c). Effect of sources and levels of sulfur on dry matter accumulation at 30 (3a), 60 (3b) and 90 (3c) DAS.

Chlorophyll content (SPAD value)

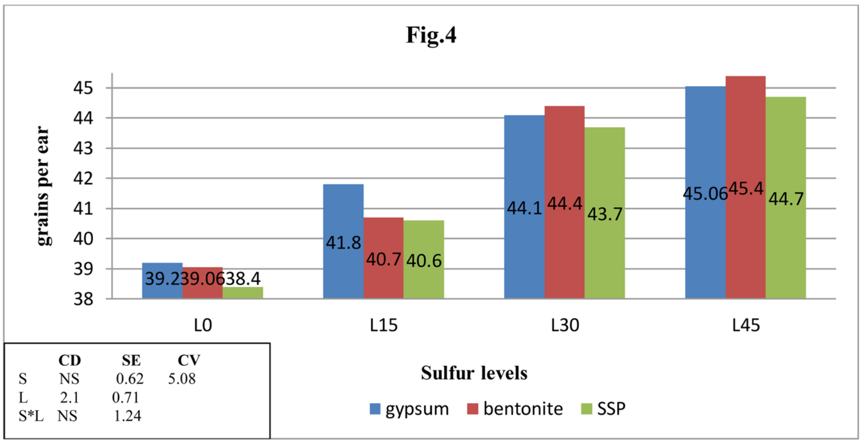
From (Figs. 2a, b, c) it can be concluded that application of different sources had no significant effect on chlorophyll at 30, 60 DAS whereas at 90 DAS it was noted to be significant. It can be interpreted that different sources utilized might have equally affected the wheat crop's chlorophyll content at 30 and 60 DAS. At 90 DAS significantly highest chlorophyll content (48.4) was noted due to Bentonite application whereas significantly the lowest content in SSP (46.9), which was only a marginal increase of 3.19%. Increasing levels from 0 to 45 kg S ha^{-1} showed significant (Figs. 2a, b, c) results on chlorophyll content only at 60 and 90 DAS. Among levels highest chlorophyll values (45.2, 49.8) were obtained at 45 kg S ha^{-1} and the lowest (37.9, 43.5) was noted to be 0 kg S ha^{-1}.The tune of increase in chlorophyll content at 60 and 90 DAS was 19.2, 14.4 % due to 45 kg S ha^{-1} application when compared to 0 kg S ha^{-1}. Interaction showed significant result on chlorophyll at 30 DAS. Bentonite applied at the rate of 45 kg S ha^{-1} resulted in highest chlorophyll values at 30 DAS which increased to the tune of 10.4% over control. Results obtained by Erdem *et al.* (2016) confirmed that sulfur application showed increasing SPAD values from 39 in control treatment to 41, 42 and 45 in 25, 50 and 100 mg S kg^{-1}. Based on two field trials Skudra and Ruza (2017) reported that the chlorophyll content of wheat leaves, stems and ears was increased due to additional sulfur fertilization.

Dry matter accumulation (t ha^{-1})

The effect of sources on dry matter accumulation accounted to be non significant (Figs. 3a, b, c) at 30, 60 DAS but it was significant at 90 DAS. At 90 DAS significantly the maximum (7.2 t ha^{-1}) dry matter accumulation was noted in Bentonite treated plots and significantly the minimum was noted in Gypsum (7.06 t ha$^{-1)}$. Significance in dry matter accumulation (0.4, 3.1, 7.8 t ha^{-1}) was noted up to 45 kg S ha^{-1} among levels at 30, 60 and 90 DAS whereas the lowest (0.3, 2.5, 6.5 t ha^{-1}) was noted to be that of 0 kg S ha^{-1}. Dry matter accumulation increased to the tune of 10.8, 20.1 and 20.2 % at 30, 60 and 90 DAS due to 45 kg S ha^{-1} application over control. Interaction resulted in non-significant effect on dry matter accumulation at all stages indicating that there is no difference among different plots across the layout. However among the interactions sulfur applied at 45 kg ha^{-1} via. Bentonite showed maximum dry matter accumulation at all stages. It is self-evident that a consistent and balanced supply of nutrients from the start resulted in vigorus plant growth, increased leaf area and the number of tillers and thus increased dry-matter accumulation (Pooniya and Shivay 2011). The straw dry weight of bread wheat increased from 12.69 g pot^{-1} in 0 mg S kg^{-1} to 13.2 g pot^{-1} in 50 mg S kg^{-1} solely due to sulfur treatments alone (Orman and Ok 2012). Average dry matter yield of wheat was 0.95, 1.4, 1.48 and 1.52 g plant^{-1} due to sulfur applied via $CaSO_4$ in four doses i.e. 0, 25, 50 and 100 mg S kg^{-1} (Erdem *et al.* 2016). Increment in sulfur levels showed significance in improving dry matter production at 30, 60 and 90 DAS with 40 kg S ha^{-1} reporting the highest values (Navatha *et al.* 2017) and this results were also in line with Kalala *et al.* (2016). The highest dry weight g m^{-2} was reported with a higher dose of 45 kg S ha^{-1},

Table 2. Effect of sources and levels on CGR and RGR at 30-60 and 60-90 days.

Treatments	CGR		RGR	
	30-60 days	60-90 days	30-60 days	60-90 days
Sources				
Gypsum	8.1	14.04	0.028	0.012
Bentonite	7.9	14.8	0.027	0.013
SSP	8.1	14.2	0.028	0.013
Mean	8.03	14.3	0.027	0.012
CD ($p\leq0.05$)	NS	0.4	NS	0.0003
SE	0.08	0.14	0.0002	0.0001
Levels				
L0	7.3	13.1	0.027	0.013
L15	7.7	13.9	0.027	0.013
L30	8.3	14.6	0.028	0.012
L45	8.9	15.7	0.028	0.013
Mean	8.05	14.3	0.027	0.012
CD	0.27	0.48	0.0008	NS
SE	0.09	0.16	0.0003	0.0001
Interaction				
CD($p\leq0.05$)	NS	NS	NS	0.0007
SE	0.16	0.28	0.0005	0.0002
CV	3.47	3.42	3.27	3.55



	CD	SE	CV
S	NS	0.62	5.08
L	2.1	0.71	
S*L	NS	1.24	

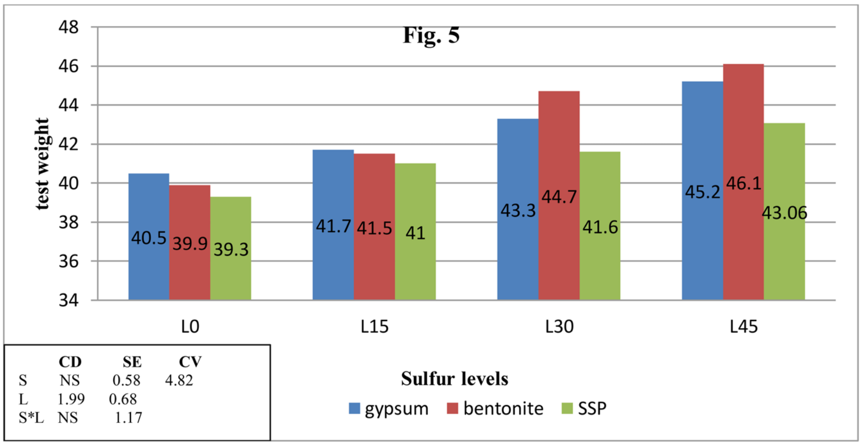
Fig. 4. Effect of sources and levels of sulfur on grains per ear.

which was comparable to 30 kg S ha^{-1}. At 30 DAT, it was significantly superior to doses of 15 kg S ha^{-1} and 0 kg ha^{-1} and the same pattern was observed throughout the crop growth cycle (Singh *et al.* 2017).

Crop growth rate (g m^{-2} day^{-1}) and relative growth rate (g g^{-1} day^{-1})

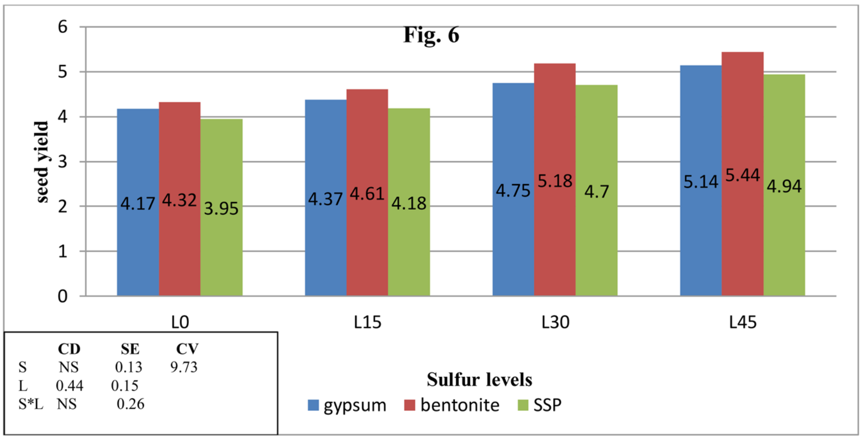
Results related to CGR from Table 2 revealed that effect of sources had no significant impact from 30-60 days whereas it showed a significant impact at 60-90 days. At 60-90 days Bentonite application reported a magnitude of 5.41% increase in dry matter accumulation over Gypsum which was the least effective. CGR was substantially improved due to the increment of sulfur levels at both 30-60 and 60-90 days. Sulfur at 45 kg S ha^{-1} reported to show the highest CGR (7.3, 15.7 g m^{-2} day^{-1}) at 30-60 and 60-90 DAS, on the contrary the lowest (7.3, 13.1 g m^{-2} day^{-1}) was reported in 0 kg S ha^{-1}. The magnitude of increase in 45 kg S ha^{-1} applied plots was 21.4, 5.39 % when compared to control.

Changing sources and interactions had no impact at 30-60 DAS, but both had a significant impact on RGR at 60-90 days (Table 2). Changing sulfur levels from 0 to 45 kg S ha^{-1} showed significance at 30-60 DAS whereas it was non-significant at 60-90 DAS.



	CD	SE	CV
S	NS	0.58	4.82
L	1.99	0.68	
S*L	NS	1.17	

Fig. 5. Effect of sources and levels of sulfur on test weight.



	CD	SE	CV
S	NS	0.13	9.73
L	0.44	0.15	
S*L	NS	0.26	

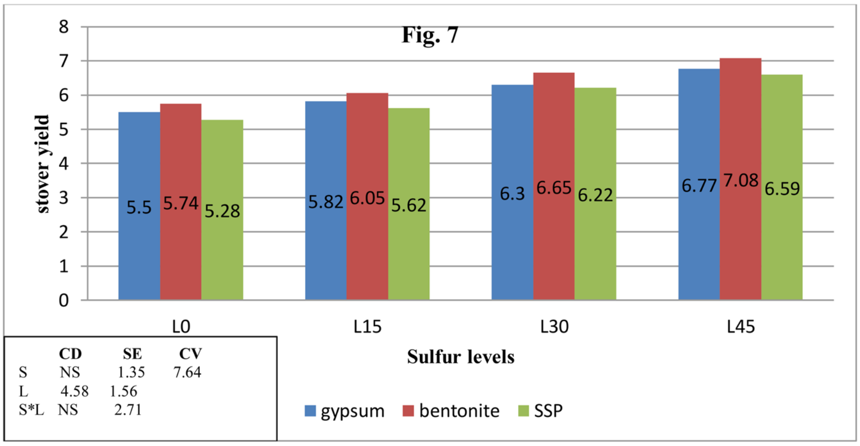
Fig. 6. Effect of sources and levels of sulfur on seed yield.

At 30-60 DAS the maximum value of RGR was noted in 45 kg S ha^{-1} whereas the lowest was 0 kg S ha^{-1}.

Yield and yield attributes

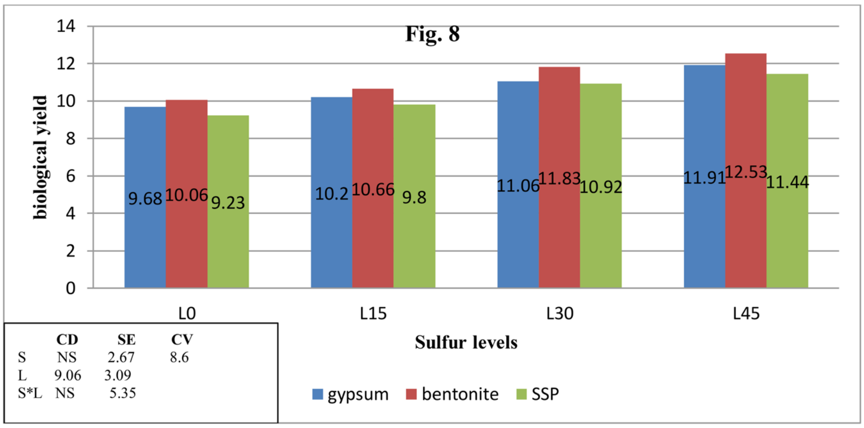
Application of different sulfur sources showed a non-significant impact on yield attributes like number of grains per ear and test weight of wheat indicating that the sources applied were equally effective over each other. Increasing sulfur levels from 0 to 45 kg ha^{-1} levels proved to have significanceon number of grains per ear (Fig. 4) and test weight (Fig. 5). 45 kg S ha^{-1} reported to show the maximum test weight (45.06 g) and grains per ear (44.8) at harvest. The magnitude of increase in test weight and grains per ear were 12.28 and 15.83 % in L4 (45 kg S ha^{-1}) when compared to L1 (0 kg S ha^{-1}). Interaction effect showed non-significant effect on both test weight and grains per ear. Test weight and grains per panicle were significantly affected up to 40 kg S ha^{-1} as denoted by the results obtained by Singh *et al*. (2012). Irrespective of the sources, sulfur application resulted in significantly improving the number of grains per panicle of rice (Ram *et al.* 2014).

Yield (seed, straw and biological yield) of wheat



	CD	SE	CV
S	NS	1.35	7.64
L	4.58	1.56	
S*L	NS	2.71	

Fig. 7. Effect of sources and levels of sulfur on stover yield.



	CD	SE	CV
S	NS	2.67	8.6
L	9.06	3.09	
S*L	NS	5.35	

Fig. 8. Effect of sources and levels of sulfur on biological yield.

due to switching of sulfur sources was found to be non-significant indicating that switching sources showed no positive impact and they equally affected the yield of wheat. Although sources were non-significant the highest yield was obtained due to usage of Bentonite. Yield was significantly affected by increment in sulfur levels from 0 to 45 kg S ha^{-1}. 45 kg S ha^{-1} resulted in maximum yield among levels. The magnitude of increase noted in straw, seed and biological yield was 23.63, 24.3 and 23.95 % due to 45 kg S ha^{-1} application over control. Interaction was reported to show a non-significant effect on yield of wheat indicating that there is no difference among different plots across the layout. However among interactions, Bentonite applied at the rate of 45 kg S ha^{-1} (Figs. 6, 7, 8) had the maximum yield when compared to other interactions. Jaga (2013) reported that increased doses of sulfur application from 0 to 60 kg S ha^{-1} caused a significant improvement in grain yield and straw yield of wheat which was tested in two sites. In terms of percentage response, grain yield and straw yield were 31.4, 37.9, 46.1 % and 4.8, 10 and 17.4% higher over control (Jaga 2013). Klikocka *et al.* (2016) reported that S fertilization increased grain production by 3.58 % by enhancing the effect of NPK.

CONCLUSION

Sulfur sources and interaction effect in many of the parameters were found to be non-significant however application of sulfur at the rate of 45 kg ha^{-1} helped in maximizing growth parameters and yield parameters of wheat thereby leading to increased production. The suitable dose of sulfur range can be interpreted to be 30-45 kg ha^{-1} for getting better advantage in wheat crop. The conclusion is based on one year of experimental data; however, further research may be conducted to confirm the above findings.

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