Communications in Soil Science and Plant Analysis

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/lcss20

Effect of sulfur fertilization, varieties and irrigation scheduling on growth, yield, and heat utilization efficiency of indian mustard (*Brassica Juncea* L.)

Kiran Rana , Manoj Parihar , J P Singh & Rajesh Kumar Singh

To cite this article: Kiran Rana , Manoj Parihar , J P Singh & Rajesh Kumar Singh (2020) Effect of sulfur fertilization, varieties and irrigation scheduling on growth, yield, and heat utilization efficiency of indian mustard (*Brassica Juncea* L.), Communications in Soil Science and Plant Analysis, 51:2, 265-275, DOI: 10.1080/00103624.2019.1705325

To link to this article: https://doi.org/10.1080/00103624.2019.1705325

COMMUNICATIONS IN SOIL SCIENCE AND PLANT ANALYSIS
2020, VOL. 51, NO. 2, 265–275
https://doi.org/10.1080/00103624.2019.1705325

OPEN ACCESS Check for updates

Effect of sulfur fertilization, varieties and irrigation scheduling on growth, yield, and heat utilization efficiency of indian mustard (*Brassica Juncea* L.)

Kiran Rana[a], Manoj Parihar [b], J P Singh[a], and Rajesh Kumar Singh[a]

[a]Department of Agronomy, Institute of Agricultural Science, Banaras Hindu University, Varanasi, UP, India; [b]Crop Production Division, ICAR-Vivekananda Parvatiya Krishi Anusandhan Sansthan (VPKAS), Almora, UK, India

ABSTRACT

A field experiment was conducted to evaluate the effect of sulfur fertilization and irrigation scheduling on mustard hybrids in Varanasi, India. Experiment comprised 18 treatment combination involving three irrigation scheduling (0.4, 0.6 and 0.8 IW/CPE) and two hybrids (NRCHB-506 and PAC 432) as main plot treatment and three sulfur (S) levels (0, 30 and 60 kg S ha^{-1}) as sub-plot treatment in split-plot design replicated thrice during *Rabi* season (Oct–March) of 2015–16 and 2016–17. Statistical analysis of the results revealed that individually irrigation scheduling at 0.8 IW/CPE, mustard variety 'PAC 432' and sulfur application at 60 kg ha^{-1} reported to have maximum plant height, number of primary and secondary branches, dry matter accumulation, number of siliquae plant^{-1}, number of seeds siliqua^{-1}, siliqua length and seed yield. Similar results were also obtained in relation to dry matter heat use efficiency (DM-HUE) at different stages and seed yield HUE. However, the variation in most of the parameters observed with either 0.6 or 0.8 IW/CPE and application of 30 or 60 kg S ha^{-1} was found non-significant during the course of the trial. In terms of interaction, mustard variety 'PAC 432' irrigated at 0.8 and 0.6 IW/CPE and fertilized with 60 or 30 kg S ha^{-1} proved significantly superior over other treatments and recorded the highest plant height, better yield constituents and maximum yield, while the lowest values for the same were recorded in 'NRCHB-506' irrigated at 0.4 IW/CPE with no sulfur application during both the years of experimentation.

ARTICLE HISTORY
Received 19 August 2019
Accepted 3 December 2019

KEYWORDS
Growth; heat utilization; irrigation scheduling; mustard; sulfur; yield

Introduction

Rapeseed mustard is the second-most important oilseed crop in India, next only to soybean, with almost one-fourth share in both area and production (Jat et al. 2019). It is cultivated in an area of 6.3 million hectares with a production of 8.0 million tonnes yielding 1324 kg ha^{-1}, whereas in Uttar Pradesh, mustard is grown in the area of about 6.79 lakh hectares with an annual production of approximately 9.45 lakh tonnes (DOAC 2017). There exists a huge gap between the global productivity (20.47 q ha^{-1}) and India's productivity (13.24 q ha^{-1}) which need to be bridged with the expansion of area under high yielding varieties (hybrids) due to their improved genetic potential (Rana, Singh, and Parihar 2019). In addition, climate change manifested in uneven, untimely and inadequate rainfall aggravates the soil moisture stress condition during both vegetative and reproductive phases of crop growth. This could be addressed primarily with better water management through scientific irrigation scheduling (irrigation water depth (IW) to cumulative pan evaporation

CONTACT Manoj Parihar manojbhu7@gmail.com ICAR-Vivekananda Parvatiya Krishi Anusandhan Sansthan, Almora, India
Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/lcss.

(CPE) ratio, i.e.,, IW/CPE) which will boost both production and productivity of mustard as well as minimize the risk associated with climate change.

Further, the yield potential of any crop is best utilized in the presence of optimum fertilization and irrigation. In terms of nutritional requirement, sulfur (S) plays a major role in determining yield, quality and resistance of mustard toward various stress factors. The multi-functionality of sulfur is also evident in chlorophyll synthesis, seed protein, enzymatic and vitamin components which is sine qua non for superior nutritional and market quality oilseed production. Under irrigated condition, sulfur can bring a corresponding increase in yield to the tune of up to 50% (Aulakh 2003) but increased and indiscriminate use of high analysis fertilizer with low or no sulfur has led to sulfur deficient soils. This calls for additional sulfur application in oilseed crops in general and mustard in particular so as to meet the higher oilseed demand of the country. Despite plentiful information, as mentioned above, on the beneficial effect of different inputs on the productivity of crops, reports on cumulative effects of the same on the performance of hybrid mustard in are limited in general and with respect to eastern Uttar Pradesh in particular. Therefore, this field experiment was undertaken to assess the response of mustard varieties to irrigation scheduling and sulfur fertilization in the eastern Uttar Pradesh of India.

Materials and methods

Site description and soil type

A field experiment was carried out during the *Rabi* season of 2015–16 and 2016–17 at the Agricultural Research Farm (25°20′ N, 83°03′ E; 76.216 m) of the Institute of Agricultural Sciences, Banaras Hindu University, Varanasi. This region receives an average annual precipitation of 1100 mm and accounts for annual potential evapo-transpiration (PET) of 1525 mm resulting in an annual moisture deficit of about 425 mm. Generally, the maximum and minimum temperature ranged between 20–42 °C and 9–28 °C, respectively. The climate and initial soil characteristics of the experimental site during the course of the trial are provided in Tables 1 and 2, respectively. The soil of the experimental site was sandy clay loam in texture with slightly alkaline pH, low in organic carbon and available nitrogen, medium in available phosphorus, potassium and sulfur. The average value of organic carbon, available nitrogen, phosphorus, potassium and sulfur during the period of experiment were observed as 0.438%, 207.21, 20.26, 236.40 kg ha^{-1} and 19.8 mg kg^{-1}soil, respectively.

Experimental setup

The experiment consisted of 6 main plots and 3 subplots with 18 treatment combinations which were arranged in a split-plot design with 3 replications. The main plots consisted of 6 treatment combinations of 3 irrigation scheduling based on IW/CPE ratio (Irrigation water/cumulative pan

Table 1. Climate parameters of the research site during the period of experimentation.

	Precipitation (mm)		Max. temperature (°C)		Minimum temperature (°C)		Evaporation (mm)	
Months	I	II	I	II	I	II	I	II
October	23.0	5.4	32.31	32.24	21.02	21.0	2.92	2.93
November	0.0	0.0	29.78	28.22	17.47	13.74	2.25	2.02
December	0.8	0.0	23.38	21.15	11.01	11.35	1.56	1.0
January	7.7	1.0	22.82	22.07	9.89	9.93	1.39	1.61
February	2.4	0.0	26.67	26.41	13.21	11.83	2.62	2.58
March	35.4	0.0	32.16	31.94	17.40	15.76	3.94	4.37

I = first year (2015–16); II = second year (2016–17).

Table 2. Physico-chemical properties of the experimental site.

Particulars	Years	
	2015–16	2016–17
a. Mechanical composition		
Sand	51.49	51.37
Silt	25.72	25.77
Clay	22.79	22.86
Textural Class	Sandy Clay Loam	
Bulk Density (g cm^{-3})	1.45	1.41
Particle Density (g cm^{-3})	2.62	2.63
Porosity (%)	44.70	46.40
b. Chemical properties		
Organic carbon (%)	0.432	0.445
pH (1:2.5 Soil: water suspension)	7.80	7.72
Electrical conductivity (1:2.0 Soil: water suspension) (dSm^{-1}) at 25°C	0.191	0.186
Available Nitrogen (kg ha^{-1})	205.28	209.15
Available Phosphorus (kg ha^{-1})	19.11	21.42
Available Potassium(kg ha^{-1})	235.22	237.59
Available S (mg kg^{-1} soil)	18.87	20.73

evaporation), namely, irrigation at 0.4 IW/CPE (I_1), irrigation at 0.6 IW/CPE (I_2) and irrigation at 0.8 IW/CPE (I_3) and two varieties, namely, 'NRCHB-506′ (V_1) and 'PAC 432′ (V_2). The subplots consisted of three treatments, namely, no sulfur (S_1), application of sulfur @ 30 kg ha^{-1} (S_2) and sulfur @60 kg ha^{-1} (S_3).

Cultivation practices

After field preparation and pre-sowing irrigation, furrows were opened at a spacing of 45 cm between rows and seeds of both the varieties were sown on 17 October in both the year (2015 and 2016) with a seed rate of 5 kg ha^{-1}. Uniform application of a recommended dose of fertilizer (RDF) for mustard hybrid (N-P_2O_5-K_2O 120-60-40 kg ha^{-1}) was carried out. Half of the recommended dose of N (60 kg ha^{-1}) and full dose of P (60 kg ha^{-1}) and K (40 kg ha^{-1}) were applied as basal with source as urea (46% N), diammonium phosphate (18% N and 46% P_2O_5) and muriate of potash (60% K_2O), respectively. Sulfur with source as gypsum (18.5% S) was applied at a rate according to the treatment. The remaining half dose of nitrogen was top-dressed through urea after 35–40 days of sowing. A pre-emergence application of Pendimethalin 30 EC was given at 1 l ha^{-1}. Thinning was done after 15–20 days to maintain the plant-to-plant spacing of 15 cm. All the inter-cultivation practices except irrigation scheduling were kept uniform in the entire plots. Irrigation of 5 cm depth was provided as per the IW/CPE ratio which came out as one, two and three irrigation in 0.4, 0.6 and 0.8 IW/CPE, respectively.

Observation of parameters

Different agronomic traits and yield constituents, viz., plant height (cm), number of primary and secondary branches, number of siliquae $plant^{-1}$, siliqua length (cm), number of seeds $siliqua^{-1}$, test weight (g) with seed and biological yield were recorded as per standard procedure at harvest. The growing degree days (GDD) were computed from the date of sowing onwards till harvest by considering the base temperature (T_b) of the crop as 5 °C using the following formula (Singh and Singh 2014):

Accumulated GDD (degree-day) = $\{\Sigma(T_{max.} + T_{min.})/2\}-T_b$

where $T_{max.}$ is daily maximum air temperature, $T_{min.}$ is daily minimum air temperature.

Heat utilization efficiency was expressed in kg ha^{-1} $degrees\text{-}day^{-1}$ and calculated as:

Seed Yield-Heat Utilization Efficiency (SY-HUE) = seed yield/GDD

Dry matter Heat Utilization Efficiency (DM-HUE) was calculated at three stages, namely at 50% flowering, complete siliqua formation and at harvest as:

DM-HUE = dry matter/GDD

Analysis of data

Recorded data were analyzed using an appropriate method of 'Analysis of Variance (ANOVA)' given by Gomez and Gomez (1984). The mean significant differences were compared by Tukey's HSD test at $p < .05$. The Pearson correlation analysis among parameters was performed using the R-square (R version 3.5.1). Principal component analysis (PCA) was performed using R-square (R version 3.5.1) to display the correlation between the various parameters and their relationship with the different treatments.

Results and discussion

Agronomic traits

The data related to agronomic traits (Table 3) as recorded at harvest revealed a significant difference among the treatment variables during the course of the investigation. Among the different irrigation scheduling, mustard crop irrigated at 0.8 IW/CPE showed maximum plant height, number of primary branches, number of secondary branches and dry matter accumulation at harvest and was observed significantly superior to 0.4 IW/CPE during the course of the investigation. Data also revealed that IW/CPE ratio of 0.6 was significantly superior to IW/CPE ratio of 0.4 but at par with 0.8 IW/CPE during both the years. Optimum soil moisture in the crop root zone associated with higher IW/CPE ratios must have led to better nutrient uptake, cell growth and division, higher photosynthetic activity and ultimately, better agronomic traits. The results are substantiated by the research findings of Piri and Sharma (2006), Yadav, Tripathi, and Trivedi (2010), Dadhich et al. (2015) and Rathore et al. (2017).

Among the varieties tested, significant variation was exhibited and mustard hybrid 'PAC 432′ recorded better performance with significantly higher plant height (195.46 and 188.58 cm), number of primary branches (7.51 and 7.09), number of secondary branches (16.54 and 16.44) and dry matter accumulation at harvest (786.59 and 755.15 g m^{-2}) in comparison to 'NRCHB-506′ in first and second year of research, respectively. The marked variation can be attributed to the varietal characteristics and genetic potential as also reported by Rakesh et al. (2012) and Meena, Meena, and Meena (2013).

Table 3. Agronomic traits of Indian mustard at harvest in relation to irrigation scheduling, varieties and levels of sulfur on Indian mustard.

	PH		PB		SB		DMA	
Treatment	I	II	I	II	I	II	I	II
Irrigation scheduling								
0.4 IW/CPE	173.97a	169.51a	6.35a	5.95a	13.70a	13.42a	578.91a	573.66a
0.6 IW/CPE	190.54b	184.55b	7.26b	6.91b	16.00b	15.94b	694.08b	685.09b
0.8 IW/CPE	201.05b	193.70b	7.88b	7.57b	17.60b	17.22b	786.59b	755.15b
Varieties								
NRCHB-506	181.57a	176.59a	6.82a	6.53a	14.99a	14.61a	625.89a	625.29a
PAC 432	195.46b	188.58b	7.51b	7.09b	16.54b	16.44b	747.17b	717.31b
Levels of sulfur (kg S ha^{-1})								
0	181.37a	173.78a	6.62a	6.27a	13.87a	14.44a	597.92a	583.60a
30	190.22b	184.03b	7.33b	6.97b	16.28b	15.69b	700.69b	685.94b
60	193.96b	189.95b	7.54b	7.19b	17.15b	16.44b	760.98b	744.36b

PH = plant height (cm); PB = number of primary branches plant^{-1}; SB = number of secondary branches plant^{-1}; DMA = dry matter accumulation at harvest (g m^{-2}); I = first year (2015–16); II = second year (2016–17). Data followed by a similar letter are not significantly different at $p < 0.05$ level of significance according to Tukey HSD.

Among the investigated sulfur levels, the application of sulfur at 60 kg ha^{-1} though being at par with 30 kg S ha^{-1} ensued significant improvement in agronomic traits at harvest than no sulfur application during the period of experimentation. Sulfur application might have increased metabolic activity and photosynthetic rate due to its engagement in chlorophyll formation, enzyme activation as well as primary and secondary metabolism. The results are also substantiated by the findings reported by Ray et al. (2014), Singh et al. (2017) and Yadav and Dhanai (2018).

Yield constituents and yield

A significant effect of treatments was noted on the seed yield as well as yield constituents of mustard (Table 4). Among the irrigation scheduling, an increase in the frequency of irrigation with increasing IW/CPE ratio brought out successive increment in yield attributes, namely, number of siliquae plant^{-1}, number of seed siliqua^{-1}, siliqua length and 1000-seed weight as well as seed yield of mustard. The maximum values of these given characters were observed with the application of irrigation at 0.8 IW/CPE which was significantly superior to crop irrigated at 0.4 IW/CPE but remained statistically at par to 0.6 IW/CPE during both the years of research. However, for siliqua length, 0.8 IW/CPE was significantly different from 0.6 IW/CPE. A longer interval between consecutive irrigations at 0.4 IW/CPE in comparison to 0.6 and 0.8 IW/CPE created a moisture stress environment resulting in inadequate water and nutrient uptake and shorter developmental period and consequently, inferior yield attributes and lower seed yield. These results were parallel to those reported by Phogat, Sanjay, and Kaushik (2009), Dash et al. (2013) and Ray et al. (2015).

Among the varieties tested under the experiment, mustard hybrid 'PAC 432′ was observed significantly superior to 'NRCHB-506′ in relation to the number of siliquae plant^{-1} and number of seeds siliqua^{-1}, while in terms of siliqua length and 1000-seed weight, latter was reported to perform better than the former one due to its bolder seed size. However, 'PAC 432′ produced 8.38 and 11.35% significantly higher seed yield than 'NRCHB 506′ during the first and second year of experimentation, respectively. Archana and Singh (2011) and Yadav et al. (2018) also recorded similar variation in cultivars in terms of yield attributes and yield which could be attributed to their genetic differences as also exemplified in agronomic traits.

Application of sulfur had a significant influence on the number of siliquae plant^{-1}, number of seed siliqua^{-1}, siliqua length and 1000-seed weight, as well as seed yield and improvement in the attribute, was noticed with a successive increase in the rate of sulfur application from 0 to 60 kg ha^{-1}. Though the highest values of these attributes were reported with the application of 60 kg S ha^{-1}, but difference between 30 and 60 kg S ha^{-1} was found non-significant during both the years except for

Table 4. Yield constituents and yield of Indian mustard at harvest in relation to irrigation scheduling, varieties and levels of sulfur on Indian mustard.

	SPP		SL		SPS		TW		SY	
Treatment	I	II	I	II	I	II	I	II	I	II
Irrigation scheduling										
0.4 IW/CPE	407.66a	387.07a	4.07a	4.05a	11.96a	11.91a	3.25a	3.26a	2154a	2067a
0.6 IW/CPE	464.47b	437.97b	4.65b	4.55b	14.36b	14.01b	4.10b	4.02b	2403b	2321b
0.8 IW/CPE	498.51b	473.91b	5.11c	5.15c	15.53b	15.15b	4.35b	4.24b	2603b	2506b
Varieties										
NRCHB-506	431.73a	410.08a	4.83a	4.77a	13.24a	13.04a	4.04a	3.98a	2291a	2175a
PAC 432	482.02b	455.89b	4.40b	4.40b	14.64b	14.34b	3.76b	3.70b	2483b	2422b
Levels of sulfur (kg S ha^{-1})										
0	431.63a	412.42a	4.28a	4.32a	13.07a	12.85a	3.57a	3.50a	2162a	2073a
30	464.04b	438.00b	4.70b	4.65b	14.06b	13.86b	4.00b	3.94b	2454b	2372b
60	474.96b	448.53b	4.85b	4.78b	14.71b	14.36b	4.14c	4.07b	2545b	2449b

SPP = number of siliquae plant^{-1}; SL = siliqua length (cm); SPS = number of seeds siliqua^{-1}; TW = 1000-seed weight (g); SY = seed yield (kg ha^{-1}); I = first year (2015–16); II = second year (2016–17). Data followed by a similar letter are not significantly different at $p < 0.05$ level of significance according to Tukey HSD.

1000-seed weight in the first year. The improved performance of mustard with higher sulfur rates could be ascribed to sulfur functioning in a favorable nutritional environment of the rhizosphere as well as plant system. In addition, sulfur also accelerates the differentiation of vegetative tissue to reproductive one stimulating floral primordial development leading to improved yield attributes and higher seed yield. Similar findings were also reported by Singh and Thenua (2016), Rajput et al. (2018) and Shivran et al. (2018).

Cumulative effect of treatment variables

Interaction effect of irrigation scheduling, varieties and sulfur level was found significant for yield attributes, namely number of siliquae plant^{-1} (Figure 1), number of seeds siliqua^{-1}(Figure 2), 1000-seed weight (Figure 3) as well as for seed yield (Figure 4) of mustard during the period of experimentation. It was found that mustard hybrid 'PAC 432' with irrigation at 0.8 IW/CPE and 60 kg S ha^{-1} recorded significantly the highest number of siliquae plant^{-1}, number of seed siliqua^{-1}, 1000-seed weight and seed yield as compared to other treatment combinations during both the years. The lowest values for these attributes were observed with 'NRCHB-506' with 0.4 IW/CPE and no sulfur application during both the years. The results can be discussed in the light of the additive effect of the individual treatment variable for the said characteristics wherein favorable soil moisture condition, congenial nutritional environment, accelerated physiological processes and genetic potential of the variety acted and brought out significantly superior results. The results are in parallel with the study of Yadav, Tripathi, and Trivedi (2010) and Ray et al. (2015).

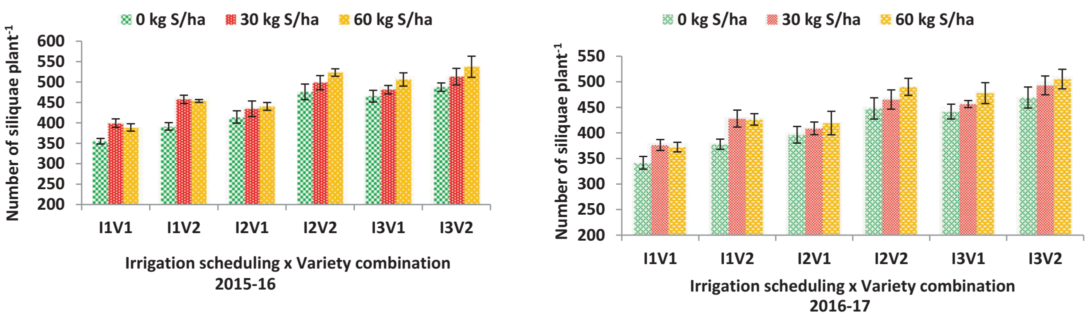

Figure 1. Interaction effects of irrigation scheduling, varieties and sulfur levels on the number of siliquae plant^{-1} during the period of experimentation (I1, I2 and I3 are irrigation at 0.4, 0.6 and 0.8 IW/CPE, respectively; V1 and V2 are 'NRCHB-506' and 'PAC 432', respectively).

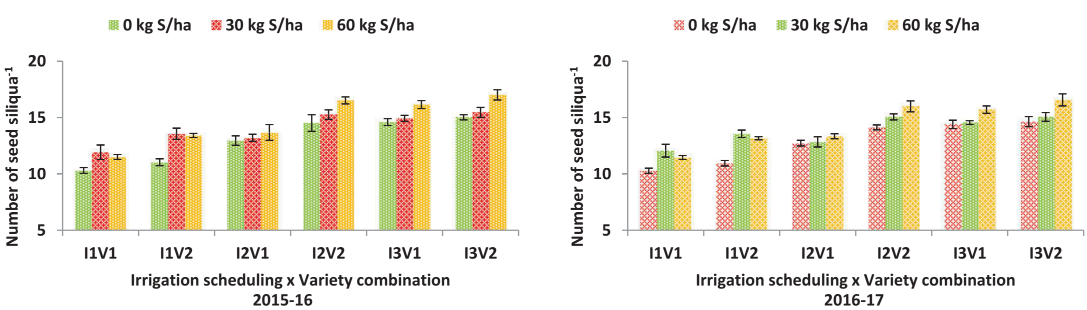

Figure 2. Interaction effects of irrigation scheduling, varieties and sulfur levels on the number of seed siliqua^{-1} during the period of experimentation (I1, I2 and I3 are irrigation at 0.4, 0.6 and 0.8 IW/CPE, respectively; V1 and V2 are 'NRCHB-506' and 'PAC 432', respectively).

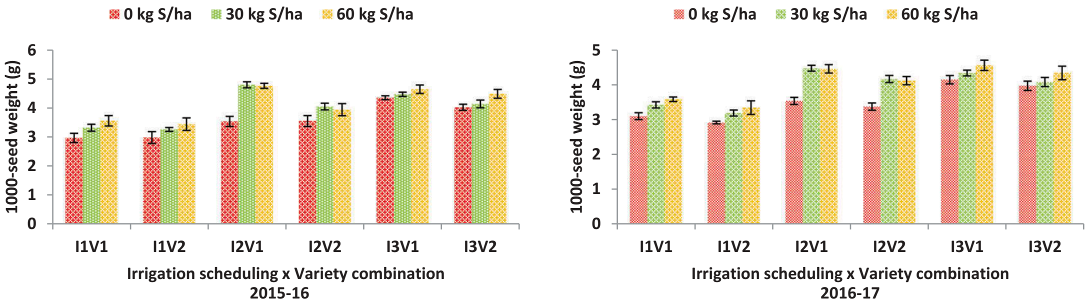

Figure 3. Interaction effects of irrigation scheduling, varieties and sulfur levels on 1000-seed weight (g) during the period of experimentation (I1, I2 and I3 are irrigation at 0.4, 0.6 and 0.8 IW/CPE, respectively; V1 and V2 are 'NRCHB-506' and 'PAC 432', respectively). Error bars represent the standard error.

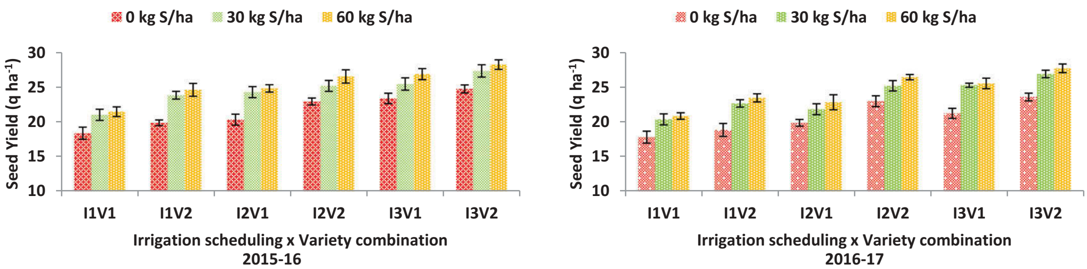

Figure 4. Interaction effects of irrigation scheduling, varieties and sulfur levels on seed yield (q ha^{-1}) during the period of experimentation (I1, I2 and I3 are irrigation at 0.4, 0.6 and 0.8 IW/CPE, respectively; V1 and V2 are 'NRCHB-506' and 'PAC 432', respectively). Error bars represent the standard error.

Heat utilization efficiency (HUE) of dry matter and seed yield

The effect of irrigation scheduling, varieties and sulfur application on heat utilization efficiency (Table 5) was reported significant during the course of the experiment. Among the different irrigation scheduling, the application of irrigation at 0.8 IW/CPE showed maximum dry matter HUE at different stages of crop growth as well as seed yield HUE. DM-HUE at 50% flowering and complete siliqua formation stage under 0.8 IW/CPE was significantly superior to preceding levels of irrigation (0.6 and 0.4 IW/CPE); however, DM-HUE at harvest and seed yield HUE were reported at par with 0.6 and 0.8 IW/CPE but superior to 0.4 IW/CPE. Data also revealed that the IW/CPE ratio of 0.6 was significantly superior to the IW/CPE ratio of 0.4 but at par with 0.8 IW/CPE during both the years. Higher heat utilization efficiency denotes more efficient use of heat for dry matter production as well as seed yield and is determined through better light interception and leaf area development (Aggarwal et al. 2015) which are reported higher with an increased level of irrigation. Similar differences in heat utilization efficiency as a response to different irrigation schedules were also reported by Nayak et al. (2017) in rice, Singh and Singh (2014) in mustard and Solanki et al. (2017) in wheat.

Among the varieties tested, significant variation was exhibited and mustard hybrid 'PAC 432' recorded superior performance with significantly higher DM-HUE at 50% flowering (1.72 and 1.57 kg ha^{-1}degree-day^{-1}), at complete siliqua formation (4.11 and 4.33 kg ha^{-1}degree-day^{-1}) and at harvest (4.11 and 4.18 kg ha^{-1}degree-day^{-1}) as well as higher seed yield HUE (1.11 and 1.37 kg ha^{-1}degree-day^{-1}) in comparison to 'NRCHB-506' in first and second year of research, respectively. The difference in varietal characteristics, better agronomic traits and higher seed yield of 'PAC

Table 5. Heat Utilization efficiency (HUE) of Indian mustard in relation to irrigation scheduling, varieties and levels of sulfur on Indian mustard.

	Dry matter(DM) HUE (kg ha^{-1}degree-day^{-1})						Seed yield HUE (kg ha^{-1}degree-day^{-1})	
	50% flowering		CSF		Harvest			
Treatment	I	II	I	II	I	II	I	II
Irrigation scheduling								
0.4 IW/CPE	1.54a	1.43a	3.36a	3.55a	3.08a	3.25a	0.91a	1.13a
0.6 IW/CPE	1.62a	1.49a	3.86b	4.05b	3.69b	3.86b	1.03b	1.27b
0.8 IW/CPE	1.82b	1.61b	4.45c	4.67c	4.17b	4.26b	1.13b	1.37b
Varieties								
NRCHB-506	1.59a	1.45a	3.67a	3.85a	3.18a	3.39a	0.94a	1.14a
PAC 432	1.72b	1.57b	4.11b	4.33b	4.11b	4.18b	1.11b	1.37b
Levels of sulfur (kg S ha^{-1})								
0	1.49a	1.41a	3.40a	3.55a	3.18a	3.31a	0.91a	1.13a
30	1.71b	1.54b	3.92b	4.13b	3.72b	3.88b	1.06b	1.30b
60	1.77b	1.59b	4.34c	4.58c	4.03b	4.19b	1.11b	1.34b

CSF = Complete Siliqua Formation; I = first year (2015–16); II = second year (2016–17). Data followed by a similar letter are not significantly different at $p < 0.05$ level of significance according to Tukey HSD.

432′could have attributed for the said manifestations as also reported by Tharannum et al. (2016) and Choudhary et al. (2018).

Among the investigated sulfur levels, both DM-HUE and seed yield HUE showed an increment with a successive increase in the sulfur levels with maximum values of the given parameter noted with 60 kg S ha^{-1}. Application of sulfur at 30 and 60 kg ha^{-1} caused a significant improvement in DM-HUE at 50% flowering, complete siliqua formation and at harvest as well as higher seed yield HUE than no sulfur application but remained at par with each other except for DM-HUE at complete siliqua formation during both the years. Sulfur application increased metabolic activity and promoted meristematic growth leading to improved growth characters and yield and consequently, higher HUEs. The results are also substantiated by the findings reported by Ray et al. (2014), Singh et al. (2017) and Yadav and Dhanai (2018).

Principal component analysis (PCA)

The PCA comprising two principal components (PC_1 and PC_2) explained 80.5% of the total variation in 2015–16 and 82.5% in 2016–17. In 2015–16, PC_1 explained 71.1% and PC_2 explained 9.4% of the total variation. In 2016–17, PC_1 explained 70.8% and PC_2 explained 11.7% of the total variation. A strong correlation was observed between various components, viz., yield, plant height, number of primary branches, number of secondary branches, number of siliquae plant^{-1}, number of seeds siliqua^{-1}, siliqua length and 1000-seed weight. Superimposition of 18 treatment combinations on mustard yield and yield components revealed that combination of 0.8 IW/CPE with 60 kg sulfur ha^{-1} on ‘PAC 432′ produced highest values for the given attributes and showed significant correlation with these parameters (Figure 5) along with application of irrigation at 0.6 IW/CPE and 30 kg S ha^{-1}.

The correlation matrix is provided in Figure 6. In 2015–16, there were significant positive correlations between different characters ($p < .001$) except between siliqua length and plant height which represented neutral interaction and the relation of siliqua length with a number of secondary branches plant^{-1}, number of siliquae plant^{-1}, number of seed siliqua^{-1}and seed yield was found significant at $p < .05$. Similarly, in 2017–18, significant positive correlations were observed among most of the traits ($p < .001$), while the correlation of plant height, number of secondary branches plant^{-1}, number of siliquae plant^{-1}, number of seed siliqua^{-1}and seed yield with siliqua length was found significant at $p < .01$.

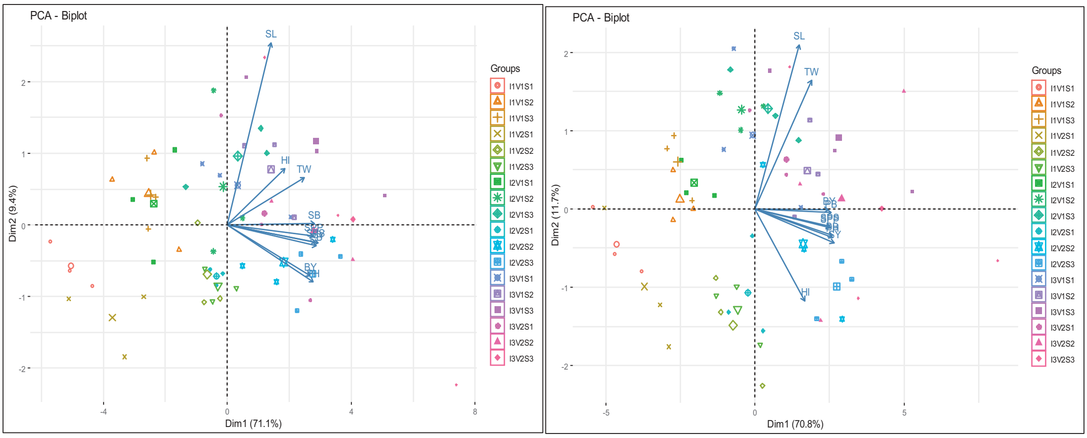

Figure 5. PCA graphs of 18 treatment combinations for yield, yield components and agronomic traits of the years 2015–16 (a) and 2016–17 (b).

PH = plant height; PB = number of primary branches plant^{-1}; SB = number of secondary branches plant^{-1}; SPP = number of siliquae plant^{-1}; SPS = number of seeds siliqua^{-1}; SL = siliqua length; TW = 1000-seed weight; SY = seed yield; I1 = 0.4 IW/CPE; I2 = 0.6 IW/CPE; I3 = 0.8 IW/CPE; V1 = NRCHB-506; V2 = PAC 432; S1 = no sulfur; S2 = 30 kg S ha^{-1}; S3 = 60 kg S ha^{-1}

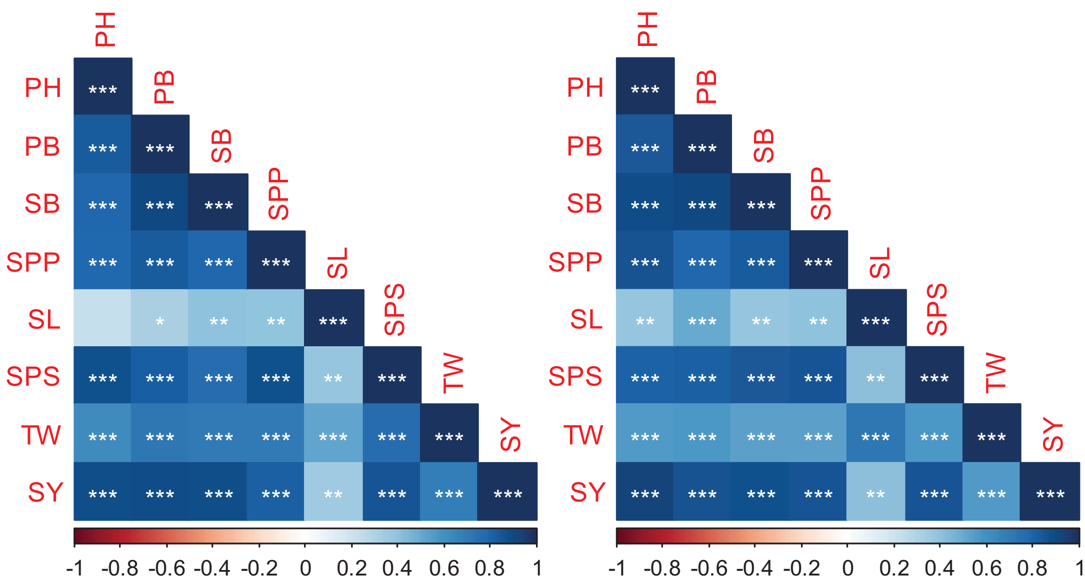

Figure 6. Correlation matrix among various plant growth and yield attributes for 2015–16 (left) and 2016–17 (right); the blue color corresponds to (+) positive interaction, red color corresponds to (–) negative interaction and white corresponds to neutral interaction. Significant level (***0.001, **0.01, *0.05). PH = plant height; PB = number of primary branches plant^{-1}; SB = number of secondary branches plant^{-1}; SPP = number of siliquae plant^{-1}; SPS = number of seeds siliqua^{-1}; SL = siliqua length; TW = 1000-seed weight; SY = seed yield.

Conclusion

Based on 2-year experiment, it may be safely concluded that irrigation of mustard at 0.8 IW/CPE produced a crop with improved agronomic traits and yield constituents, consequently, highest seed yield. Also, irrigation at 0.8 IW/CPE resulted in significantly higher heat utilization efficiency in terms of dry matter at different stages and seed yield in comparison to a lower level of irrigation associated with 0.4 IW/CPE. Similarly, variety 'PAC 432′ also performed superior to the 'NRCHB-506′ in relation to observed parameters of crop growth and yield. Increasing application of sulfur brought significant improvement in growth traits, yield attributes and yield in comparison to no sulfur application during both the years of experimentation. Consequently, more efficient use of heat was also reported with increasing sulfur fertilization.

Overall, application of 60 kg S with irrigation at 0.8 IW/CPE in 'PAC 432′ variety of mustard greatly enhanced the number of seed siliqua^{-1}, number of siliquae plant^{-1}, siliqua length, 1000-seed weight and ultimately, yield as also evident through PCA but was at par with, treatment comprising 30 kg S with irrigation at 0.6 IW/CPE in 'PAC 432′ compared to other combinations.

Acknowledgments

The author is highly grateful to the Department of Science and Technology (DST) for financial assistance through the DST-INSPIRE fellowship for undertaking doctoral research program.

Funding

This work was supported by the DST-INSPIRE [IF150062].

ORCID

Manoj Parihar http://orcid.org/0000-0002-2977-5905

References

Aggarwal, N., A. Singh, S. P. Singh, and J. S. Kang. 2015. Heat utilization vis-à-vis crop performance of mechanically transplanted rice as affected by tillage systems and nitrogen levels. *Journal of Agrometeorology* 17 (1):84–89.

Archana, K., and R. P. Singh. 2011. Performance of mustard hybrids under different sowing dates and spacings. *Pantnagar Journal of Research* 9 (1):16–19.

Aulakh, M. S. 2003. Crop responses to sulphur nutrition. In *Sulphur in Plants*, edited by Y. P. Abrol and A. Ahmad . Springer, Dordrecht: Springer.

Choudhary, D., R. Singh, C. S. Dagar, A. Kumar, and S. Singh. 2018. Temperature based agrometeorological indices for Indian mustard under different growing environments in western Haryana, India. *International Journal of Current Microbiology and Applied Sciences* 7 (1):1025–35. doi:10.20546/ijcmas.

Dadhich, R. K., R. S. Meena, M. L. Reager, and B. C. Kansotia. 2015. Response of bio-regulators to yield and quality of Indian mustard (*Brassica juncea* L. Czernj. and Cosson) under different irrigation environments. *Journal of Applied and Natural Sciences* 7 (1):52–57. doi:10.31018/jans.v7i1.562.

Dash, A. K., B. R. Nayak, N. Panigrahy, S. Mohapatra, and P. K. Samant. 2013. Performance of groundnut (***Arachis hypogea***) under different levels of sulphur and irrigation. *Indian Journal of Agronomy* 58 (4):578–82.

DOAC. 2017. *Agricultural statistics at a glance*. Directorate of Economics and Statistics, Department of Agriculture and Cooperation. Ministry of Agriculture, Government of India.

Gomez, K. A., and A. A. Gomez. 1984. *Statistical procedures for agricultural research*. USA: John Wiley & Sons.

Jat, R. S., V. V. Singh, P. Sharma, and P. K. Rai. 2019. Oilseed brassica in India; Demand, supply, policy perspective and future potential. *OCL* 26:8. doi:10.1051/ocl/2019005.

Meena, D. S., V. R. Meena, and A. K. Meena. 2013. Fertilizer management studies on growth and productivity of hybrid Indian mustard *Brassica juncea* (L.). *Journal of Oilseed Brassica* 4 (1):39–42.

Nayak, B. R., N. Panigrahy, S. Mohapatra, A. K. Mohanty, B. Sahoo, P. N. Jagdev, and S. Patel. 2017. Heat utilization and productivity of summer transplanted rice (***Oryza sativa*** L.) in relation to irrigation schedules and date of transplanting. *Journal of Agrometeorology* 19 (3):242–45.

Phogat, V., K. Sanjay, and R. D. Kaushik. 2009. Response of India mustard (*Brassica juncea*) to irrigation levels and quality of irrigation water. *Environment and Ecology* 27 (1):53–57.

Piri, I., and S. N. Sharma. 2006. Physiological analysis of growth and yield of Indian mustard as affected by irrigation and sulphur. *Indian Journal of Plant Physiology* 11 (3):253.

Rajput, R. K., S. Singh, J. Varma, P. Rajput, M. Singh, and S. Nath. 2018. Effect of different levels of nitrogen and sulphur on growth and yield of Indian mustard (*Brassica juncea* (L.) Czern and Coss.) in salt affected soil. *Journal of Pharmacognosy and Phytochemistry* 7 (1):1053–55.

Rakesh, S., S. B. Singh, S. S. Manhas, and K. Anil. 2012. Effect of different levels of sulphur and varieties on growth, yield and quality of Indian mustard. *International Journal of Plant Sciences (Muzaffarnagar)* 7 (2):290–94.

Rana, K., J. P. Singh, and M. Parihar. 2019. Manifestation of improved cultivars, irrigation and sulphur in mustard growth, productivity, quality and profitability: A review. *Journal of Pharmacognosy and Phytochemistry* 8 (3):2778–82.

Rathore, S. S., K. Shekhawat, B. K. Kandpal, and O. P. Premi. 2017. Improvement of physiological and productivity traits of Indian mustard (*Brassica juncea* L.) through micro-irrigation and fertigation under hot semi-arid eco-region. *Indian Journal of Agricultural Sciences* 87 (9):1257–62.

Ray, K., A. K. Pal, H. Banerjee, and A. Phonglosa. 2014. Correlation and path analysis studies for growth and yield contributing traits in Indian mustard (*Brassica juncea* L.). *International Journal* of *Bio-resource* and. *Stress Management* 5 (2):200–06.

Ray, K., K. Sengupta, A. K. Pal, and H. Banerjee. 2015. Effects of sulphur fertilization on yield, S uptake and quality of Indian mustard under varied irrigation regimes. *Plant, Soil and Environment* 61 (1):6–10. doi:10.17221/860/2014-PSE.

Shivran, H., S. Kumar, R. Tomar, and G. Veer. 2018. Effect of various irrigation schedule and sulphur levels on economics of Indian mustard [***Brassica juncea*** L.]. *IJCS* 6 (4):12–14.

Singh, K. K., R. K. Srivastava, K. M. Singh, A. K. Singh, K. Ranjan, and J. Prasad. 2017. Effect of sulphur levels on mustard (*Brassica juncea* L.) yield in Muzaffarpur District of Bihar. *Journal of AgriSearch* 4 (3):206–08. doi:10.21921/jas.v4i03.9024.

Singh, M. P., and N. B. Singh. 2014. Thermal requirement of Indian mustard (*Brassica juncea* L.) at different phonological stages under late sown condition. *Indian Journal of Plant Physiology* 19 (3):238–43. doi:10.1007/s40502-014-0072-0.

Singh, S. B., and O. V. S. Thenua. 2016. Effect of phosphorus and sulphur fertilization on yield and NPS uptake by mustard (*Brassica juncea* L.). *Progressive Research-An International Journal* 11 (1):80–83.

Solanki, N. S., S. D. Samota, B. S. Chouhan, and G. Nai. 2017. Agrometeorological indices, heat use efficiency and productivity of wheat (***Triticum aestivum***) as influenced by dates of sowing and irrigation. *Journal of Pharmacognosy and Phytochemistry* 6 (3):176–80.

Tharannum, A. M., S. Ram, R. Niwas, K. Naresh, and R. Shalu. 2016. Thermal time requirements of ten genotypes of Brassica species at Hisar. *Journal of Agrometeorology* 18 (1):131–33.

Yadav, A., A. K. Singh, R. Chaudhari, and S. R. Mishra. 2018. Effect of planting geometry on growth and yield of mustard [*Brassica juncea* (L.)] varieties. *Journal of Pharmacognosy and Phytochemistry* 7 (3):2624–27.

Yadav, M. S., and C. S. Dhanai. 2018. Effect of fertilizers on yield and yield attributing characters of mustard (*Brassica juncea* L. Czern & Coss). *Journal of Pharmacognosy and Phytochemistry* 7 (2):2300–03.

Yadav, R. P., M. L. Tripathi, and S. K. Trivedi. 2010. Yield and quality of Indian mustard (*Brassica juncea* L.) as influenced by irrigation and nutrient levels. *Indian Journal of Agronomy* 55 (1):56–59.