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Effects of sulphur fertilization on yield, S uptake and quality of Indian mustard under varied irrigation regimes

K. Ray[1], K. Sengupta[1], A.K. Pal[1], H. Banerjee[2]

[1]Department of Agronomy, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, West Bengal, India
[2]Regional Research Station, Bidhan Chandra Krishi Viswavidyalaya, Kakdwip, South 24 – Parganas, West Bengal, India

ABSTRACT

Field experiment was conducted on clay loam soil during winter season of 2010–2011 and 2011–2012 at the Research Farm, Bidhan Chandra Krishi Viswavidyalaya, West Bengal to study the influence of sulphur (S) levels and irrigation on quality and yield of mustard (cv. Varuna, T-59). Results revealed that yield attributes and yield of crop were highest with 60 kg S/ha, mostly at par with 45 kg S/ha. Double irrigation at flower initiation (30 days after sowing (DAS)) and siliqua development stages (60 DAS) was best with respect to growth, yield attributes, yield, S uptake and oil percent in seed. Effects of both S levels and irrigations on glucosinolate and fatty acid content were non-significant except on progoitrin. The erucic:oleic acid ratio was inversely related to the subsequent increase in S doses, thereby suggesting the qualitative improvement of oil with S application. Oil percent has a negative correlation with sinigrin and gluconapin content. The uptake of S was positively correlated with oleic acid content but showed lower or even negative correlation with other fatty acids. Therefore, irrigation (twice at 30 DAS and 60 DAS) in combination with 45 kg S/ha are recommended for improving yield attributes, yield, oil percent and S uptake of Indian mustard.

Keywords: *Brassica juncea*; elemental S; irrigation schedules; seed and stover yield; nutrient

India is the third largest producer of rapeseed-mustard (Piri et al. 2011) having 5.90 million hectares area with 6.41 million tonnes production, but the average yield of rapeseed-mustard in India is only 1145 kg/ha (Economic survey 2013) due to the lack of optimum use of nutrients and improper water management. Indian mustard is responsive to irrigation, and the most efficient water use by mustard depends on number as well as timing of irrigation at critical growth stages. Increase in the amount of water by increasing the number of irrigation augmented the leaf water potential, stomatal conductance, light absorption, and leaf area index which ultimately increased growth, yield attributes (Ray et al. 2014) and quality (Majid and Simpson 1999).

Application of sulphur was reported to increase yield attributes and yield of Indian mustard (Patel et al. 2009, Kumar et al. 2011), which also has a significant effect on oil, fatty acid (Ahmad and Abdin 2000) and glucosinolates content in mustard seed (Falk et al. 2007). The relative proportions of individual glucosinolates viz. sinigrin (allyl isothiocyanate), gluconapin (3-butenyl glucosinolate) and progoitrin (2-hydroxy-3-butenyl glucosinolate) are influenced by sulphur application (Hassan et al. 2007). Consequently, the present study was based on the hypothesis that increasing irrigation and sulphur levels may enhance the yield attributes, yield, sulphur uptake and quality of mustard.

MATERIAL AND METHODS

Field experiments were conducted during winter season of 2010–2011 and 2011–2012 at the Research

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Farm of Bidhan Chandra Krishi Viswavidyalaya, West Bengal, India (22°56'N, 88°32'E, altitude 9.75 m a.s.l.) on clay loam soil having pH 6.21 (Jackson 1967), EC 0.104 dS/m (Jackson 1967), oxidizable organic carbon 0.43% (Walkley and Black 1934), available N 393.5 kg/ha (Subbiah and Asija 1956), available P 23.91 mg/kg (Olsen et al. 1954), available K 70 mg/kg (Brown and Warncke 1988) and available S 14.3 mg/kg (Chesnin and Yien 1951). The treatments comprised of three irrigation schedules on critical growth stages (I_1 – one irrigation at flower initiation stage (30 days after sowing (DAS)); I_2 – one irrigation at siliquae development stage (60 DAS), and I_3 – two irrigations at 30 DAS and 60 DAS in the main plot) and four sulphur levels (S_0 – no sulphur; S_1 – 30 kg S/ha; S_2 – 45 kg S/ha, and S_3 – 60 kg S/ha) in the sub plots replicated thrice, and were laid out in split-plot design. Bentonite clay (elemental S) was applied 30 days before seed sowing. Seeds of Indian mustard cv. Varuna (T-59) were sown at 7 kg/ha at the first week of October with 45 cm × 10 cm spacing with a pre-sowing irrigation. Other cultural practices including recommended fertilizer levels (80:17.2:33.2 kg N:P:K/ha) were kept the same for all treatments. Metasystox @0.2% was sprayed thrice at 10 days interval during pod development stage to protect the crop from aphids. Oil content (in percent) was determined by taking a sample of seeds of each plot of all the replications following the standard method (AOAC 1960). For determination of the fatty acid content, fatty acid methyl esters were prepared from samples of the total oil, by transmethylation using 14% BF_3 – methanol plus methanol plus benzene (Morrison and Smith 1964). The percentage weight of fatty acids was calculated from the chromatograms by area normalization method (Nogare and Juvet 1966). Glucosinolate content of mustard seed was estimated by high-performance liquid chromatography using chromatograms following the standard method (AOAC 1960). The sulphur content in seed was determined with di-acid digestion by turbidity method on a spectrophotometer using 420 nm wavelengths (Jackson 1973). The collected data were analyzed statistically by the analysis of variance technique using SPSS (version 18.0, Chicago, USA). The Duncan's multiple range test (DMRT) was applied to determine the least significant difference (*LSD*) at $P < 0.05$ unless otherwise mentioned (Duncan 1955).

RESULTS AND DISCUSSION

Yield attributes and yield. Effect of sulphur and irrigation on yield attributes and yield was significant (Table 1). Plants grown with single irrigation either at 60 DAS and 30 DAS were statistically at par with respect to the number of seeds per siliqua, seed yield and stover yield. Double irrigation exhibited higher seed and stover yield over single irrigation at 30 DAS (7.74% and 6.68%, respectively) and 60 DAS (10.97% and 9.75%, respectively). The availability of adequate moisture during critical growth stages (flower initiation and siliqua development) might have enabled the plants to attain a greater biomass, thereby increasing yield of the crop (Piri et al. 2011). However, plants receiving single irrigation at 60 DAS might have witnessed

Table 1. Seed yield, stover yield, seed oil percent and sulphur (S) uptake of Indian mustard as influenced by S and irrigation levels (pooled data of two years)

Treatment		Number of siliquae/plant	Number of seeds/siliqua	Seed yield (t/ha)	Stover yield (t/ha)	Oil percent	S uptake in seed (kg/ha)
Irrigation	once at 30 DAS	302.74^{b}	11.53^{b}	1.43^{b}	5.17^{b}	37.47^{b}	15.39^{b}
	once at 60 DAS	286.64^{c}	11.71^{b}	1.38^{b}	5.00^{b}	36.71^{b}	14.77^{c}
	twice at 30 and 60 DAS	307.52^{a}	12.81^{a}	1.55^{a}	5.54^{a}	40.88^{a}	17.51^{a}
Sulphur level (kg/ha)	0	286.13^{d}	11.36^{c}	1.28^{c}	4.68^{c}	35.26^{c}	13.21^{c}
	30	294.25^{c}	12.02^{b}	1.43^{b}	5.01^{b}	37.74^{b}	14.78^{b}
	45	305.27^{b}	12.21^{ba}	1.55^{a}	5.52^{a}	39.14^{b}	17.47^{a}
	60	310.21^{a}	12.46^{a}	1.56^{a}	5.72^{a}	41.26^{a}	18.10^{a}

Means followed by a different letter are significantly different at $P < 0.05$ by Duncan's multiple range test. DAS – days after sowing

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a greater water stress up to 60 days thereby resulting in lower yield than that of single irrigation at 30 DAS. An increasing trend for number of seeds per siliqua and number of siliquae per plant with the increase in irrigation levels was also reported by Kashved et al. (2010).

Application of 60 kg S/ha recorded higher seed and stover yield (17.95% and 18.18% over zero-S, respectively) (Table 1). Sulphur fertilization with 45 kg/ha was more efficient than 60 kg S/ha in increasing the seed yield which might be supplemented with increased number of siliquae/plant (Patel et al. 2009) and seeds/siliqua (Kumar et al. 2011). Sulphur, with its involvement in the metabolic processes, enhances the meristematic activity and thus causes higher apical growth with expansion of photosynthetic surface (Piri et al. 2012).

Sulphur uptake and oil content. Double irrigation exhibited significantly higher oil percent and S uptake than single irrigation (Table 1). However, sulphur uptake was higher in plants irrigated once at 30 DAS than 60 DAS, but oil percent of seed was at par. Two irrigations might have enhanced the turgidity and cell division resulting in higher meristematic activity leading to a greater uptake of S which, in turn, enhanced the oil percent (Ray et al. 2014). Sulphur at higher rate (60 kg/ha) produced seeds with higher oil percent. However, S fertilization at 45 kg/ha exhibited no significant difference in S uptake with that of 60 kg/ha. Earlier studies also showed that successive increase in S-levels on mustard led to increased S uptake (Sharma et al. 2009) as well as oil content (Kumar and Trivedi 2012).

Glucosinolate content. Irrigation and sulphur did not show any noteworthy effect on glucosinolate content; however, progoitrin content differed significantly with S application (Table 2). An non-significant effect of irrigation on glucosinolate content of mustard seed was demonstrated earlier by Majid and Simpson (1999). An increase in sinigrin and progoitrin was noticed with the increase in S levels from 0–60 and 0–45 kg S/ha, respectively, while the trend was reverse for gluconapin content with an increase in S-levels from 0–45 kg S/ha. An decrease in glucosinolate content might be accorded to an increase in N:S ratio and increased vegetative growth probably outpaces the glucosinolate biosynthesis thereby, diluting their content (Rosen et al. 2005).

Table 2. Glucosinolate content (μmol/g seed) in Indian mustard as influenced by sulphur and irrigation levels (pooled data of two years)

Treatment	Sinigrin	Gluconapin	Progoitrin
Irrigation			
Once at 30 DAS	6.41[a]	34.09[a]	2.30[a]
Once at 60 DAS	6.37[a]	34.29[a]	2.37[a]
Twice at 30 and 60 DAS	6.42[a]	34.32[a]	2.37[a]
Sulphur level (kg/ha)			
0	6.35[a]	34.42[a]	2.15[b]
30	6.36[a]	34.27[a]	2.36[a]
45	6.39[a]	34.05[a]	2.45[a]
60	6.49[a]	34.19[a]	2.42[a]

Means followed by a different letter are significantly different (otherwise statistically at par) at $P < 0.05$ by Duncan's multiple range test. DAS – days after sowing

Table 3. Fatty acid content (%) in Indian mustard as influenced by sulphur and irrigation levels (pooled data of two years)

Treatment		Oleic acid	Linoleic acid	Linolenic acid	Erucic acid
Irrigation	once at 30 DAS	15.20[a]	12.60[a]	9.20[a]	49.00[a]
	once at 60 DAS	15.53[a]	12.89[a]	9.30[a]	49.28[a]
	twice at 30 and 60 DAS	15.50[a]	12.69[a]	9.25[a]	49.68[a]
Sulphur level (kg/ha)	0	14.80[a]	12.52[a]	9.07[a]	50.20[a]
	30	15.30[a]	12.53[a]	9.33[a]	49.57[a]
	45	15.73[a]	12.97[a]	9.23[a]	48.87[a]
	60	15.80[a]	12.89[a]	9.37[a]	48.63[a]

Means followed by a different letter are significantly different (otherwise statistically at par) at $P < 0.05$ by Duncan's multiple range test. DAS – days after sowing

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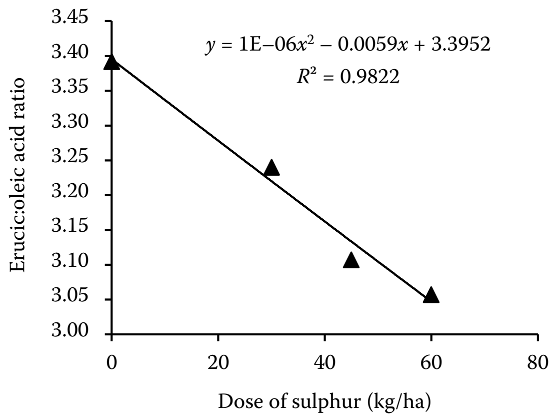

Figure 1. Relationship of sulphur levels with erucic:oleic acid ratio of Indian mustard

Fatty acid content. Irrigation regimes did not show any significant effect on fatty acid content (Table 3). However, oleic acid content was increased with the extent of water stress, and single irrigation at 60 DAS exhibited the highest oleic acid content. A similar trend of the increase in oleic acid content for sunflower was reported by Flagella et al. (2002). We found that the main effect of sulphur was a non-significant increase in oleic acid content and a decrease in erucic acid content (Table 3). Greater application of S reduced the conversion of oleic acid ($C_{18:1}$) to erucic acid ($C_{22:1}$), leading to the reduced $C_{22:1}/C_{18:1}$ ratio (Figure 1) and, thus, improved the quality of mustard oil (Ahmad and Abdin 2000).

Correlation studies. Oil percent had a negative correlation with sinigrin and gluconapin content, while the correlation was positive between oil percent and S uptake in seed. Among various glucosinolates, only progoitrin content was significantly correlated at $P < 0.05$ with oil percent and S uptake, respectively. There was a negative correlation between sinigrin and gluconapin and also between gluconapin, and progoitrin. However, a very low correlation was noticed between sinigrin and progoitrin. As these three components altogether form the glucosinolate content of seed, increase in one component might be at the cost of another, thereby giving low or even negative correlation among them. A lower correlation between glucosinolate content and oil percent was demonstrated previously by Chauhan et al. (2008).

Data (Table 4) also revealed that there was a very low correlation among different fatty acids. The uptake of S was positively ($P < 0.01$) correlated with the oleic acid content but showed lower or even negative correlation with other fatty acids. Surprisingly, a similar trend was noticed while considering the correlation among oil percent and fatty acid content.

Table 4. Correlation among sulphur (S) uptake, oil percent, glucosinolate and fatty acid content in seed

Parameter	Glucosinolate			oil percent	S uptake
	sinigrin	gluconapin	progoitrin		
Sinigrin	1	–	–	–	–
Gluconapin	–0.357*	1	–	–	–
Progoitrin	0.333*	–0.209	1	–	–
Oil percent	0.262	–0.157	0.387*	1	–
S uptake	0.261	–0.154	0.447**	0.767**	1

	fatty acid				oil percent	S uptake
	oleic	linoleic	linolenic	erucic		
Oleic acid	1	–	–	–	–	–
Linoleic acid	0.250	1	–	–	–	–
Linolenic acid	0.194	0.122	1	–	–	–
Erucic acid	0.026	0.351*	0.003	1	–	–
Oil percent	0.478**	0.108	0.198	–0.048	1	–
S uptake	0.478**	0.257	0.213	–0.091	0.767**	1

*$P < 0.05$ (2-tailed); **$P < 0.01$ (2-tailed)

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Irrigation at 30 DAS and 60 DAS (given twice) are strongly recommended for improving yield attributes, yield, oil percent and S uptake of Indian mustard cv. Varuna (T-59). However, S fertilization at 45 kg S/ha may be effective in terms of yield and S uptake of the crop.

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Corresponding author:

Mr. Krishnendu Ray, Bidhan Chandra Krishi Viswavidyalaya, Faculty of Agriculture, Department of Agronomy, Mohanpur, Nadia 741 252, West Bengal, India; e-mail: krishnenduray.bckv@gmail.com