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INFLUENCE OF IRRIGATION SCHEDULING AND SULPHUR FERTILIZATION ON GROWTH AND PRODUCTIVITY OF INDIAN MUSTARD (*Brassica juncea* L.)

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ABSTRACT

A field trial was at the Agronomy Research Farm of Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya (U.P.), during the *rabi* season of 2022-23, to find out the effect of different irrigation scheduling and sulphur levels on growth, yield attributes and yield of mustard (*Brassica juncea* L.) cv. *Varuna*. The trial was performed in split-plot design with three replications, having three moisture regimes is main plot 0.6 IW/CPE ratio (I_1), 0.8 IW/CPE ratio (I_2) and flowering and pod formation stage (I_3), and five sulphur levels in sub plot @ 0, 20, 30, 40 and 50 kg S ha^{-1} (S_0 to S_4). Among moisture regimes, I_1 give best result and having the tallest plants (172.3 cm at harvest stage), highest leaf area index (4.78 at 60 DAS) and maximum dry matter accumulation (677.3 g plant $^{-1}$), which resulted into a better grain yield of 21.0 q ha^{-1} and stover yield of 46.5 q ha^{-1} which performed 18.5% and 4% more than I_2 and I_3, respectively. Furthermore, at different sulphur levels, 50 kg ha^{-1} (S_4) recorded the best plant height (172.7 cm), leaf area index (4.85) and dry matter (696.9 g plant^{-1}), and having highest grain yield (21.7 q ha^{-1}) and stover yield (47.9 q ha^{-1}), which is 24% more than the control, though it stayed statistically at par with 40 kg S ha^{-1}. The interaction between irrigation and sulphur levels was found to be non-significant for all the characters studied in this research. It can thus be concluded that irrigating mustard at 0.6 IW/CPE ratio along with 50 kg S ha^{-1} gives the best growth and yield under the agro-climatic conditions of the Indo-Gangetic plain.

***Keywords* :** IW/CPE, irrigation, Growth, sulphur, mustard.

Introduction

Indian mustard (*Brassica juncea* L.) is a key member of the Brassicaceae family. It is one of the most important oilseed crops throughout the world after soybean and groundnut, ranking as the third most important edible oilseed crop globally after soybean and palm oil (Chand *et al.*, 2021). In India, it dominates the rapeseed-mustard group, covering approximately 90% of the total acreage (Limbalkar *et al.*, 2023) and playing a crucial role in the national oilseed economy (Kumar *et al.*, 2020). Beyond its significant contribution to vegetable oil production, mustard oil is highly valued for its unique nutritional profile-being low in saturated fats and rich in essential omega-3 and omega-6 fatty acids (Jat *et al.*, 2019; Kumar *et al.*, 2020; Verma *et al.*, 2023) which offer substantial cardiovascular health benefits (Verma *et al.*, 2023). Additionally, the remaining seed meal serves as a vital protein source for animal feed (Verma *et al.*, 2023). Despite its importance, India continues to rely heavily on imports to meet domestic demand (Kumar *et al.*, 2020), underscoring the critical need to enhance productivity through improved agricultural practices (Limbalkar *et al.*, 2023; Saha *et al.*, 2024). Indian mustard exhibits an optimal photosynthetic response at temperatures ranging from 15-20°C and thrives in well-drained, well-aerated soils. While cultivated across diverse soil textures, ranging from sandy loam to clay loam, the crop performs best in light loam soils. Although frequently characterized as suitable for rainfed cropping due to its relatively low water requirement of approximately 24-40 cm, the current national productivity often falls short of the theoretical yield potential (Verma *et al.*, 2023). Consequently, to address the heavy reliance on edible oil imports (Kumar *et al.*, 2020), the implementation of supplemental irrigation and balanced nutrient management, particularly sulphur application is essential for maximizing growth and yield, thereby enhancing domestic production (Limbalkar *et al.*, 2023). Sulphur plays a pivotal role in the biochemical pathways of *Brassica juncea*, directly influencing vegetative development, seed yield, and oil quality through its contribution to amino acid and protein synthesis (Piri, 2011; Piri *et al.*, 2012). Furthermore, optimizing these inputs is critical for mitigating the adverse effects of soil moisture depletion and poor nutrient availability on the crop's vegetative and reproductive growth phases (Manna & Siddique, 2025). Given that many Indian soils are characterized by significant sulphur deficiency, the systematic application of this nutrient becomes a strategic necessity for enhancing seed oil content and overall crop productivity (Sharma *et al.*, 2020; Singh *et al.*, 2023). In this context, the integration of targeted irrigation scheduling with precise sulphur fertilization is hypothesized to alleviate physiological stress, thereby maximizing the metabolic efficiency and yield potential of the crop (Bahadur *et al.*, 2025; Choudhary *et al.*, 2024). Consequently, the present investigation was undertaken to evaluate the synergetic impact of varied moisture regimes and sulphur application levels on the growth, yield attributes, and overall productivity of mustard under the agro-climatic conditions of the region (Dhaliwal *et al.*, 2022; Yendrembam *et al.*, 2025). Furthermore, this study seeks to determine the optimal irrigation thresholds and sulphur fertilization rates necessary to enhance biomass accumulation and harvest index, as these parameters are fundamentally linked to seed production efficiency in mustard (Manna & Siddique, 2024; Piri *et al.*, 2011). By systematically examining these variables, this research aims to establish an evidence-based framework for optimizing input efficiency, ultimately contributing to the sustainable intensification of Indian mustard production in the Indo-Gangetic plains (Rana *et al.*, 2019; Ray *et al.*, 2015). Specifically, the study evaluates how moisture availability and sulphur nutrition modulate metabolic processes and yield components to bridge the gap between current farm yields and potential productivity (Kumar *et al.*, 2025; Piri *et al.*, 2013). The systematic evaluation of these management practices provides critical insights into refining agronomic protocols for maximizing water use efficiency and nutrient uptake in oilseed cultivation (Kumar *et al.*, 2025; Verma *et al.*, 2018). Moreover, sulphur acts as a critical component in enzymatic activities and the synthesis of glucosinolates, thereby enhancing the crop's resilience against both biotic and abiotic stressors (Maurya *et al.*, 2023). Sulphur is the fourth most important nutrient after nitrogen, phosphorus and potassium for Indian agriculture. Sulphur is also involved in the formation of chlorophyll, glucosides and glucosinolates (mustard oils), activation of enzymes and sulfhydryl (SH-) linkages that are the source of pungency in oilseeds (Kumar *et al.*, 2018).

Materials and Methods

The experiment was conducted during *rabi* season of 2022-23 at Agronomy Research Farm of Acharya Narendra Deva University of Agriculture & Technology, Kumarganj, Ayodhya (U.P.) situated at subtropical zone in Indo Gangetic Plain having alluvial calcareous soil and lies between 24.4^0 - 26.56^0 North latitude and $82^0$12-83.980 East longitude with an elevation of about 113 meters from mean sea level. The experiment was laid out in split -plot design with 3 replications. There are 15 treatment combinations, having three moisture regimes *viz.*, 0.6 IW/CPE ratio (I_1), 0.8 IW/CPE (I_2), Irrigation applied at flowering and pod formation stage (I_3) were investigated with five sulphur levels *viz.*, control (S_0), 20 kg ha^{-1} (S_1), 30 kg ha^{-1} (S_2), 40 kg ha^{-1} (S_3) and 50 kg ha^{-1} (S_4) were kept in different plots. The mustard variety was used '*Varuna*' which was sown at a spacing of 45 cm × 15 cm. The climate of the field is semi-arid with hot summer and cold winter. The region receives an average annual rainfall about 1040 mm. The 80% of the total rainfall is received during monsoon season from July to September with a few showers in winter season. In context to determine the physico-chemical properties of the soil of experimental field and its fertility status, the soil samples were collected randomly from different places of the experimental field with the help of soil auger up to a depth of 0-15 cm prior to the application of fertilizers. These samples were well mixed together and finally a composite sample representing the whole field was taken and analysed the composite sample in laboratory. The results obtained from soil analysis indicated that the soil of experimental field was silt loam in texture with a slightly alkaline in reaction. Besides, it was low in available nitrogen and phosphorus, medium in available potassium and deficient in sulphur and boron. The Plant height (cm) was recorded by selecting five plants randomly from each plot and tagged. The height was measured in centimeters with the help of meter scale from the base of the plant to top of the plant and mean values have been presented at 30, 60, 90 DAS and at harvest. The leaf area index of five plants was measured by automatic leaf area meter at 30, 60 and 90 DAS of the crop. Leaf area index was calculated with the help of following formula given by Watson (1947): Leaf area index (LAI) = Leaf area (cm^2)/ Ground area (cm^2). The Dry matter accumulation $plant^{-1}$(g $plant^{-1}$) were recorded by randomly selected five plants from border rows at 30, 60, 90 DAS and at harvest after sun drying, materials were kept in an oven at 65 ^{0}C till the constant weight. The average weight was recorded and presented as dry matter $plant^{-1}$ (g $plant^{-1}$). For number of siliquae $plant^{-1}$. The total siliquae separated from five randomly selected plants were counted and average was recorded and reported as number of siliquae $plant^{-1}$. Number of seeds $siliqua^{-1}$: Five siliquae selected to measure the length were threshed and thus healthy seeds obtained were counted carefully and take the average to represent as number of seeds $siliqua^{-1}$. Length of siliqua (cm): Length of five randomly selected siliquae from the different plants was measured and finally average was calculated and presented as length of siliqua in cm. Test weight (g): One thousand healthy seeds were counted from the representative sample of each plot and weighted as to record 1000-seeds weight in g. Seed yield (q ha^{-1}): From the individual plot, the net plot area was harvested separately and produce was sun dried. After sun drying, the crop was threshed and produce was cleaned. The seed weight was recorded in kg $plot^{-1}$ and finally converted in to q ha^{-1} by using conversion factor. Stover yield was computed by deducting the seed yield from the total biological yield recorded $plot^{-1}$ and expressed in q ha^{-1} by multiplying with conversion factor.

Result and Discussion

Plant Height

The plant height of mustard as affected by different moisture regimes and sulphur levels is presented in table 1 and fig 1. It is evident from the data that moisture regimes had significantly affected at all crop growth. Maximum plant height (22.8, 75.3, 142.3, 172.3 cm) was recorded with 0.6 IW/CPE ratio (I_1) at successive crop growth stage, which was significantly superior over rest of the treatment. In separate field experiments evaluated the effect of differential irrigation regimes and confirmed about the significant positive impact of irrigation on agronomic traits such as plant height Rathore *et al.*, (2019). Among different sulphur levels that plant height differed significantly at all crop growth stage. Maximum plant height (23.4, 75.5, 142.7, 172.7 cm) was recorded with application of 50 kg S ha^{-1} (S_4), which was at par with (S_3) treatment. The results of present investigation are also in agreement with the finding of Dongarkar *et al.* (2005).

Table 1 : Effect of moisture regimes and sulphur levels on plant height at successive growth stage of mustard

Treatments	Plant Height (cm)			
	30 DAS	60 DAS	90 DAS	At harvest
Moisture regimes				
I_1	22.8	75.3	142.3	172.3
I_2	22.6	67.3	127.1	153.8
I_3	22.0	70.8	133.8	161.9
SEm±	0.41	1.14	2.45	2.60
CD at 5%	NS	2.88	6.22	6.60
Sulphur levels (kg ha^{-1})				
S_0	21.5	66.1	124.9	151.1
S_1	22.0	68.5	129.4	156.6
S_2	22.6	71.1	134.4	162.6
S_3	22.9	74.5	140.8	170.4
S_4	23.4	75.5	142.7	172.7
SEm±	0.53	1.47	3.17	3.36
CD at 5%	1.14	3.14	6.77	7.18

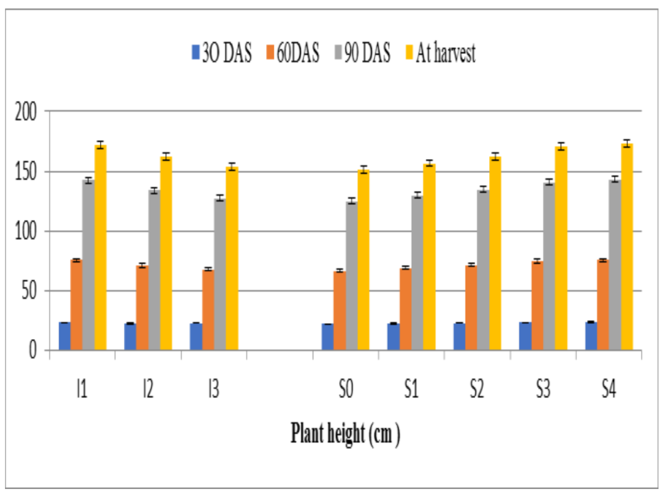

Fig. 1 : Effect of moisture regimes and sulphur levels on plant height at successive growth stage of mustard.

Leaf Area Index

Data pertaining to leaf area index of mustard as affected by different levels moisture regimes and sulphur levels presented in table 2 and depicted in fig 2. The maximum leaf area index (1.69, 4.78 ,3.64) was recorded with 0.6 IW/CPE ratio which was significant at all crop growth stages. Piri *et al.* (2006) and Piri *et al.* (2011) reported that the increased plant height and branch number per plant with higher moisture conditions as compared with less moisture availability to plants. Leaf area index of mustard on different sulphur level was maximum in (S_4) 50 kg S ha^{-1} which was at par with (S_3) in 60,90 DAS but at 30 DAS which was at par with S_3, S_2, S_1. While minimum LAI (1.61, 4.09, 3.12) was recorded with S_0 at various stages of growth. Nath *et al.*, 2018. Prajapati *et al.*, 2023 reported significant effect on plant height, leaf area index, dry matter accumulation plant^{-1} and number of branches plant^{-1} with increase in the levels of sulphur from 0-60 kg ha^{-1}.

Table 2 : Effect of moisture regimes and sulphur levels on leaf area Index at successive growth stage of mustard.

Treatments	Leaf Area Index		
	30 DAS	60 DAS	90 DAS
A. Main Plot- Moisture regimes			
I_1	1.69	4.78	3.64
I_2	1.64	4.37	3.33
I_3	1.67	4.50	3.42
SEm±	0.03	0.06	0.05
CD at 5%	NS	0.16	0.12
B. Sub plot- Sulphur levels (kg ha^{-1})			
S_0	1.61	4.09	3.12
S_1	1.63	4.40	3.35
S_2	1.68	4.61	3.51
S_3	1.70	4.79	3.64
S_4	1.72	4.85	3.70
SEm±	0.04	0.08	0.06
CD at 5%	0.08	0.17	0.13

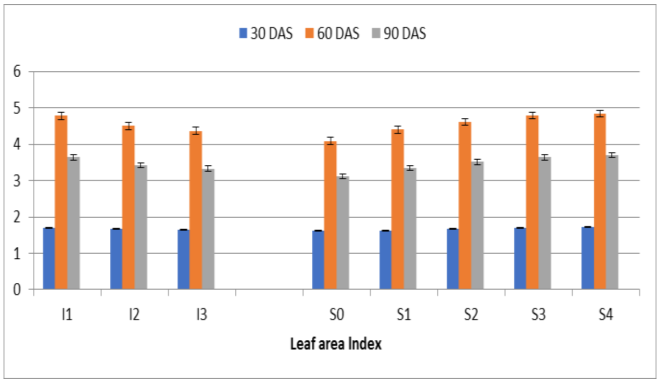

Fig. 2 : Effect of moisture regimes and sulphur levels on leaf area Index at successive growth stage of mustard.

Dry matter production (g plant^{-1})

Data pertaining to dry matter accumulation of mustard as affected by different levels moisture regimes and sulphur levels presented in table 3 and depicted in fig 3. It is evident from the data that dry matter accumulation was significantly affected by moisture regimes at all growth stages except 30 DAS. Highest dry matter accumulation (60.9, 213.3, 474.1 and 677.3) was recorded with 0.6 IW/CPE ratio which was superiorly significant except at 30 DAS. Result showed that application of two irrigations significantly increased the India mustard yield as indicated by dry matter accumulation, seed production, biological/ biomass yield, and harvest index, in comparison to no irrigation Piri *et al.* (2011).

Dry matter accumulation of mustard on different sulphur level was maximum (61.4, 219.5, 487.8 ,696.9) in (S_4) 50 kg S ha^{-1} which was at par with S_3. The increasing levels of sulphur up to 45 kg/ha significantly increased dry matter accumulation at 45 and 90 DAS at harvest over the control in both years. The findings are aligned Ray *et al.*, (2014). The chloroplast protein synthesis is stimulated by availability of Sulphur to plant and higher synthesis of chloroplast results in greater photosynthetic efficiency and ultimately increased dry matter production

Table 3 : Effect of moisture regimes and sulphur levels on Dry matter accumulation at successive growth stage of mustard

Treatments	Dry matter accumulation (g m^{-2})			
	30 DAS	60 DAS	90 DAS	At harvest
A. Main Plot- Moisture regimes				
I_1	60.9	213.3	474.1	677.3
I_2	59.0	182.4	405.4	579.2
I_3	59.7	206.1	458.0	654.3
SEm±	1.1	3.24	8.16	9.93
CD at 5%	NS	8.21	20.69	25.17
B. Sub plot- Sulphur levels (kg ha^{-1})				
S_0	58.3	181.3	403.1	575.8
S_1	59.0	187.4	416.5	595.1
S_2	59.6	199.4	443.2	633.1
S_3	61.0	215.4	478.7	683.9
S_4	61.4	219.5	487.8	696.9
SEm±	1.41	4.18	10.54	12.83
CD at 5%	NS	8.94	22.53	27.41

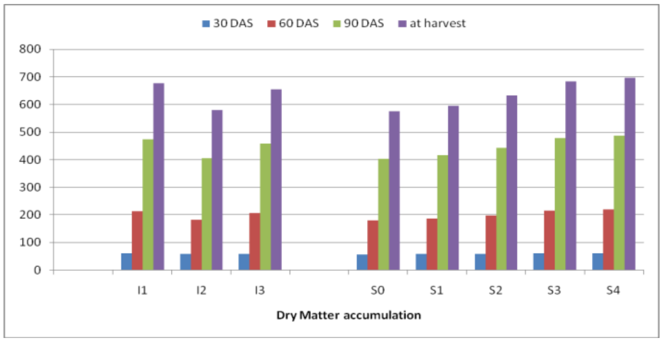

Fig. 3 : Effect of moisture regimes and sulphur levels on Dry matter accumulation at successive growth stage of mustard

Number of siliquae plant^{-1}

Data pertaining to number of siliqua plant^{-1} as influenced by different level of moisture regimes and sulphur levels (Table 4 and Fig. 4). The number of siliqua plant^{-1} was significantly affected by moisture regimes during experiment and maximum number of siliquae plant^{-1} is significant was recorded in 0.6 IW/CPE ratio at flowering and pod formation stage. The significant improvement in the mustard seed yield might be the cumulative effect of significant improvement in the value of yield attributes like number of siliquae per plant, number of seeds/siliqua and test weight which was aligned with findings of Gangasaran and Giri (1985). The number of siliqua plant^{-1} differed significantly among the different sulphur levels. Maximum number of siliqua plant^{-1} was recorded with application of 50 kg S ha^{-1}, which was at par with 40 kg S ha^{-1} and application of 30 kg S ha^{-1}. Similar result was found by Singh *et al.* (2019).

Number of seed siliqua^{-1}

Data pertaining to length of siliqua as influenced by different level of moisture regimes and sulphur levels (Table 4). The number of seed siliqua^{-1} was significantly affected by moisture regimes during experiments. The highest number of seed siliqua^{-1} was recorded in 0.6 IW/CPE ratio is significant. The significant improvement in the mustard seed yield might be the cumulative effect of significant improvement in the value of yield attributes like number of siliquae per plant, number of seeds/siliqua and test weight. Rathore *et al.* (1987).

The length of siliqua differed significantly among the different sulphur levels. Highest number of seed siliqua^{-1} was recorded with application of 50 kg S ha^{-1}, which was at par with 40 kg S ha^{-1}. In separate field experiments revealed that different yield parameters as well as productivity of mustard were influenced significantly by sulphur levels and the higher were associated with application of the highest sulphur level (60 kg S ha^{-1}) but significant difference was noticed up to 45 kg ha^{-1} Kumar *et al.* (2017).

Length of siliqua (cm)

Data pertaining to length of siliqua as influenced by different level of moisture regimes and sulphur levels Table 4. Length of siliqua was significantly affected by moisture regimes during experiments. The maximum length of siliqua was recorded with 0.6 IW/CPE ratio. Noted improvement in total number of siliquae plant^{-1}, length of siliqua, number of seeds siliqua^{-1}, test weight and seed yield with increasing IW/CPE ratio and maximum values of these parameters were recorded under 0.8 IW/CPE ratio. Meena *et al.* (2011).

Length of siliqua differed significantly among the different sulphur levels. maximum length of siliqua was recorded with application of 50 kg S ha^{-1}, which was at par with 40 kg S ha^{-1}. However, the minimum length of siliqua was recorded under control. Rajput *et al.*, (2018) also revealed that different yield parameters as well as productivity of mustard were influenced significantly by sulphur levels and the higher length of siliqua, number of siliquae plant^{-1}, number of seeds siliqua^{-1}, seed and stover yield were associated with application of the highest sulphur level (60 kg S ha^{-1}) but significant difference was noticed up to 45 kg ha$^{-1.}$

Test weight (g)

The different level of moisture regimes and sulphur levels was given in table 4 and in fig 4. The maximum test weight was recorded with 0.6 IW/CPE ratio. The significant improvement in the mustard seed yield might be the cumulative effect of significant improvement in the value of yield attributes like number of siliquae per plant, number of seeds/siliqua and test weight. Singh and Srivastava (1986), Reddy and Sinha (1987). Among sulphur levels, maximum test weight was recorded with application of 50 kg S ha^{-1}, which was at par with 40 kg S ha^{-1}, 30 kg S ha^{-1} and 20 kg S ha^{-1}.This might to be observed that higher level of sulphur (30 kg ha^{-1}) produced higher number of siliquae plant$^{-1,}$ seeds sliliqua^{-1} and test weight leading to higher seed and stover yield as compared to restricted or no sulphur application Kapur *et al.* (2010).

Table 4 : Effect of moisture regimes and sulphur levels on yield attributes and yield of mustard

Treatments	Yield Attributes			
	No. of siliqua plant^{-1}	**Number of seed siliqua^{-1}**	**Length of siliqua (cm)**	**Test wt. (g)**
A. Main Plot- Moisture regimes				
I_1	311.88	13.28	7.90	4.97
I_2	281.05	12.08	7.22	4.53
I_3	249.49	12.44	7.42	4.74
SEm±	4.747	0.177	0.127	0.077
CD at 5%	12.026	0.449	0.321	0.196
B. Sub plot- Sulphur levels (kg ha^{-1})				
S_0	252.63	11.73	7.00	4.62
S_1	272.23	12.33	7.40	4.71
S_2	286.62	12.60	7.50	4.76
S_3	295.02	12.93	7.70	4.80
S_4	297.53	13.40	7.97	4.86
SEm±	6.12	0.22	0.16	0.10
CD at 5%	13.09	0.48	0.35	0.21

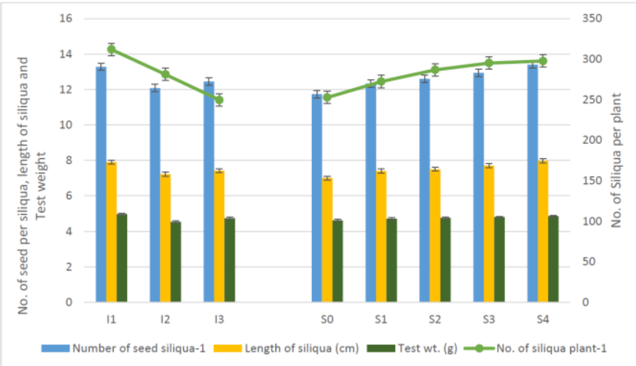

Fig. 4 : Effect of moisture regimes and sulphur levels on yield attributes of mustard.

Seed yield (q ha^{-1})

Data pertaining to seed yields as influenced by different level of moisture regimes and sulphur levels presented in Table 5 and depicted in Fig 5. The highest seed yield was recorded in 0.6 IW/CPE ratio. There was 18.52% and 4.18% increase in seed yield on 0.6 IW/CPE ratio over 0.8 IW/CPE ratio and at flowering and pod formation. Similar results were also reported by Meena *et al.* (2011). Among sulphur levels highest seed yield was recorded with application of 50 kg S ha^{-1} (S_4), which was at par with 40 kg S ha^{-1}. There was 23.90%,17.48%,10.22%,1.88% increase in seed yield on 50 kg S ha^{-1} over 40 kg S ha^{-1}, 30 kg S ha^{-1}, 20 kg S ha^{-1} and control. Observed that higher level of sulphur (30 kg ha^{-1}) produced higher number of siliquae plant^{-1}, seeds sliliqua^{-1} and test weight leading to higher seed and stover yield as compared to restricted or no sulphur application. Similar findings were also reported by Kumar *et al.* (2009).

Stover yield (q ha^{-1})

Stover yield significantly influenced by moisture regimes and sulphur levels presented in table 5 and in fig 5. The maximum stover yield (46.56 q ha^{-1}) was obtained in 0.6 IW/CPE ratio (I_1) which was at par with flowering and pod formation stage (I_3). Sulphur level significantly showed the effect on stover yield and highest stover yield (47.93 q ha^{-1}) was recorded with application of 50 kg S ha^{-1} (S_4), which was at par with 40 kg S ha^{-1} (S_3). and was found significantly superior over rest of sulphur levels. There was increase in yield (19.79%,16.95%, 9.98%,1.84%) increase in stover yield on 50 kg S ha^{-1} over 40 kg S ha^{-1},30 kg S ha^{-1},20 kg S ha^{-1} and control. The increase in stover yield under adequate sulphur supply might be ascribed mainly due to better translocation of photosynthates from source to sink. Sulphur also stimulates the pod setting, seed formation and oil synthesis in the seed of mustard and it increases the biological yield of mustard. Rajput *et al.* (2018) and Piri *et al.* (2020).

Table 5 : Effect of moisture regimes and sulphur levels on yield of mustard

Treatments	***Yield***	
	Seed yield (q ha^{-1})	**Stover yield (q ha^{-1})**
Moisture regimes		
I_1	21.0	46.5
I_2	17.8	40.0
I_3	20.3	45.1
SEm±	0.37	0.7
CD at 5%	0.94	1.79
Sulphur levels (kg ha^{-1})		
S_0	17.5	40.0
S_1	18.5	40.9
S_2	19.7	43.5
S_3	21.3	47.0
S_4	21.7	47.9
SEm±	0.48	0.91
CD at 5%	1.02	1.95

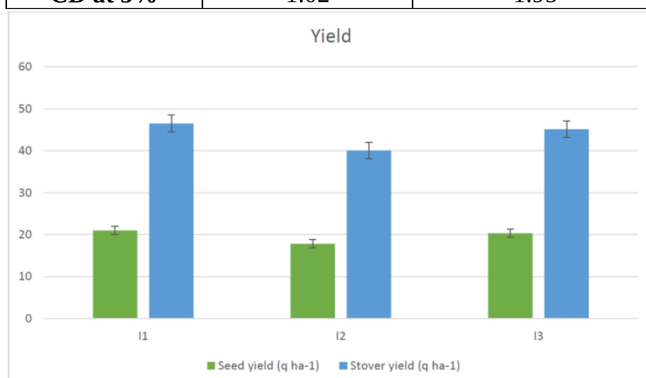

Fig. 5 : Effect of moisture regimes and sulphur levels on yield of mustard

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