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Wheat yield as affected by sources of sulfur and its time of application

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Abstract

Sulfur is one of the essential secondary macronutrients which play an important role in the growth and production of wheat. The research was conducted to assess the influence of sulfur sources on wheat which applied at different times. The experiment was designed in RCBD replicated thrice. Main plot factor consists of different times of sulfur application (26th Oct, 10th Nov and 25th Nov 2017) and sulfur sources served as sub plot factor (i.e. Control, Ammonium sulfate, Elemental sulfur, Sulfate of potash and Gypsum @ 60 kg ha^{-1}). The experimental results shows that influence of various application times of sulfur was significant ($p \leq 0.05$) on seed yield (kg ha^{-1}), seed spike^{-1}, and 1000 grain mass (g). Maximum height of plant (82.9cm), tillers per m^2 (357.2), thousand seed mass (42.2 g), biomass yield (10767 kg/ha), seed yield (4427 kg/ha), grains spike^{-1}(57), SO_4-S content (96.95 mg kg^{-1}) at heading stage and SO_4-S concentration (0.47%) in leaves was recorded from treatment of Sulfate of potash. Maximum biomass yield (9368 kg ha^{-1}), 1000-seed mass (41.7 g), seed yield (3891 kg ha^{-1}), seeds spike^{-1} (54.6), and concentration of SO_4-S (79.29 mg kg^{-1}) in soil at flowering time from sulfur application at sowing time. Sulfate of potash (SOP) showed maximum response in term of grain yield compared with other sources of sulfur. Application time of sulfur at sowing time performed better in term of yield in contrast to other dates of sulfur application. It is concluded that source of sulfur as sulfate of potash when applied at sowing time has produced maximum yield of wheat crop.

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Introduction

Wheat (*Triticum aestivum* L.) belongs to family Poaceae which is also known as *Gramineae*. Wheat is considered as one of the leading cereals in the world and is used to feed most of the world population. Wheat is an important and essential cereal crop of under-developed countries (Khalil and Jan, 2005). Pakistan is among major wheat producing countries of the world. During 2015-16 wheat was cultivated on 9260,000 ha which produced 25482000 tons grain with average yield (national) of 2752 kg ha^{-1} (Pakistan Economic Survey, 2015-2016). In the whole world wheat is consumed as a 2^{nd} major food crop after rice by human population in the world. The production of wheat crop in Pakistan is less than developed countries. The reasons for this low production are unawareness in people regarding the proper use of fertilizers at proper time during various growth phases of crops. The contamination, unavailability of superior seeds at sowing time and high costs of inorganic fertilizers also plays a key role in limiting the yield (Pathak *et al.*, 2006). The factors which affect agriculture production in Pakistan consist of deficient irrigation, improper fertilizer use, highly alkaline soils, low quality agricultural research work, and land alteration along with land tenancy safety (U.N, 2000).

The sulphur deficiency was generally noticed in cereals crops due to over usage of inorganic P fertilizers which comprise fewer amounts of sulphur and due to less accumulation of sulfur from atmosphere. The deficiency of sulfur can significantly decrease quality and yield of wheat (Zhao *et al.*, 1999a; McGrath, 2003; Gyori, 2005). The insufficient supply of sulfur commonly limit the crop to achieve its possible yield, content of protein, quality and sufficient usage of N (Sahota, 2006). Sulfur is necessary for plant growth. The plant tissues consists sulfur approximately 0.25 to 0.52% on dry weight basis. Sulfur is required by plants in similar amounts to that of P (Dekock *et al.*, 2002; Ali *et al.*, 2008). The sulfur deficiency will produce short height in plants and will reduced growth, delayed maturity, lowest spikelets/tillers and more susceptibility to stresses (Doberman and Fairhurst, 2000). Sulfur has synergetic effect on uptake of nitrogen, phosphorus, potassium and zinc which results in high production of crop. The sulfur fertilizer application is a possible method to reduce the absorption of unwanted harmful element such as sodium and chloride due to its negative association Therefore S-fertilizer application is beneficial for enhancing quality and crops yield and soil conditions (Tandon, 1991; Zhang *et al.*, 1999).

The sulphur demand of wheat is comparatively high due to its rapid early growth and less mineralization of sulfur from SOM (Johnson, 1999). Many researchers have reported increases in wheat yield due to sulfur fertilization (Randall and Wrigley, 1986; McGrath and Zhao, 1995). Riley *et al.* (2000) concluded that application of E-sulfur and sulfate fertilizers has ensured 36% increase in yield of wheat crop. The sulphur sources includes soluble sources i.e., sulfate of potash, ammonium sulfate and elemental sulfur which is insoluble source and must be oxidized to be available to plants, and gypsum which is slightly soluble. Farmers are interested in using sulphur fertilizer sources in their crop rotation. Several studies have reported the impact of various plant available sulfur sources on sulphur uptake and response of crop yield (Schoenau and Grant 2005).

The research carried out with insoluble source of sulfur (elemental sulfur) has indicated its insignificant effect on yield of annual crop and therefore should be added to soil at least one year before so that the prills of elemental sulfur are oxidized to SO_4 plant available form. The preliminary results showed that application placement of sulphur prills affect dispersion of prill and oxidation. The reaction of crops to sources of sulfur was changeable and was parallel to both sources of SO_4 and elemental sulfur (S_o). The Crops responded better to S_o in case of shallow integration of prills in the spring using harrows before cultivating or placing the prills in band (shallow) with 2.50 cm (depth) and then cultivating the seeds with help of opener of hoe the following day in similar path of fertilizer band (Nutall *et al*., 1993).The aims of this trial were to consider the influence of sulfur (S) sources and its application time on S availability and uptake by wheat crop and its resulting effect on production and yield traits of wheat.

Methodology

The research was carried out to assess the impact of various S-fertilizers and its application time on yield performance of wheat crop at The University of Agriculture, Peshawar during winter 2017-18. The field study was practiced in RCB design (split plot) replicated thrice. The area of sub-plot was 5m x3m. The wheat variety (Pirsabak-2013) was used as test variety in this experiment. The different application times of sulfur fertilizer were allotted to main plots and various sources of S-fertilizer served as sub plot factor. The sulfur sources i.e. (Ammonium sulfate (AS), E-Sulfur (ES), Sulfate of potash (SOP), and Gypsum (G) were amended at the rate of 60 kg ha^{-1} (Khan *et al*., 2006) one month before sowing, 15 DBS and at the time of sowing. The basal dose of NPK (120-90-60 kg ha^{-1}) consists of Urea, MOP and DAP. The representative soil sample before cultivation was taken at 15 cm depth and evaluated for different physico-chemical properties (Table 1).

The data on height of plant (cm), maturity days, tillers/m^2, seeds $spike^{-1}$, biomass and seed yield (kg/ha) were recorded. Various soil physical and chemical properties, such as soil pH, EC, texture, bulk density, lime, OM, total N, extractable phosphorous and potassium was analyzed by various techniques described by McLean (1982), Richard (1954), Gee and Bahadur(1986), Blake and Hartge(1986), Nelson and Sommer(1982), Nelson(1982), Bremner and Mulvaney (1982), and soltanpour and schawab (1977), respectively. The soil samples at 15 cm depth at heading and harvesting stage of wheat were also taken from each sub-plot for analysis of soil SO_4-S by (Verma, 1977) method. The 10 wholly ripened leaves were collected at heading phase from experimental unit for determination of SO4-S. The oven dry sample (one gram) was collected and digested by wet digestion method as described by Richards (1954). The leaf SO_4-S concentration was analyzed by a technique given by Bardsley and Lancaster (1960).

Weather data of experimental site

The Fig. 1 shows weather data of the research area during the period from sowing up to harvesting of wheat crop. That reveals consistent reduction in temperature from October 2017 up to February 2018. However gradual increase in temperature was recorded from Feb, 2018 to May 2018. High temperature was recorded in May, 2018 compared with minimum temperature in Feb, 2018. The soil texture class of study area was silt-loam (Table 1). The soil pH value was 7.67 (alkaline) and EC was 0.13 dS m^{-1}. The EC value was less than 1 dS m^{-1} which reveals that soil was non-saline. The soil P was in medium range. The soil OM, K and N content was insufficient in soil.

Statistical analysis

All the collected data was examined statistically by MSTATC computer software (Russel and Eisensmith, 1983) according to the appropriate procedure used for randomized complete block design. The least significant difference (LSD) at ($P \leq 0.05$) was applied in case of significant F-test for mean comparisons to classify the significance between treatments means (Steel and Torrie, 1997).

Results and discussion

Tillers m^{-2}

The influence of sulfur sources on tillers m^{-2} of wheat was significant ($P \leq 0.05$) and the impact of application time was non-significant (Table 2). Greater tillers per m^2 (357.2) was counted when sulfate of potash was amended. The sources of sulfur fertilizers i.e. ammonium sulfate and gypsum ranked 2nd and 3rd with tillers number of 356.9 m^{-2} and 339.4 m^{-2} respectively. Whereas significantly lowest (263.1) tillers per m^2 was measured in untreated plot.

The result showed that application times of sulfur for tillers m^{-2} was not significant however, highest tillers m^{-2} was noted when sulfur fertilizers was applied 15 days before sowing.

Table 1. Physical and chemical properties of experimental site.

Property	Value	Unit
Texture	Silt loam	-
Electrical conductivity (EC)	0.13	dSm^{-1}
pH	7.67	-
Bulk Density	1.17	$g\ cm^{-3}$
$CaCO_3$ content	17.13	%
Organic matter content	0.80	%
Total Nitrogen	0.31	%
Extractable Phosphorous	4.43	$mg\ kg^{-1}$
Extractable Potassium	86.23	$mg\ kg^{-1}$
Available SO_4-S	27.67	$mg\ kg^{-1}$

Lowest tillers m^{-2} (319.3) was obtained when sulfur fertilizers amended at sowing time. The reason of maximum tillers m^{-2} with SOP application may due to sufficient supply of both K and SO_4. Ammonium sulfate ranked 2nd in tillers m^{-2} is because of its high solubility. Ali *et al.* (2012) concluded that tillers were considerably enhanced by raising the level of sulfur amendment. Maximum tillers per five plants (110) were recorded from sulphur application of 50 kg S ha^{-1}. Khan *et al.* (2007) investigated that by application of SOP at (60 kg ha^{-1}) considerably increased the number of tillers m^{-2}. Dewal and Pareek (2004) suggested that tillers per m^2 of wheat crop were considerably enhanced through application of sulphur (40 kg ha^{-1}).

Table 2. Tiller m^{-2}, plant height (cm) and days to maturity of wheat as affected by sources of sulfur and its application time.

Treatment	Tillers m^{-2}	Plant height (cm)	Days to maturity
Application Time			
30 DAS	326	77.07	153.4
15 DAS	333.8	79.31	153.7
At sowing	319.3	78.78	153.4
Sulfur Sources			
0	363.1 c	72.07 d	154.6 a
G	339.4 ab	80.23 ab	152.9 b
ES	315.2 b	76.99 c	153.1 b
AS	356.9 a	79.72 bc	153.9 ab
SOP	357.2 a	82.92 a	153.1 b
LSD $_{(0.05)}$for TA	ns	Ns	Ns
LSD $_{(0.05)}$for SS	38.5	2.99	1.12
Interaction (TA×SS)	ns	Ns	Ns

DBS=days before sowing, G=gypsum, ES=elementalsulfur, AS= ammonium sulphate, SOP=sulphate of potash, TA= times of application, SS=sulfur sources, ns=non-significant.

Mean values of the same category followed by different letters are significantly different at $P \leq 0.05$ level of probability using LSD test.

Plant height (cm)

The different sources of sulfur fertilizer has considerably ($P \leq 0.05$) enhanced plant height and was not significantly affected by times of application ($P \geq 0.05$) (Table 2). The interaction of different sources of S-fertilizer and application times was non-significant ($P \geq 0.05$). The highest plant height (82.92 cm) was observed when sulfate of potash was applied followed by gypsum applied with plant height of 80.23 cm. Among sources of sulfur fertilizer i.e.

ammonium sulfate and elemental sulfur were ranked 3rd and 4th with height of plant 79.72 (cm) and 76.99 (cm) correspondingly. However, significantly lowest plant height of 72.07 cm was observed in control. Different application times showed no significant difference on plant height. The time of application of sulfur fertilizers 15 days before sowing has produced highest plant height (79.31 cm) followed by time of application (at sowing time) with plant height of 78.78 (cm). The lowermost plant height of 77.07 cm was observed with time of application 30 days before sowing.

Table 3. Thousand grain weight (g), grain spike^{-1}, grain yield (kg ha^{-1}), and biological yield (kg ha^{-1}) of wheat as affected by sources of sulfur and its application time.

Treatment	1000-grains weight (g)	Grain spike^{-1}	Grain yield (kg ha^{-1})	Biomass yield (kg ha^{-1})
Application Time				
30 DAS	40.3 b	52.3 b	38544 a	8805
15 DAS	40.9 ab	52.3 b	3446 b	9108
At sowing	41.7 a	54.6 a	3891 a	9368
Sulfur Sources				
0	38.7 c	48.4 b	2719 c	5350 c
G	41.3 b	53.4 a	3811 b	10101 a
ES	41.1 b	53.2 a	3755 b	8670 b
AS	41.5 ab	53.3 a	3939 ab	10581 a
SOP	42.2 a	57.0 a	4427 a	10767 a
LSD $_{(0.05)}$for TA	0.751	1.96	365	Ns
LSD $_{(0.05)}$for SS	0.787	4.46	694	957
Interaction (TA×SS)	1.363	ns	ns	1659

DBS=days before sowing, G=gypsum, ES=elemental sulfur, AS= ammonium sulphate, SOP=sulphate of potash, TA= times of application, SS=sulfur sources, ns=non-significant

Mean values of the same category followed by different letters are significantly different at P≤0.05 level of probability using LSD test.

The maximum increase in plant height with application of sulfur might be attributed to indirect involvement of sulfur in photosynthesis process of plants (Patil*et al.*, 2014). Safi *et al.* (2016) described that plant height of wheat was significantly enhanced in treatment of SOP at rate of 25 kg ha^{-1}, 35 kg ha^{-1} and 45 kg ha^{-1} correspondingly. The variation in plant due to rate of fertilizer source might be due to variable inherited traits of wheat varieties and diverse climatic-soil circumstances. Khan *et al.* (2007) resulted that SOP application (60 kg ha^{-1}) has significant effect on improvement of plant height. Parmar *et al.* 2018 concluded that ammonium sulphate has significantly improved plant height of sesame crop at harvest. Saeed *et al.* (2012) discovered that addition of nitrogen (100 and 120 kg ha^{-1}) along with sulfur (20 and 35 kg ha^{-1}) has formed taller plants. Negi *et al.* (2010) suggested that sulphur sources i.e., zypmite and gypsum at 3 levels i.e., 20 kg ha^{-1}, 40 kg ha^{-1} and 60 kg ha^{-1} significantly affected plant height of mustard crop.

Days to maturity

The impact of sulfur sources on days to maturity was significant (P≤0.05) (Table 2). The different application time of sulfur fertilizers on maturity days of wheat was not significant (P≥0.05) and the interaction among them was also not consistent. Highest days to maturity (154.6) were observed in control (no application of sulfur) followed by ammonium sulphate with days to maturity of 153.9. Minimum maturity days 152.9 were observed from source of sulphur (gypsum). The highest maturity days of 153.7 was resulted when sulfur fertilizers amended 15 DBS. The lowermost days to maturity (153.4) was noted in time of sulphur application time 30 DBS and at time of sowing. The sulphur deficiency may result in reduced growth, minimum spikelets, short stature plants, less number of tillers, susceptible to stress condition and late maturity (Doberman and Fairhurst, 2000). However, wheat crop in control (no application of sulfur) took more days to maturity.

Table 4. SO_4-S concentration (mg kg^{-1}) in soil at heading and harvesting stage and SO_4-S concentration (%) at heading in leaves of wheat as affected by sources of sulfur and different times of application of sulphur.

Treatment	SO_4-S concentration at heading (mg kg^{-1} soil)	SO_4-S concentration at harvest (mg kg^{-1} soil)	SO_4-S concentration of leaves (%)
Application Time			
30 DAS	70.75	48.61	0.31
15 DAS	66.31	53.19	0.37
At sowing	79.29	67.51	0.35
Sulfur Sources			
0	19.22 b	11.36 c	0.14 b
G	66.25 ab	60.46 b	0.319 ab
ES	87.25 a	78.35 a	0.31 ab
AS	90.92 a	64.85 ab	0.47 a
SOP	96.95 a	67.18 ab	0.47 a
LSD $_{(0.05)}$ for TA	ns	Ns	Ns
LSD $_{(0.05)}$ for SS	30.78	14.8	0.18
Interaction (TA×SS)	ns	25.64	Ns

DBS=days before sowing, G=gypsum, ES=elemental sulfur, AS= ammonium sulphate, SOP=sulphate of potash, TA= times of application, SS=sulfur sources, ns=non-significant.

Mean values of the same category followed by different letters are significantly different at P≤0.05 level of probability using LSD test.

Weight of 1000 grains (g)

The data on 1000-seed mass was consistently (P≤0.05) impacted by various sulfur sources as well as by time of application of sulfur (Table 3.). The interaction of sources of sulfur fertilizer and time of application was significant (P≤0.05). Heaviest 1000-grains mass (42.2 g) was verified from treatments with SOP (sulphate of potash) followed by ammonium sulfate with 1000 grain weight (41.5 g). The sources of sulfur fertilizer i.e gypsum and elemental sulfur were ranked 3rd and 4th giving 41.3 g and 41.1 g of 1000 seed weight respectively. The time of application of sulfur at sowing time has given maximum weight of 1000 seeds (41.7 g) followed by sulphur application time (15 DBS) with thousand grain weight 40.9 g. The lowest weight of 1000 seeds was 40.3 g and was recorded for time of application of sulfur (30 days before sowing). The Table 2 reveals highest 1000-grains weight (43.0 g) from interaction of sulphur source (elemental sulfur) when applied at sowing time of wheat crop. The interaction of sulfur source fertilizer (sulfate of potash) with application time (15 days before sowing) was ranked 2nd in thousand grain weight (42.6 g). The least 1000-seeds mass (37.7 g) was observed from interaction of control (no application of sulfur) and sulfur application time (30 days before sowing of wheat crop). The highest 1000 grain weight with sulphate of potash (SOP) and ammonium sulfate may due to sufficient supply of both K and SO_4 in SOP and high solubility of ammonium sulfate. The heaviest thousand grain weight due to sulfur application may be due to efficient metabolic activities which increased the gluten and moisture contents in grain.

Sarfaraz *et al.*, 2014 concluded that weight of 1000 maize grains was improved by sulfur at 60 kg/ha and it reduced beyond 60 kg/ha. This is optimal amount of sulfur application in soil and above this level of sulfur, the grain yield and yield traits were decreased. Khan *et al.* 2006 stated that sulphur application through gypsum (60 kg ha^{-1}) has enhanced thousands grains weight in contrast to control treatment. Pasha *et al.* 2010 investigated that sulfur applied from source of gypsum (50 kg ha^{-1}) has enhanced the weight of thousand wheat grains tailed by application rate of 25 kg/ha of sulphur. Ali *et al.* (2012) noted that increasing sulfur fertilizer rates by ½ ratios has improved thousand grains weight. Dewal and Pareek (2004) also reported that 1000-seeds mass of wheat was considerably influenced by sulphur (40 kg S ha^{-1}).

Seeds spike^{-1}

Sulphur application time has considerably ($P \leq 0.05$) enhanced seeds $spike^{-1}$of wheat crop (Table 3). The sources of sulfur fertilizer showed significant variation ($P \leq 0.05$) and increased seeds $spike^{-1}$ of wheat and the interaction among them was non-considerable ($P \geq 0.05$). Sulphate of potash has resulted highest grains $spike^{-1}$ of (57.0) followed by gypsum with grains $spike^{-1}$ (53.4).

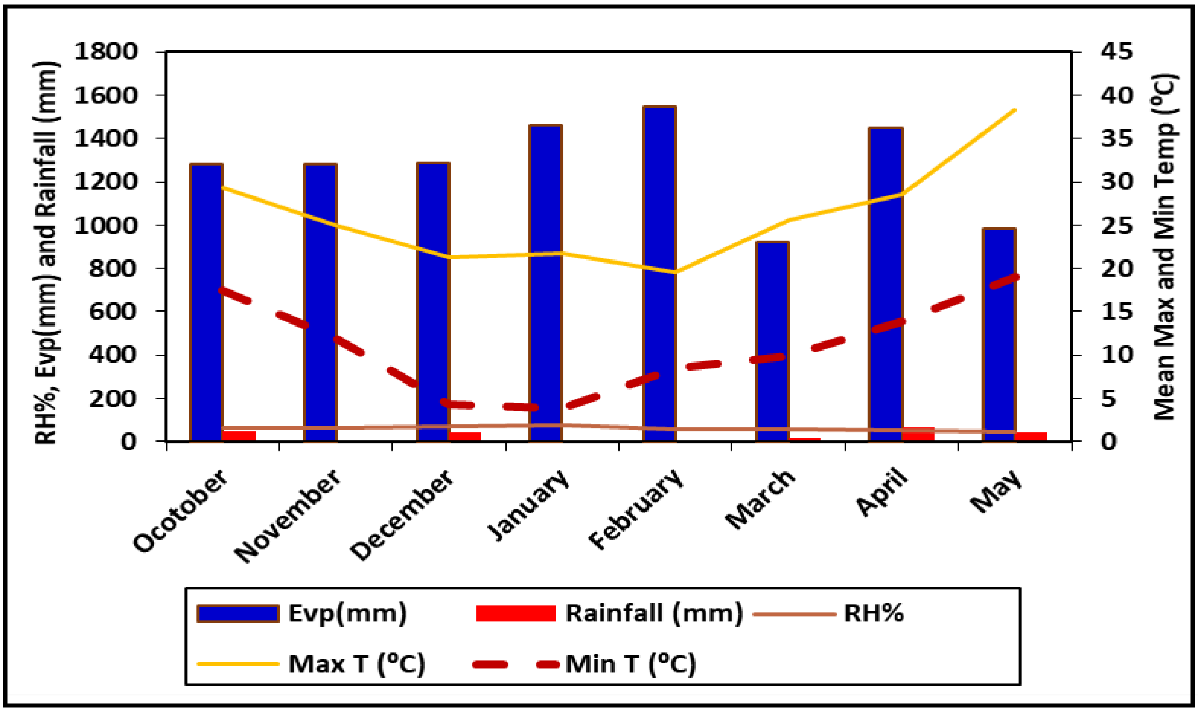

Fig. 1. Weather data of The University of Agriculture Peshawar (2017-18) Source: Pakistan Forest Institute Peshawar, 2017-18.

The sulphur sources (ammonium sulfate and elemental sulfur) were ranked 3rd and 4th with 53.3 and 53.2 seeds $spike^{-1}$ correspondingly. The time of application of sulfur (at sowing time) has produced highest seeds $spike^{-1}$ (54.6). Sulphur application times 15 and 30 DBS produced minimum seeds $spike^{-1}$ (52.3). Tabatabaei *et al.* 2012 concluded that seeds $spike^{-1}$ (45.58) was considerably increased with treatment (160 kg/ha of potassium sulphate). The variable response of grains $spike^{-1}$ to rate of sulfur fertilizer maybe due to variable climatic and soil condition. Ali *et al.* (2012) observed that increasing sulfur fertilizer rate (0, 25, 50 and 75 kg of sulphur ha^{-1}) has enhanced seeds $spike^{-1}$, seeds yield, and 1000-seeds mass.

The sulfur amended (@50 kg S ha^{-1}) has maximized seeds yield (4040 kg ha^{-1}), seeds $spike^{-1}$ (63.6), and thousand seeds mass (47 g). Pasha *et al.* (2010) investigated that sulfur application (50 kg ha^{-1}) through gypsum has increased number of grains ear^{-1} (46.80) in wheat crop.

Grains yield (kg ha-1)

The seed yield of wheat was statistically considerably ($P \leq 0.05$) affected by various sulphur sources and its time of application (Table 3). The interaction of different sources of sulfur and different times of application of sulfur was not significant ($P \leq 0.05$). Highest grains yield (4427 kg/ha) was achieved from source of sulfur (sulfate of potash) followed by source of sulfuri.e ammonium sulphate, gypsum, and elemental sulfur with grains yield of 3939, 3811,and 3755 kg ha^{-1} correspondingly. That reveals an increase of 40.16%, 38.10%, 44.86% and 62.81% in grain yield harvested from treatments of different sulphur sources (gypsum, elemental, ammonium sulphate and sulphate of potash) respectively compared with control. Lowest grains yield of 2719 kg ha^{-1} was harvested from control (no sulfur application). Heaviest seeds production of (3891 kg/ha) was harvested from time of sulfur application at sowing time. Minimum grains production of 3446 kg/hawas observed from time of sulphur application (15 DBS). Timely application of sulfur sources at sowing time of wheat crop has indicated maximum performance in grain production then early application of sulfur before sowing of wheat crop. Grain yield is based on yield components and it is the final product of wheat crop. The yield of wheat was highly influenced by solubility potential of different sources of sulfur. There are various sources of sulfur fertilizers available to farmers (Schoenau and Malhi, 2009). Sulfur sources include completely soluble ammonium and potassium sulfate, insoluble elemental sulphur that must be oxidized to sulfate in plant available form and gypsum (calcium sulfate) which is slightly soluble. The considerable variance in seed yield of wheat crop may be because of variable solubility potential of different sulfur sources. In addition to that the impact of climatic and soil properties will greatly influence yield performance of wheat. Khan *et al.* 2006 investigated that application of sulphur up to 60 kg/hasulphur has enhanced grain yield in contrast to control. This indicated increased grain yield by 42.8% with sulphur application in contrast to control. Singh *et al.* (2014) investigated that grain and straw yield of wheat was improved due to highest sulfur application (45 kg ha^{-1}) which revealed 22% and 27% increase in straw and grain yield compared with control. Yang-xin *et al.* (2017) confirmed that application of sulfur at (60 kg/ha) has considerably enhanced seed production. Ali *et al.* (2012) revealed that grain yield was improved by increasing the rate of application of S-fertilizer. Maximum grain production (4040 kg ha^{-1}) of wheat was observed at the rate of S (50 kg ha^{-1}) which revealed 26% increase than control. Pellet *et al.* (2003) stated that application of sulfur has considerably maximized yield by 15% in contrast to control. Sulfur applications also improved total sulfur uptake in the aerial biomass. Pasha *et al.* (2010) suggested that sulphur application through gypsum at @ 50 kg/ha confirmed maximum wheat seed yield (4744 kg/ha). Kulczyki, (2010) investigated the influence of sulphur through (soil and foliar application) in wheat and reported that sulphur application through soil (@ 80 kg/ha) significantly enhanced grain production in comparison to control.

Biomass yield (kg ha-1)

The results indicated that biological yield was significantly ($P \leq 0.05$) affected by different sources of sulfur fertilizer and was not significantly ($P \geq 0.05$) affected by different application time of sulfur. The interaction of different sources of sulfur and its application time was significant ($P \leq 0.05$) is presented in Table 3. Sulfate of potash has enhanced biomass yield (10767 kg/ha) followed by ammonium sulfate, gypsum, and elemental sulfur with biomass yield of 10581, 10101, and 8670 kg ha^{-1} correspondingly. That reveals an increase of 88%, 62%, 97%, and 101% in biological yield of wheat harvested from various sources of sulfur fertilizer (i.e. gypsum, elemental sulfur, ammonium sulphate and sulphate of potash) respectively compared with control. Minimum biomass yield (5350 kg ha^{-1}) was harvested in control (no sulfur). Sulfur application at sowing has produced maximum biomass yield (9368 kg ha^{-1}). The sulphur application time (15 days before sowing) was ranked 2nd with biological yield of 9108 kg ha^{-1}. Lowest biomass yield (8805 kg ha^{-1}) was observed from time of application (30 DBS). The interaction of sulphur source (ammonium sulfate) and application time of sulphur (30 days before sowing) has produced maximum biomass yield of 11793 kg ha^{-1}. The interaction of sulphur source (Sulphate of potash) and application time of sulphur (at sowing of wheat crop) was ranked 2nd in biological yield (10974 kg/ha). The minimum biomass yield of 5265 kg ha^{-1} was harvested from interaction of control and sulfur application time (15 DBS).The variation in biomass yield of wheat is confirmed is due to solubility potential of sulfur sources. The ammonium and potassium sulfate are soluble in soil. The elemental sulphur is very slow in solubility while gypsum (calcium sulfate) is slightly soluble in soil (Schoenau and Malhi, 2009). The sources of sulfur affect biomass yield because of their solubility potential in soil and availability of microbes for sulfur oxidation. Tabatabaei *et al.* (2012) investigated that sulphate of potash application (160 kg ha^{-1}) has enhanced grain yield and yield traits of wheat. Ahmed *et al.* (2017) revealed that canola was most responsive in term of biomass yield as compared to wheat and peas to sulfur fertilizers (ammonium thiosulfate, potassium sulfate, elemental sulfur, ammonium sulfate, and gypsum) applied at 20 kg S ha^{-1}. It may be due to variable requirement of sulfur for different crops, climatic and different soil conditions. Dewal and Pareek (2004) investigated that application of sulphur at (@ 40 kg ha^{-1}) has considerably enhanced biological yield of wheat.

The difference in above results may be due to different available initial soil sulfur level, different soil texture, and climatic condition. Sarfaraz *et al.* (2014) concluded that soil sulfur application and foliar sulfur application has enhanced yield and growth indices of maize. They further reported that sulfur application (60 kg/ha) to the soil at time of sowing has significantly boosted maize productivity. Khan *et al.* 2006 suggested that biomass and stover yield of maize were increased with sulfur application (60 kg ha^{-1}). Kulczyki, (2010) investigated that wheat biological yield significantly increased in those plots amended with S 80 kg ha^{-1} in soil and 10 dm^3 ha^{-1} as foliar spray.

SO_4-S concentration (mg/kg) in soil at heading stage of wheat crop

The various sources of sulfur have significantly ($P \leq 0.05$) affected SO_4-S concentration (mg kg^{-1}) in soil at heading time of wheat (Table 4). The different sulphur application time has not considerably ($P \geq 0.05$) affected level of SO_4-S (mg/kg) in soil. Highest SO_4-S concentration of 96.95 mg kg^{-1} was observed when sulphate of potash (SOP) was applied followed by ammonium sulfate and elemental sulfur with SO_4-S concentration of (90.92 and 87.25 mg kg^{-1}). The source of sulfur (gypsum) was ranked 4th with SO_4-S concentration of 66.25 mg kg^{-1} and least concentration of SO_4-S (19.22 mg kg^{-1}) was calculated in plot (no sulfur). Maximum SO_4-S (79.29 mg kg^{-1}) was measured from time of sulfur application at sowing time followed by time of application of sulfur (30 days before sowing) with SO_4-S concentration of 70.75 mg kg^{-1}. Ahmed *et al.* (2017) reported that sources of sulfuri. esulfate and thiosulfate sources had significantly supplied high rates of SO_4-S (mg cm^{-2}) than control. The source of sulfur (potassium sulphate) has supplied highest rates of SO_4-S at Star City soil and Melfort soil. The supply rates were reliable with good yield responses were observed in canola crop to different sources of sulphur over 8 weeks of application. The elemental sulphur (ES) has the least effect on enhancing soil sulfate supply rate. Khan *et al.* (2006) investigated that sulphur application (60 kg ha^{-1}) has indicated up to 74.7 (mg kg^{-1}) of SO_4-S at silking stage of maize crop. They suggested that 68.77 mg kg^{-1} as optimum SO_4-S concentration in soil for highest maize yield. The application of two doses of 5 and 10 dm^3 ha^{-1}as soil applied S has significantly lowered the soil reaction and enhanced the content of sulfate as compared to control treatments (Kulczyki, 2010).

SO_4-S concentration (mg kg^{-1}) at harvesting time in soil

Different sulfur sources have consistently ($P \leq 0.05$) affected SO_4-S concentration (mg kg^{-1}) at harvesting time in soil, whereas the effect of application time was not significant ($P \geq 0.05$). The interaction of sources of sulfur and application time was significant ($P \leq 0.05$).

Highest SO_4-S concentration (78.35 mg kg^{-1}) was observed from source of sulfur (elemental sulfur) followed by sulfate of potash and ammonium sulfate with SO_4-S concentration of 67.18, and 64.85 mg kg^{-1} correspondingly. Minimum SO_4-S concentration (11.36 mg/kg) was observed from plot treated with no sulfur. Highest SO_4-S concentration (67.51 mg kg^{-1}) was noted at time of sowing followed by time of application (15 DBS) with SO_4-S concentration (53.19 mg/kg). Lowest SO_4-S concentration (48.61 mg/kg) was observed from time of application 30 days before sowing. Khan *et al.* (2006) revealed that SO_4-S concentration of soil at harvesting stage was considerably different at different levels of applied sulfur. Barbora (1995) revealed that concentration of SO_4-S was enhanced by 4 mg kg^{-1} per annual application of 20 kg S ha^{-1}. Singh *et al.* (2014) noted that sulphur application at the 0-45 kg/ha has enhanced the content of available sulphur in surface soil than lower layers.

SO_4-S concentration (%) in leaves

The time of application of sulfur has not considerably ($P \geq 0.05$) influenced SO_4-S level (%) in leaves of wheat crop (Table 4.) but the impact of different sources of sulfur fertilizer was statistically different on concentration (%) of SO_4-S in leaves. Their interaction was also not significant.

The maximum amount of SO_4-S (0.47%) was recorded from source of sulfur (Sulphate of potash) followed by Ammonium sulphate with SO_4-S concentration of 0.47% in leaves of wheat crop. The sources of sulphur i.e., G and ES were ranked 3rd and 4th with SO_4-S concentration of 0.3193% and 0.31% respectively in leaves of wheat crop at heading stage. Minimum SO_4-S concentration (0.14%) was noted in control. The sulphur application time (15 DBS) has enhanced SO_4-S concentration of 0.37% in wheat tissues. Lowest SO_4-S concentration of 0.31% was observed from sulfur application (30 DBS). Sarfaraz *et al.* (2014) reported that the highest concentration of SO_4-S (0.39%) was measured in maize leaves with 100 kg S ha^{-1} compared with minimum SO_4-S (0.09%) from control. Khan *et al.* (2006) revealed that concentration of sulphur in leaf tissues enhanced with increasing application rate of sulphur with maximum values of SO_4-S (0.94%) was observed from treatment of 120 kg sulfur applied compared with minimum of 0.11% in control. The content of sulfur in plant leaves was from 0.15 to 0.5% (Tandon, 1984). Maximum level of sulfur was noted with application 60 kg ha^{-1} S which produced tissue sulfur concentration of 0.46%. These concentrations are considered high to excessive (Tandon, 1984) and might be responsible for decreases in maize grain yield and other yield attributes. Nasreen and Huq (2002) confirmed the significant influence of sulfur fertilizer application on sulfur uptake by leaves.

The concentration of sulfur was lowest at vegetative and maturity stage than reproductive stage. The sulphur uptake by sunflower was considerably enhanced by maximizing applications of sulfur from zero to 80 kg S ha^{-1}. Sharma *et al.* (2009) also noted that increase in sulfur application rate from zero to 45 kg S ha^{-1} has considerably enhanced the S concentration in wheat straw and grains has increased from 0.07% to 0.32% and 0.18% to 0.36%. The uptake of sulphur was minimum in control plot and improved with increasing in levels of sulfur.

Conclusion

The source of sulfur (sulfate of potash) has maximized grains yield (4427 kg ha^{-1}) followed by ammonium sulphate, G, and elemental sulfur with grains yield of 3939 kg ha^{-1}, 3811 kg $ha^{-1}$and 3755 kg ha^{-1} separately. That reveals an increase of 40.16%, 38.10%, 44.86%, and 62.81% in grain yield harvested from treatments of various sulphur sources (i.e G, ES, AS, and SOP) respectively in contrast to control. The sulfur application at the time of sowing has produced maximum grains yield of 3891 kg ha^{-1} which showed 12.91% increase in grain production compared with sulphur application time (15 DBS).

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Authors' contributions

Prof. Dr. Mohammad Jamal khan has planned and supervised the experiment. Mr. Muhammad Owais Khan has conducted the experiment and drafted the manuscript. Prof. Dr. Mohammad Shafi, Dr.Shazma Anwar and Dr.Asad Ali Khann has performed statistical analysis of data and revised the manuscript.

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