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Productivity, profitability and sulphur use efficiency of Mustard (*Brassica juncea* L.) as influenced by weed management and sulphur fertilization under semiarid conditions of Rajasthan

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Abstract
A field experiment was conducted during winter 2014-15 and 2015-16 at Agronomy research farm, Jobner, Rajasthan to evaluate the effect of weed management practices and sulphur fertilization on productivity, profitability and sulphur use efficiency of mustard (*Brassica juncea* (L.) Czern & Coss). The results indicated that plots under twice hand weeding (HW) at 25 and 45 (DAS) had the significantly highest growth and yield attributes followed by pendimethalin at 0.75 kg/ha (PE). Among weed management practices, the highest seed and straw yield (2.49 t/ha and 7.14 t/ha) were obtained with two HW and pendimethalin (2.16 t/ha and 6.24 t/ha) treatments (Pooled data two years). The highest net returns were also obtained with two HWs, and the increment to the tune of 14.9, 20.1 and 36.5 % over pendimethalin, one HW and trifluralin (0.75 kg/ha), respectively. Sulphur fertilization at 40 kg/ha significantly improved the growth, yield attributes and yield over the preceding levels. However, it remained statistically at par with 60 kg S/ha. Two HW was also found best for agronomic efficiency (AE) and apparent recovery (RE) of applied S (25.82 kg seed/kg S; 57.23%). Maximum AE and RE were obtained with 40 kg S/ha.

Keywords: mustard, Pendimethalin, S fertilization, sulphur use efficiency and hand–weeding

Introduction
Indian mustard [*Brassica juncea* (L.) Czern and Coss] occupies a prominent place being next in importance to soybean and groundnut, both in area and production. In India, it is cultivated on 6.5 m ha with 7.8 mt production and 1208 kg/ha productivity (Anonymous 2013-14) [1]. There is no scope of increasing the acreage under this crop at the cost of food grain crops. Thus, the only way to increase the production is to increase its productivity through sound crop production technology. Heavy weed growth is a major recognized bottleneck in realizing the yield potential of mustard. Weeds appear to be among the most serious menace in crop production due to their extensive losses. Due to severe weed competition, the yield reduction in Indian mustard may go as high as 70 per cent (Tiwari and Kurchania, 1993) [11].
For successful control of weeds during this stage, one HW at 25 to 30 DAS is required, but in view of scanty availability of labour and ever increasing wages, the manual weed control has become cumbersome, labour intensive, time consuming and costly. Therefore, it is essential to search out effective pre-plant incorporation (PPI) and/ or pre-emergence (PE) herbicide which can take care of early flush of weeds. There has been a growing concern about depletion of the available pool of sulphur, particularly in light textured soils with low organic matter content. The depletion of sulphur is due to increased removal by adoption of high yielding and fertilizer responsive crop varieties, increased cropping intensity, extensive use of sulphur free fertilizers and inclusion of pulses and oilseed crops in cropping sequences. Sulphur has been reported to be deficient mainly in the soils of Jaipur, Jodhpur and Udaipur districts of Rajasthan (Tandon, 1986). Global reports of sulphur deficiency and consequent crop responses particularly in oilseeds crops are quite ostensible. Sulphur plays a multiple role in the nutrition of oil seed crops. Sulphur resembles N in its role and the function of S in plant is comparable with P in terms of overall needs and it can be equated with K in terms of economics (Tiwari *et al.*, 2003b). Thus, optimum quantity of nutrient and proper weed management is of paramount importance to productivity and sulphur use efficiency of mustard

Materials and methods
The field experiment was conducted during the winter (*rabi*) 2014-15 and 2015-16 at Jobner,

Jaipur, Rajasthan ($27^{0}05'$N; $75^{0}28'$E, of above mean sea level). The soil was loamy sand having low organic carbon (0.21%) and available N (128.6 kg/ha), medimum in P (15.4 kg/ha) and K (148.6 kg/ha) and slightly alkaline (pH 8.2). The experiment was laid out in split plot design with three replications. The main plot comprised seven weed – control treatments [weedy check, one HW at 25 DAS, two HW at 25 and 45 DAS, pendimethalin at 0.75 kg/ha (PE), trifluralin at 0.75 kg/ha (PPI), isoproturon at 1.0 kg/ha (PE) and oxyflourfen at 0.125 kg/ha (PE), and three sulphur levels (0, 20, 40 and 60 kg/ha) were taken as subplots. Mustard cultivar 'Lakshmi' was sown with standard package of practices. Three irrigations were applied to the crop. Rainfall received during the crop growing season was 21.40 and 3.60 mm in 2014-15 and 2015-16, respectively. Pre emergence application of pendimethalin (Dost 30 EC), isoproturon (Isoguard 75 WP) and oxyfluorfen (Orbit 23.5 EC) was applied one day after sowing as per treatment. Trifluralin (Treflan 48 EC) was applied and mixed into the soil one day before sowing. A knapsack sprayer was used for spraying herbicides using a spray volume of 700 litres/ha. In the plots ear marked for hand – weeding, the operation was done at 25 and 45 DAS with the help of *Kassi* as per treatment. Half dose of nitrogen and full dose of phosphorus was applied as basal dose through urea and DAP, remaining dose of nitrogen was top dressed at the time of first irrigation. Sulphur was applied and mixed into the soil through zypsum as per treatment before sowing. Sowing was done with '*pora*' method in rows spaced at 30 cm with average depth of 5 cm and seed rate of 5 kg/ha. All the plant protection measures were adopted to take health cropAt maturity stage, after leaving two rows on each side as well as 50 cm along the width of each side, a net plot area of 3 m x 1.8 m was harvested separately for recording the yield attributes and yields. The harvested material was tied and tagged and kept on threshing floor sun drying. Mustard seeds were cleaned by winnower and yield was recorded. Straw yield was obtained by subtracting seed yield from total biomass yield. Yield was expressed in t/ha. The harvest index was calculated by economic yield by biological yield and expressed in percentage. Net returns were calculated based on seed and straw yield and prevailing market price of mustard seed. The sulphur concentration in seed and straw yield were determined by standard method. The uptake/accumulation of sulphur in mustard seed and straw was calculated by multiplying the dry matter yield with their concentration. Agronomic efficiency (AE), recovery efficiency (RE) and physiological efficiency were calculated by standard formulae. All the observation during individual years as well as in pooled analysis were statistically analyzed for their test of significance using the *F*-test (Gomez and Gomez, 1984). The significant of difference between treatment means were compared with t critical difference at 5 % level of probability.

Results and discussion

Weed management

Growth parameters: The plant height, number of branches/plant, dry matter accumulation (DMA), number of siliquae/plant, seeds/siliqua and 1,000-seed weight were significantly influenced by different weed control treatments. All the weed control treatments i.e. hand weeding and herbicide application significantly influenced the growth and yield attributes of the crop as compared weedy check plot (Table1). Two hand weedings done at 25 and 45 DAS recorded the highest plant height during all the stages with 45.9 % taller than the weedy check at harvest stage. Two HW at 25 and 45 DAS recorded the highest crop dry matter of 312.6 g/m row length at harvest stage among all the treatments, registering a remarkable increase of 32.2, 34.9, 79.7, 92.8, 147.5 and 210.7 per cent over pendimethalin at 0.75 kg/ha, one HW at 25 DAS, trifluralin at 0.75 kg/ha, isoproturon at 1.0 kg/ha, oxyfluorfen at 0.125 kg/ha and weedy check treatment, respectively. Remaining at par with one HW at 25 DAS, pendimtahlin at 0.75 kg/ha also registered significant enhancement of 35.9, 45.8, 87.2 and 135.0 per cent at harvest stage over trifluralin at 0.75 kg/ha, isoproturon 1.0 kg/ha, oxyfluorfen at 0.125 kg/ha and weedy check treatments, respectively and thus emerged as the next better treatments. Two hand weedings done at 25 and 45 DAS and pendimethalin at 0.75 kg/ha were the most superior and statistically similar treatments recorded higher number of branches/plant. Attaining 7.4 and 7.2 at harvest, these treatments recorded 68.6 and 65.4 per cent increase in number of branches/plant, respectively, over weedy check. These treatments were closely accompanied by one HW at 25 DAS wherein 6.90 branches/plant were noted at harvest stage. Oxyfluorefen at 0.125 kg/ha registered 11.7, 25.5 and 27.2 per cent increase in plant height, crop dry matter production and number of branches/plant over weedy check and thus was found as the least effective herbicidal treatment.

The improvement in growth attributes of mustard under the influence of different weed control treatments in present investigation could mainly be ascribed to the reduced density and dry weight of weeds. It resulted significant reduction in competition for growth inputs *viz*., space, moisture, nutrients, light etc. The weed free environment provided by these treatments reduced the crop-weed competition to the extent of their efficacy in weed control which led to better growth of crop in terms of plant height, number of branches and dry matter accumulation. Weed free environment also saved nutrients, moisture, sunlight and space that would have otherwise been utilized by freely growing weeds under infested conditions. Thus, adequate availability of light, space as well as better edaphic and nutritional environment along with improvement in physiological and morphological characters of the plant in rhizosphere led to greater photosynthetic rate, thereby more accumulation of dry matter under better treatments. Contrary to this, uncontrolled weed growth throughout the crop season in weedy check plots arrested the crop growth due to high degree of crop-weed competition. Mechanical treatments (HW) also improved the physical condition of the soil by making it loose and porous and providing greater aeration that might have accelerated the establishment and proliferation of roots and ultimately the plant growth. In addition of providing weed free environment to crop, excellent growth observed under HW twice and one HW treatments in comparison to herbicides alone could be the another possible reason of higher values of growth parameters. Significant improvement in growth attributes due to two HW has also been reported by Sharma *et al.* (2002) [8] and Degra *et al.* (2011) [2] in mustard. Whereas, kumar *et al.* (2012) in mustard reported superiority of pendimethalin.

Two HW done at 25 and 45 DAS resulted in the maximum number of siliquae/plant, test weight. Application of pendimethalin at 0.75 kg/ha (PE) and one HW at 25 DAS were the next superior and equally effective treatments in enhancing yield attributes of mustard. These treatments increased the number of siliquae/plant to the tune of 56.9 and 54.1 per cent over weedy check. Whereas, extent of increase in seeds/siliqua was 36.8 and 21.8 per cent, respectively. Since, hand weeding provided weed free environment to crop, excellent crop growth was noted under two HW treatments. Similar results were also reported by Marmat *et al.* (2003). Relatively poor yield attributes recorded under inferior treatments like oxyfluorfen might be attributed to the poor crop growth due to phytotoxicity as was observed in early growth stages that affected yield contributing characters.

Productivity: Seed and straw yield were significantly influenced by different weed control treatment. Significantly maximum seed and straw yield of mustard were significantly influenced by all the treatments. Two hand weeding treatment provided the long time weed control and hence resulted in appreciably higher yields over to unweeded plots. Pre emergence application of pendimethalin at 0.75 kg/ha and one HW at 25 DAS were the next superior and equally effective treatments in enhancing yield of mustard. They also improved the seed yield by margin of 58.2 and 55.6 per cent over weedy check. The corresponding increase in straw yield was 40.1 and 39.5 per cent and biological yield was 44.4 and 43.2 per cent. Remaining at par with each other, trifluralin at 0.75 kg/ha and isoproturon at 1.0 kg/ha also gave 39.6 and 34.3 per cent higher seed yield and 27.2 and 26.5 per cent higher straw yield over weedy check, but they were found inferior to above described treatments. These treatments kept the crop almost weed free up to 40-50 DAS which resulted significant reduction in competition for nutrients and other growth resources by weeds as a consequence of which reduction in dry matter and nutrient depletion by weeds occurred. Reduced weed-crop competition under these superior treatments saved a considerable amount of nutrients for crop growth that led to enhanced crop growth by utilizing greater moisture and nutrients from deeper soil layers. Under weed infested condition, although, the vegetative growth reached up to a level, but the sink was not sufficient enough to accumulate the meaningful photosynthates translocating towards seed formation. Similar results were also reported by Yadav *et al*. (2014). The most severe competition throughout the crop season due to unrestricted weed growth under weedy check plots increased the removal of nutrients and moisture by weeds thereby adversely effecting the crop growth. It also reduced the translocation of photosynthates towards seed formation having adverse effect on yield attributes which in turn reduced the yield to the minimum level. Results achieved in this investigation are strongly supported by Chauhan *et al*. (2005) and Singh *et al*. (2006) in mustard.

Profitability and S use efficiency: All the weed control treatments provided significantly higher net returns and B: C ratio in comparison to weedy check which is obviously due to higher seed yield obtained under different weed control treatments (Table 3). Two HW treatment fetched the maximum net return with B: C ratio of 3.04 thus increasing it by x10^3 ` 32.98/ha over weedy check. Pendimethalin at 0.75 kg/ha (PE) was the next better and the best herbicidal treatment. However, it was found at par with one HW at 25 DAS (x$10^3$ ` 48.60/ha) with B: C ratio of 2.89. Trifluralin at 0.75 kg/ha and isoproturon at 1.0 kg/ha recoded 68.4 and 58.4 per cent more net returns over weedy check with B: C ratio of 2.78 and 2.66. The higher net returns and B: C ratio recorded under these superior treatments can be explained easily with the corresponding higher seed yield. The maximum B: C ratio (3.06) under pendimethalin seems to be due to comparatively lower cost of treatment application. Due to unrestricted weed growth in weedy check treatment recoded the lowest seed yield that was eventually reflected in the lowest net returns (25.39 x10^3/ha) and B: C ratio (2.11). Results of the present investigation are in cognizance with the finding of Kumar *et al*. (2012) [6, 7]. The maximum AE and RE were reported under two HW treatment. Which was accompanied by one HW at 25 DAS and pendimethalin at 0.75 kg/ha, registering a significant increase of 74.2, 62.4 and 48.0 per cent in AE and 173.0, 141.0 and 118.5 per cent in RE over unweeded control.

Sulphur fertilization

Growth parameters: The results showed that growth and yield attributes were significantly influenced by sulphur fertilization (Table 1). Significant response in these parameters was obtained up to 40 kg S/ha. It is perhaps due to better nutritional environment for plant growth at active vegetative stages as a result of improvement in root growth, cell multiplication, elongation and cell expansion in plant body. Our findings are in conformity with the results of Kumar and Yadav (2007) [5]. A strong positive correlation was observed between seed yield of mustard and its yield attributing characters (Table 4).

Productivity and profitability: The seed and straw of mustard also increased significantly with every increase in level of S up to 40 kg/ha (Table 2). However, further increase in its level to 60 kg/ha was not up to the level of significance. This may be attributed to the increasing levels of S which resulted in greater accumulation of carbohydrates, protein and their translocation to the reproductive organs, which in turn might have improved all the growth and yield determining characters, resulting more seed yield. As seed yield is primarily a function of cumulative effect of yield attributing characters, the higher values of these attributes can also be assigned as the most probable reason for significantly higher seed yield. It is well evidenced from the positive correlation between crop dry matter accumulation (Table 4). Dubey *et al*. (2013) [3] have also documented significant and positive influence of sulphur application on yield attributes and yield of mustard crop. Increase in fertilization of sulphur level up to 0 to 40 kg/ha also fetched additional net returns of ` 23.28x10^3/ha over control with B: C ratio of (2.95) (Table 3), which is primarily due to higher seed yield with comparatively lesser additional cost of S. Improvement in yield attributes and yield due to S fertilization have also been reported earlier by Kumar and Yadav (2007) [5] in mustard crop.

Thus, two HW done at 25 and 45 DAS and application of sulphur at 60 kg/ha increased the growth, yield attributes and yield of mustard crop as compared to another treatments. From profitability point of view, pendimethalin at 0.75 kg/ha in combination with 40 kg S/ha proved the best herbicidal treatment in achieving higher profitability under semi arid eastern plan zone of Rajasthan.

Table 1. Effect of weed management and sulphur fertilization on growth and yield attributes of mustard (pooled data of two years

Treatments	Plant height (cm) at harvest	DMA (g/m row length) at harvest	Number of branches/plant	Siliquae /plant	Seeds/ plant	1,000–seed weight (g)
Weed control						
Weedy check	138.2	100.6	4.37	149.1	8.7	4.66
One HW at 25 DAS	184.0	231.8	6.90	229.8	10.6	5.63
Two HW at 25 & 45 DAS	201.7	312.6	7.37	257.8	11.6	5.87

Pendimethalin @ 0.75 kg/ha (PE)	197.1	236.4	7.23	234.0	11.9	5.68
Isoproturon @ 1.0 kg/ha (PE)	170.3	162.1	6.40	200.4	9.6	5.17
Oxyfluorfen @ 0.125 kg/ha (PE)	154.4	126.3	5.56	178.0	8.8	4.76
Trifluralin @ 0.75 kg/ha (PPI)	173.8	174.0	6.61	210.3	9.8	5.31
SEm+	3.3	4.20	0.12	4.11	0.2	0.07
CD (P=0.05)	9.7	12.25	0.34	11.99	0.5	0.22
Sulphur levels (kg/ha)						
0	127.1	155.1	4.63	154.7	7.4	4.48
20	179.6	172.9	6.54	215.9	10.5	5.35
40	192.6	216.5	7.00	230.1	11.2	5.61
60	197.4	223.3	7.20	233.2	11.5	5.74
SEm+	2.2	2.72	0.08	2.89	0.1	0.06
CD (P=0.05)	6.3	7.66	0.24	8.13	0.3	0.16

Table 2: Effect of weed control and sulphur levels on seed, straw yield (t/ha) and harvest index (%)

Treatments	**Seed yield (t/ha)**	**Straw yield (t/ha)**	**Harvest index (%)**
Weed control			
Weedy check	1.37	4.47	23.28
One HW at 25 DAS	2.13	6.23	25.40
Two HW at 25 & 45 DAS	2.49	7.14	25.87
Pendimethalin @ 0.75 kg/ha (PE)	2.16	6.26	25.65
Isoproturon @ 1.0 kg/ha (PE)	1.84	5.65	24.58
Oxyfluorfen @ 0.125 kg/ha (PE)	1.58	5.02	23.97
Trifluralin @ 0.75 kg/ha (PPI)	1.91	5.68	25.16
SEm+	0.04	0.13	0.42
CD (P=0.05)	0.12	0.38	1.24
Sulphur levels (kg/ha)			
0	1.43	4.43	24.23
20	1.99	5.78	25.49
40	2.11	6.36	24.81
60	2.17	6.54	24.85
SEm+	0.03	0.09	0.26
CD (P=0.05)	0.08	0.25	0.72

Table 3: Profitability and sulphur–use efficiencies as influenced by weed control and sulphur fertilization (pooled data of two years)

Treatments	**Net returns (x 10^3 □/ha)**	**B:C ratio**	**Agronomic efficiency (kg seed/kg S)**	**Recovery efficiency (%)**	**Physiological efficiency (kg seed/kg S uptake)**
Weed control					
Weedy check	25.39	2.11	14.82	20.96	69.22
One HW at 25 DAS	48.60	2.89	24.07	45.80	50.25
Two HW at 25 & 45 DAS	58.37	3.04	25.82	57.23	43.54
Pendimethalin @ 0.75 kg/ha (PE)	50.78	3.06	21.93	50.51	42.62
Isoproturon @ 1.0 kg/ha (PE)	40.21	2.66	16.20	35.84	44.58
Oxyfluorfen @ 0.125 kg/ha (PE)	32.06	2.35	13.31	24.27	54.77
Trifluralin @ 0.75 kg/ha (PPI)	42.75	2.78	18.42	37.23	49.33
SEm+	0.95	0.06	0.25	0.55	0.91
CD (P=0.05)	2.78	0.17	0.74	1.60	2.66
Sulphur levels (kg/ha)					
0	25.68	2.04	-	-	-
20	44.94	2.80	28.33	50.93	58.07
40	48.96	2.95	17.02	38.07	46.45
60	50.79	3.01	12.32	27.50	47.33
SEm+	0.68	0.04	0.17	0.39	0.60
CD (P=0.05)	1.91	0.11	0.49	1.10	1.68

Table 4: Correlation coefficients (r) and regression equations for the relationship between seed yield (Y) growth and yield attributing characters (X)

Parameters	**2014-15**		**2015-16**		**Pooled**	
	Correlation coefficient (r)	**Regression equation $Y = a + b_y x. X$**	**Correlation coefficient (r)**	**Regression equation $Y = a + b_y x. X$**	**Correlation coefficient (r)**	**Regression equation $Y = a + b_y x. X$**
DMA at harvest (kg/ha)	0.988^{**}	$Y = -0.257+0.029 X_5$	0.987^{**}	$Y = -0.188+0.027 X_5$	0.989^{**}	$Y = -0.227+0.028 X_5$
Number of branches/plant	0.962^{**}	$Y = -0.068+0.317X_6$	0.961^{**}	$Y = -0.025+0.304 X_6$	0.964^{**}	$Y = -0.052+0.312 X_6$
Number of siliquae/plant	0.992^{**}	$Y = -0.115+0.010 X_7$	0.994^{**}	$Y = -0.093+0.010 X_7$	0.995^{**}	$Y = -0.110+9.76 X_7$
Number of seeds/siliqua	0.935^{**}	$Y = -0.201+0.214 X_8$	0.934^{**}	$Y = -0.230+0.208 X_8$	0.936^{**}	$Y = -0.219+0.211 X_8$
1,000 seed weight (g)	0.963^{**}	$Y = -1.421+0.635 X_9$	0.924^{**}	$Y = -1.555+0.655 X_9$	0.960^{**}	$Y = -1.597+0.665 X_9$

** P= 0.01

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