The Pharma Innovation Journal 2021; 10(8): 461-464

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277- 7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2021; 10(8): 461-464

www.thepharmajournal.com
Received: 03-05-2021
Accepted: 07-06-2021

Performance evaluation of sources and levels of sulphur on yield attributes and yield of mustard (*Brassica juncea* L.) under irrigated conditions

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Abstract
A field experiment was conducted to evaluate the performance of mustard to various sources and levels of sulphur during *rabi* season of 2021 at College Farm, College of Agriculture, PJTSAU, Rajendranagar, Hyderabad. The experiment was carried out with three sources of sulphur (ammonium sulphate, gypsum and bentonite sulphur) and three levels of sulphur (20, 40 and 60 kg S ha^{-1}) with one additional treatment (control *i.e.,* 0 kg S ha^{-1}) in factorial concept and replicated thrice. A significant crop response was observed in yield attributing characters as well as in yield (seed and stover) with application of ammonium sulphate among all the three sources. Higher values of the yield also recorded on application of 60 kg S ha^{-1}, which showed parity with 40 kg S ha^{-1}.

Keywords: Sources, levels, sulphur, mustard, yield

Introduction
Mustard (*Brassica juncea* L.) a member of Cruciferae family is well known as rai, raya, laha in different parts of the country. Mustard holds nearly one third part (33.3%) of the total oilseeds production in India (Kumar *et al.,* 2019) [14]. Mustard is the second important oilseeds crop grown during *rabi* both rainfed as well as under irrigated conditions. India ranks second in area (5.96 million ha) and third in production (8.32 million tonnes) worldwide with productivity of 1397 kg ha^{-1} (Directorate of Economics and Statistics, 2018) [8]. Sulphur is the key element for oil, protein (Fe-S protein, called ferrodoxine), vitamins (Biotine, Thiamine) and flavoured compounds synthesis in plant (Chattopaddhayay and Ghosh, 2012) [6]. Sulphur provides better nutritional and market quality to oilseed crops. The escalating sulphur deficiency in Indian soils is the result of agricultural intensification with high yielding varieties and simultaneous adoption of multiple cropping systems with high analysis sulphur free fertilizers (Rathore *et al.,* 2015) [19]. In S-scarcity soil, the effectiveness of applied NPK fertilizers might be truly influenced and crop yield may not be feasible (Ahmad *et al.,* 2005) [1]. External application of sulphur fertilizer will exert a positive response in yield improvement. Among oilseeds, Indian mustard noticeably respond to sulphur fertilization. The quality and yield of seed is majorly decided by sulphur. Presumably for these reasons mustard crop needs supplementary quantity of sulphur for absolute growth, development and yield. In mustard, seed and stover yield is markedly governed by sulphur levels (Sharma *et al.,* 2009) [21]. Therefore the present investigation was carried out to study the effect of sources and levels of sulphur on performance of mustard.

Materials and Methods
A field experiment was conducted to study the "Response of mustard [*Brassica juncea* (L.) Czern. and Cosson] crop to sources and levels of sulphur nutrition" during winter (*rabi)* season of 2020-21 at the College Farm, College of Agriculture, Professor Jayashankar Telangana State Agriculture University, Rajendranagar, Hyderabad. The farm is geographically positioned at 17° 19′ N latitude, 78° 23′ E longitude and at an altitude of 542.6 m above mean sea level.

The weekly mean maximum temperature during the crop growth period (04.11.2020 to 16.02.2021) ranged from 26.4 °C to 31.7 °C with an average of 29.3 °C, while the weekly mean minimum temperature ranged from 11.1 °C to 18.6 °C with an average of 14.5 °C. The total rainfall received during the crop growth period was 2.8 mm.

The soil was found to be sandy loam in nature with slightly alkaline (pH 8.28), high in organic carbon content (0.78%), low in available nitrogen (199.54 kg ha^{-1}), high in available phosphorus (33.60 kg ha^{-1}), high in available potassium (410.45 kg ha^{-1}) and low in available sulphur content (9.74 ppm).

The present study was conducted with factorial randomized block design with ten treatments and three replications. Each replication was splitted into ten equal parts and treatments were imposed in it. Basically, sources and levels of sulphur fertilizer were used for experimental purpose. All the treatments were allocated randomly to the plots to avoid same treatments in nearby plots. The treatment combinations and symbols used were: T_1 (S_1L_1): Ammonium sulphate @ 20 kg ha^{-1}, T_2 (S_1L_2): Ammonium sulphate @ 40 kg ha^{-1}, T_3 (S_1L_3): Ammonium sulphate @ 60 kg ha^{-1}, T_4 (S_2L_1): Gypsum @ 20 kg ha^{-1}, T_5 (S_2L_2): Gypsum @ 40 kg ha^{-1}, T_6 (S_2L_3): Gypsum @ 60 kg ha^{-1}, T_7 (S_3L_1): Bentonite sulphur @ 20 kg ha^{-1}, T_8 (S_3L_2): Bentonite sulphur @ 40 kg ha^{-1}, T_9 (S_3L_3): Bentonite sulphur @ 60 kg ha^{-1} and T_{10} (S_0L_0): Control.

The recommended fertilizer dose of 80:40:40 kg of N, P_2O_5 and K_2O ha^{-1} was applied to all the treatments. Half of nitrogen, Phosphorus and Potassium were applied as basal, whereas rest of the nitrogen applied at 20 and 40 DAS. Nitrogen was applied in the form of urea (46% N), Phosphorus as di-ammonium phosphate (46% P_2O_5) and potash as muriate of potash (60% K_2O), respectively. The sources of sulphur were ammonium sulphate (24% S), gypsum (18.6% S) and bentonite sulphur (90%). All the sources of sulphur were applied basal.

Result and Discussion

Number of branches plant^{-1}

A review of the collected data revealed that the total branches plant^{-1} at harvest stage varied significantly due to the use of different sulphur sources and significantly highest with ammonium sulphate (9.7). However, the number of branches formed by gypsum (8.7) and bentonite S (9.0) were statistically on par. The control treatment produced least number of branches plant^{-1} (6.3), proving significantly inferior to the other S source treatments.

At the harvest stage of the crop, the variation in the number of branches plant^{-1} due to different sulphur level treatments was found to be significant. The number of branches plant^{-1} increased gradually as the S level increased from 0 to 60 kg S ha^{-1}. The highest number of branches plant^{-1} (9.8) was observed from 60 kg S ha^{-1}, which was statistically equivalent to 40 kg S ha^{-1} (9.4). The application of 20 kg S ha^{-1} gave 8.3 branches. The control plot had the lowest number of branches plant^{-1} (6.3), which was statistically inferior to the other sulphur levels.

The increased branches might be ascribed due to overall improvement in plant vigour and production of sufficient photosynthates through increased plant height, leaf area, chlorophyll content of leaves and partitioning of dry matter with applied sulphur (Tandon, 1991). Increase in levels confirmed the more availability of nutrients to crop and better utilisation for branching and other vegetative growth. The similar result was found by Alam *et al.* (2014) [3] and Parihar *et al.* (2014) [15].

Number of siliquae plant^{-1}

Data indicated that S sources and levels had a significant impact on the number of siliquae plant^{-1}. Among the sources of sulphur ammonium sulphate gave significantly highest number of siliquae plant^{-1} (135.0), whereas gypsum (125.7) and bentonite S (127.2) were found to be statistically similar with respect to number of siliquae plant^{-1}.

An increase in S level from 0 to 20 kg ha^{-1} did not result in a significant increase in the number of siliquae plant^{-1} at harvest, but a further increase in S level, *i.e.* 60 kg S ha^{-1}, resulted in a significantly highest number of siliquae plant^{-1} (133.9) at harvest, which was statistically on par with 40 kg S ha^{-1} (130.4). It might be attributed due to increased process of tissue differentiation from somatic tissue to reproductive tissue. Meristematic activity and development of floral primordial might have increased due to sulphur application, which resulted in formation of more flowers and siliqua. The similar result was found by Chauhan *et al.* (2002), Alok (2007) and Bansal *et al.* (2000) [7, 4, 5].

Table 1: Yield attributes and yield of mustard as influenced by sources and levels of sulphur

Treatments	Yield attributes and yield						
Sources of sulphur	No of branches plant^{-1}	No. of siliquae plant^{-1}	Length of siliqua (cm)	No of seeds siliqua^{-1}	1000-seed weight (g)	Seed yield (kg ha^{-1})	Stover yield (kg ha^{-1})
S_1 (Ammonium sulphate)	9.7	135.1	4.89	12.46	3.76	1507	4699
S_2 (Gypsum)	8.7	125.7	4.56	11.59	3.65	1323	4143
S_3 (Bentonite S)	9.0	127.2	4.63	11.87	3.69	1379	4333
S.Em (±)	0.2	1.4	0.08	0.21	0.06	33	114
CD (0.05)	0.5	4.1	0.24	0.64	NS	98	340
Levels of sulphur							
L_1 (20 Kg ha^{-1})	8.3	123.7	4.49	11.28	3.55	1229	3957
L_2 (40 Kg ha^{-1})	9.4	130.4	4.73	12.20	3.75	1459	4546
L_3 (60 Kg ha^{-1})	9.8	133.9	4.86	12.44	3.80	1521	4672
S.Em (±)	0.2	1.4	0.08	0.21	0.06	33	114
CD (0.05)	0.5	4.1	0.24	0.64	0.20	98	340
Interaction							
S.Em (±)	0.3	2.4	0.13	0.37	0.11	57	198
CD (0.05)	NS	NS	NS	NS	NS	NS	NS
Control *vs.* other treatments							
Control	6.3	119.5	4.33	10.00	3.40	1005	3350
S.Em (±)	0.3	2.5	0.14	0.39	0.12	60	208
CD (0.05)	0.6	5.2	0.30	0.82	0.25	126	439

Length of siliqua (cm)

The length of siliqua of mustard was significantly influenced by different sources and levels of sulphur, but the interaction effect was non-significant. Sulphur sources had a significant impact on siliqua length. The use of ammonium sulphate produced significantly maximum siliqua length (4.89 cm) than the use of gypsum (4.56 cm) and bentonite sulphur (4.63 cm), whereas gypsum and bentonite S were on par.

The increment in levels of sulphur had a significant effect on length of siliqua and recorded highest at 60 kg S ha^{-1} (4.86 cm), which was on par with 40 kg S ha^{-1} (4.73 cm). The length of siliqua recorded 4.86 cm on application of 20 kg S ha^{-1}, whereas lowest being obtained at control (4.33 cm).

More availability of sulphur from ammonium sulphate, augmented the better utilisation of N there by more photosynthesis, luxuriant crop growth and better partitioning of nutrients from source to sink, resulted in increased the siliqua length. The results of present investigation are in line with those of of Jat *et al.* (2017), Patel *et al.* (2009) and Tetarwal *et al.* (2013) [10, 16, 23].

Number of seeds siliqua^{-1}

The most extreme number of seeds siliqua^{-1} (12.46) was seen with ammonium sulphate. Gypsum (11.59) showed factual equality with bentonite S (11.87) and these sulphur sources were found essentially better over control (10).

The number of seeds siliqua^{-1} increased essentially with the augmentation in sulphur levels up to 60 kg S ha^{-1}. Utilization of 60 kg S ha^{-1} brought about most noteworthy number of seeds siliqua^{-1} (12.44), which was on par with 40 kg S ha^{-1} (12.20). The number of seeds siliqua^{-1} at 20 kg S ha^{-1} was 11.28, which was comparatively lower than 40 kg S ha^{-1} and least being recorded for control (10), which communicated genuinely mediocrity over rest of sulphur portions.

The obtained results might be due to enhanced seed formation, which is attributed by more sulphur availability. Prasad *et al.* (1991) [17] reported that sulphur in presence of phosphorus stimulates flowering and seed formation in siliqua. The larger leaf area manifested due to increased levels of sulphur intensified the rate of photosynthesis and photosynthates accumulation. The greater diversion of photosynthates to sink (siliqua and seeds) and improved physiological activity of the plants, boosted the partitioning and translocation of photosynthates to the sink, which caused increased in number of seeds. These results corroborate with the findings of Kumar and Kumar (2011) [12], Kumar *et al.* (2001), Parihar *et al.* (2014) [15] and Rakesh and Banik (2016) [18].

1000-seed weight (g)

The maximum 1000-seed weight (3.76 g) was associated with ammonium sulphate, followed by bentonite S (3.69 g) and the lowest value (3.65) recorded for gypsum of the same character among the sources. The 1000-seed weight for control was found not to be influenced by sources of sulphur.

An assessment of information from table 4.1 revealed that the variations in 1000-seed weight inferable from various levels of sulphur were significant at harvest stage of mustard. With an increase in sulphur doses up to 60 kg S ha^{-1}, the weight of 1000 seeds increased in a trend. The highest 1000-seed weight was recorded from 60 kg S ha^{-1} (3.80 g), which was statistically equivalent to 40 kg S ha^{-1} (3.75 g). However, in terms of 1000-seed weight, the difference between 0 (3.40 g) and 20 kg S ha^{-1} (3.55 g) was found to be significant. This might be due to greater accumulation of photosynthates caused by each successive addition of sulphur. The considerable diversion of nutrients to seed caused deposition of nutrients and boldness, which ultimately increased the weight of seeds. Similar results were reported by Bansal *et al.* (2000), Patel *et al.* (2009), Ahmad *et al.* (2011) and Dongarkar *et al.* (2005) [5, 16, 2, 9].

Seed and stover yield (Kg ha^{-1})

The seed and stover yields were significantly responded by various sources and levels of sulphur. The use of ammonium sulphate resulted in the highest seed and stover yields (1507 and 4699 kg ha^{-1}) and was significantly superior to the other sulphur sources *i.e*., bentonite S (1376 and 4333 kg ha^{-1}) and gypsum (1323 and 4143 kg ha^{-1}) respectively. The difference in seed yields between gypsum and bentonite S as a sulphur source were not found to be significant. However, the lowest seed yield was observed from the control plot (1005 and 3350 kg ha^{-1}). The percent increase in seed and stover yield due to application of ammonium sulphate over control, gypsum and bentonite S were (49.9 & 40.2%), (13.9 & 13.4%) and (9.2 & 8.4%) respectively.

Increasing sulphur levels resulted in an increase in mustard seed and stover yields up to 60 kg S ha^{-1}. Application of 60 kg S ha^{-1} resulted in a maximum seed and stover yields of 1521 and 4672 kg ha^{-1}, which was on par to 40 kg S ha^{-1} (1459 and 4546 kg ha^{-1}) and demonstrated statistical superiority, over 20 kg S ha^{-1} (1229 and 3957 kg ha^{-1}). The most reduced seed yield (1005 and 3350 kg ha^{-1}) was recorded from control (0 kg S ha^{-1}) which showed factual inadequacy over rest of the sulphur levels. The seed and stover yield increased (51.3 & 39.4%), (23.7 & 18.0%) and (4.2 & 2.7%) due to incorporation of 60 kg S ha^{-1} over control, 20 kg S ha^{-1} and 40 kg S ha^{-1} respectively.

This might be ascribed due to the increasing levels of S which resulted in higher deposition of carbohydrate, protein and their translocation to the productive organs, which in turn enhanced all the growth and yield attributing characters resulting more seed yield. Higher S levels were responsible for increased leaf area and chlorophyll content of leaves causing higher photosynthesis, assimilation and metabolic activities which were responsible for overall improvement in vigour and yield attributes (number of siliquae, length of siliqua, number of seeds and test weight), dry matter accumulation, it's partitioning and finally seed yield of mustard. This is in conformity with Jyoti *et al*. (2012) [11], Singh and Kumar (2014) [22]. Stover yield depends on vegetative growth parameters *viz.*, plant height, number of branches per plant, and number of siliquae per plant. All of these characters were found to increase with the application of sulphur, that supported the stover yield enhancement. Similar findings were obtained by Verma *et al.* (2012) and Ray *et al.* (2015) [24, 20].

Conclusion

From the result it could be concluded that highest yield attributing characters and yield were obtained due to application of ammonium sulphate and 60 kg S ha^{-1}, while 40 kg S ha^{-1} gave on par results compared to 60 kg, proving more economical.

Acknowledgement

It is my great pleasure to give my heartfelt gratitude to Dr. M. Yakadri (Chairman), Professor & Head, Department of

Agronomy, College of Agriculture, Rajendranagar, Hyderabad and committee members, Dr. Spandana Bhatt, Scientist (Agronomy), Rice Research Centre, ARI, Rajendranagar, Hyderabad & Dr. K. Pavan Chandra Reddy, Associate Professor, Soil Science and Agricultural Chemistry, College of Agriculture, Rajendranagar, Hyderabad for their continuous help and motivation during the course of experiment.

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