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Growth, Yield, Quality and Energetics of Mustard (*Brassica juncea* (L.) Czern & Coss) as Influenced by Weed Management and Sulphur Fertilization under Semi Arid Condition of Rajasthan

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Abstract

The field experiments were conducted during *rabi* (October to march) 2014–15 and 2015–16 at Agronomy farm, Jobner, Rajasthan, India to evaluate effect of weed management practices and sulphur fertilization on growth, yield and qualityof mustard (*Brassica juncea* (L.). The experimental field was laid out in a split plot design with seven treatments of weed management with four sulphur levels and three replications.Among weed control treatment crop dry matter at harvest stage (312.6 g^{-1} row length), maximum value of CGR and RGR during all the stages of crop growth, maximum seed yield (2493 kg ha^{-1}), output energy (151500 MJ ha^{-1}), output input energy ratio (13.65), Energy use efficiency (0.225) and energy balance (140430 MJ ha^{-1}) was obtained with 2 HW at 25 and 45 DAS. Among the herbicidal treatment pendimethalin @ 0.75 kg ha^{-1} was next better treatment which was at par with one HW at 25 DAS. Among sulphur levels crop dry matter at harvest (222.3 g m^{-1} row length), maximum value of CGR and RGR during all the stages of crop growth, seed yield (2167 kg ha^{-1}), oil yield (885 kg ha^{-1}), oil yield (885 kg ha^{-1}), output energy (135918 MJ ha^{-1}), output input energy ratio (12.26), energy use efficiency (0.195 kg MJ^{-1}) and energy balance (124856 MJ ha^{-1}) were obtained with 60 kg S ha^{-1} which was at par with 40 kg S ha^{-1}.

Keywords: CGR, energetics, mustard, pendimethalin, RGR, sulphur

1. Introduction

Indian mustard is predominantly cultivated in the states of Rajasthan, Uttar Pradesh, Haryana, Madhya Pradesh, Gujarat, Punjab and Bihar. Rajasthan state contributed major part of 2.53 m ha with 3.25 mt production and 1287 kg ha^{-1} productivity. Thus, it has major share in area (46%) and production (49%) of mustard in our country. In India, it is cultivated on 6.23 m ha with 9.34 mt production and 1499 kg ha^{-1} productivity (Anonymous 2020). Among the seven oil seeds cultivation in India, the Brassica species only contribute the 28.6% in total oil seed production. Brassica species oil is used for salad, made for cooking and after the extraction of oil the protein rich extra material is used for animal feed purposes (Sardana et al., 2011) Indian mustard suffers more from weed competition especially at the early stage of crop growth. Weeds cause yield reduction to the tune of 10–58% (Banga and Yadav, 2001

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and Malik et al., 2012) depending on the type, intensity and duration of the competition. Uncontrolled weeds reduce mustard yield by 68% as compared to weed-free conditions (Degra et al., 2011). Moreover, the competition of weeds with crop plant causes severe nutrition deprivation in general (Roshdy et al., 2008). The most common practice of weed management in Indian mustard is manual weeding at 3–4 weeks after sowing. But, day to day increasing wages, scarcity of labor at peak periods and high-cost involvement compel to search other alternatives that are technically feasible and economically viable so that these measures can manage the weed below the economic threshold level and allow harnessing the yield potential of this crop (Kalita et al., 2017). Weeds are regarded as one of the major negative factors of crop production loss due to competition for nutrients, moisture, light, and space which has been reported as high as 30–70% (Tewari et al., 1998). Chauhan et al. (2005) reported that weed competition in mustard is more serious in early stage because crop growth during winter (rabi) season remains slow during the first 4–6 weeks after sowing and during later stage it grows vigorously and suppressing effect on weeds. Weed infestation during early stages reflected the crop growth and reduction in yield up to 58% (Prusty et al., 1996). At later stages, shading caused by plant height and broad dorsoventral leaves help in suppressing weed growth (Chakaiyar and Ambasht, 1990). Among the various factors responsible for the low productivity of mustard, weed control is one of the most important constraints. As this crop is grown in poor soils with poor crop management practices, weed infestation is one of the major causes of low productivity (Singh, 1992). Rao (2000) reported that reduction in crop yield has a direct correlation with weed competition. Presence of weeds reduces the photosynthetic efficiency, dry matter production and distribute of photosynthesis to economical parts and thereby, adversely affecting source and sink relationship resulting in reduction of mustard yield besides these, they increase production cost, create the pests and plant disease problem and decrease the quality of farm produce as well as value of the land.

Indian mustard suffers more from weed competition in early growth stage for light, water and nutrient including CO_2. Heavy weed growth is a major recognized bottleneck in realizing the yield potential of mustard. Weeds appear to be the most serious menace in crop production due to their extensive losses. Yield losses due to weeds varied from 25–45% depending on the type of weed flora and their intensity, stages, nature and duration of crop weed competition (Singhet al., 2001). 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). It is obvious that sulphur is an important element for protein and oil synthesis in Brassica species. Sulphur is also involved in the synthesis of oil in oilseeds. Moreover, it is also associated with the synthesis of vitamins (biotin, thiamine), metabolism of carbohydrates, proteins and fats. Glucosinolates and thioglucosides are very much affected by the deficiency of sulphur in plants.It is also a constituent of glucoside “sinigrin” (C10H16O9NS2K) which imparts the peculiar pungency to mustard oil and make it suitable for use as condiments and in the preparation of pickles, curries and vegetables. There has also been a growing concern about depletion of the available pool of sulphur, particularly in light soil 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 deficiency also results in poor flowering, cupping of leaves, reddening of stem and petiole and stunted growth. Resource poor farmers in nutrient starved soils with small and fragmented land holdings cultivate majority of the area under oilseeds in rainfed ecosystem and hence, the uncertainty of production is perpetual in the oilseed sector. The per capita consumption of edible oils in the country has witnessed a steep rise. Increasing population, rising per capita income and improvement in living standard of people has also led to increased demand of edible oil. Wide gap between supply and demand has resulted in dependency on imports to meet the additional requirement.For successful control of weeds during this stage, one HW at 25 to 30 DAS is enough, 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 has become essential to search out effective pre-plant incorporation (PPI) and/ or pre-emergence (PE) herbicide which can take care of early flush of weeds.Keeping all the facts in mind this experiment was conducted to find out theeffective and economically viable method of weed control and optimum dose of sulphur for mustard crop.

2. Materials and Methods

2.1. Description of the study area

The field experiment was conducted during the winter (*rabi*) 2014–15 and 2015–16 at Jobner, Jaipur, Rajasthan, India (27°05’N; 75°28’E, 427 meters of above mean sea level). The soil was loamy sand having low organic carbon (0.21%) and available N (128.6 kg ha^{-1}), medium in P (15.4 kg ha^{-1}) and K (148.6 kg ha^{-1}) and slightly alkaline (pH 8.2).

2.2. Experimental design and procedure

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^{-1} (PE), trifluralin at 0.75 kg ha^{-1} (PPI), isoproturon at 1.0 kg ha^{-1} (PE) and oxyflourfen at 0.125 kg ha^{-1} (PE), and three sulphur levels (0, 20, 40 and 60 kg ha^{-1}) were taken as sub-plots. 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 l ha^{-1}. 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. 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^{-1}. The harvested material was tied and tagged and kept on threshing floor sun drying. Mustard seeds were cleaned by winnower and yield was recorded. Leaving the two outer rows all the crop were harvested manually and after winnowing seed yield was converted into kg ha^{-1}. Treatment wise net plot yield was Yield was expressed in kg ha^{-1}. Plant dry weight of $meter^{-1}$ rowlength was taken for periodical dry matter. Plant of one meter row length were cut and dried for periodical crop dry matter. Observation of plant stand $meter^{-1}$ row length was taken by counting number of plants of one meter row length at three places in a plot. 1000 seed weight by taken by counting 1000 seeds of three sample of each and every treatment than average was done. Oil content in the seed was determined by "Soxhlet's apparatus using petroleum ether (60–80 °C) as an extractant (Anonymous, 1960). Oil yield (kg ha^{-1}) was calculated by multiplying per cent oil content with respective seed yield. All the observationsduring 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.

2.3. Energy use efficiency indices

Energy balance, Energy input and output was calculated using energy equivalents as suggestedby Devasenaparthyet al., 2009.

$$\text{Output input energy ratio} = \frac{\text{Output energy (MJ ha}^{-1}\text{)}}{\text{Input energy (MJ ha}^{-1}\text{)}}$$

$$\text{Energy Use efficiency (MJ ha}^{-1}\text{)} = \frac{\text{Productivity (kg ha}^{-1}\text{)}}{\text{Input energy (MJ ha}^{-1}\text{)}}$$

$$\text{Energy Balance (MJ ha}^{-1}\text{)} = \text{Output energy (MJ ha}^{-1}\text{)-Input energy (MJ ha}^{-1}\text{)}$$

Total common energy utilized during experimentation of mustard crop was 10191 MJ ha^{-1} (Field preparation -2605 MJ ha^{-1}, Manures and fertilizers -4080 MJ ha^{-1}, Seeds and sowing-772 MJ ha^{-1}, after cultivation-94 MJ ha^{-1}, Irrigation-1522 MJ ha^{-1}, Plant protection-274 MJ ha^{-1} and Harvesting and Post harvest operations-845 MJ ha^{-1}). All the data presented here in tables are pooled mean of two year of study.

3. Results and Discussion

3.1. Effect of weed management practices

3.1.1. Growth indices, yield, quality and energetics

Pooled results showed that two HW done at 25 and 45 DAS produced the maximum seed yield of 2493 kg ha^{-1} that was significantly higher over rest of treatments (Table 1). It registered a huge increase of 15.30, 17.20, 30.66, 35.78, 57.38 and 82.37% in seed yield over pendimethalin at 0.75 kg ha^{-1}, one HW at 25 DAS, trifluralin at 0.75 kg ha^{-1}, isoproturon at 1.0 kg ha^{-1}, oxyfluorfen at 0.125 kg $ha^{-1}$and weedy check treatments, respectively. Application of pendimethalin at 0.75 kg ha^{-1} was found to be the next better and most effective herbicidal treatment. Two hand weeding treatment provided the long time weed control and hence resulted in appreciably higher yields over to unweeded plots. The higher seed and straw yield obtained under superior treatments could be better explained with effectiveness in weed control in comparison to control. 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. These favourable effects in rhizosphere were more conspicuous in HW twice and one HW treatments as these improved soil tilths by making it loose and porous and thus vulnerable for the plants to utilize water and air. All these favourable effects of weed control treatments led to significant improvement in various yield attributing characters of mustard viz., number of siliquae $plant^{-1}$, seeds $siliqua^{-1}$ and test weight by providing better source-sink relationship. The significantly higher values of yield attributes coupled with higher crop dry matter under superior treatments can be ascribed as the most probable reason of higher seed yield. The increase in seed yield of mustard was also due to high harvest indices that showed greater partitioning of assimilates towards sink in the weed free environment. 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 (Degraet al., 2011; Bhalerao et al., 2011; Yadav et al., 2014; Mukherjee, 2014; Gupta et al. (2018).

Table 1: Effect of weed control and sulphur levels on WCE %, Weed competition index, periodical crop dry matter production (g m^{-1} row length), crop growth rate (CGR) and relative growth rate (RGR) of mustard at different stage

Treatments	Crop dry matter production (g m^{-1} row length)			CGR (g m^{-2} day^{-1})			RGR (mg g^{-1} day^{-1})		WCE % at harvest stage	Weed competition index
	30 DAS	60 DAS	At harvest	0 - 30 DAS	30 - 60 DAS	60 DAS - At harvest	30-60 DAS	60 DAS - At harvest		
Weed control										
Weedy check	18.3	50.0	100.6	2.03	3.53	2.29	33.26	9.50	-	45.17
One HW at 25 DAS	29.2	87.5	231.8	3.25	6.47	6.52	36.30	13.25	67.19	14.70
Two HW at 25 and 45 DAS	30.5	108.7	312.6	3.39	8.69	9.19	42.11	14.33	89.82	-
Pendimethalin @ 0.75 kg ha^{-1} (PE)	30.3	89.0	236.4	3.37	6.53	6.66	35.75	13.27	68.14	13.30
Isoproturon @ 1.0 kg ha^{-1} (PE)	25.0	68.5	162.1	2.78	4.83	4.22	33.35	11.65	43.86	26.35
Oxyfluorfen @ 0.125 kg ha^{-1} (PE)	22.0	57.7	126.3	2.44	3.97	3.10	31.92	10.57	64.95	36.48
Trifluralin @ 0.75 kg ha^{-1} (PPI)	26.1	72.4	174.0	2.90	5.15	4.59	33.58	11.92	46.52	23.47
SEm+	0.51	1.76	4.20	0.06	0.13	0.11	0.73	0.24	0.92	-
CD (p=0.05)	1.50	5.13	12.25	0.17	0.38	0.33	2.12	0.70	2.68	-
Sulphur levels (kg ha^{-1})										
0	22.6	57.7	155.1	2.51	3.90	4.41	30.74	12.91	53.21	-
20	25.4	75.0	172.9	2.82	5.51	4.42	35.33	10.87	54.50	-
40	27.4	85.0	216.5	3.04	6.40	5.93	37.28	12.23	54.06	-
60	28.2	87.4	223.3	3.14	6.57	6.13	37.37	12.27	55.64	-
SEm+	0.36	1.26	2.72	0.04	0.09	0.08	0.49	0.16	0.70	-
CD (p=0.05)	1.01	3.55	7.66	0.12	0.24	0.22	1.38	0.46	NS	-

Differences in dry matter were more apparent at later stages of crop growth than early stages. Results showed that two HWs done at 25 and 45 DAS, pendimethalin at 0.75 kg ha^{-1} and one HW at 25 DAS were the most superior and statistically similar treatments that recorded significantly higher crop dry matter of 30.5, 30.3 and 29.2 g m^{-1} row length at 30 DAS, respectively with a corresponding increase of 66.7, 65.6 and 59.6 % over weedy check treatment. Results further showed that two HW at 25 and 45 DAS recorded the highest crop dry matter of 108.7 and 312.6 g m^{-1} row length at 60 DAS and at harvest stage among all the treatments. Similar results were also obtained by Kumar et al., 2012.

Data showed that two HW at 25 and 45 DAS, pendimethalin at 0.75 kg ha^{-1} and one HW at 25 DAS were noted to be the most superior and statistically similar treatments in observing CGR during 0-30 DAS stage (3.39, 3.37 and 3.25 g m^{-2} day^{-1}) among all the treatments. Results further revealed that two hand weeding treatment registered the highest CGR of 8.69 and 9.19 g m^{-2} day^{-1} during 30-60 DAS and 60 DAS-at harvest stage of crop growth and thus found significantly superior over rest of the treatments. Pendimethalin at 0.75 kg ha^{-1} and one HW at 25 DAS were the next better and statistically similar treatments that recorded 6.53 and 6.47 g m^{-2} day^{-1} CGR during 30 - 60 DAS and 6.66 and 6.52 g m^{-2} day^{-1} uring 60 DAS- at harvest stage. Data indicated (Table 2) that two HW at 25 and 45 DAS, one HW at 25 DAS and pendimethalin at 0.75 kg ha^{-1} significantly increased the relative growth rate (RGR) in mustard during 30–60 DAS period in comparison to rest of the treatments. These treatments registered pooled mean RGR values of 42.11, 36.30 and 35.75 mg g^{-1} day^{-1} during this period. Significant improvement in growth attributes due to two HW has also been reported by Sharma et al. (2002) and Degra et al. (2011) in mustard. Whereas, Sewak et al. (2004) and Kumar et al. (2012) in mustard reported superiority of pendimethalin. Promosing results of one HW and isoproturon in enhancing growth attributes of mustard were also obtained by Kumar et al. (2012). Highest weed control efficiencies of 89.82% at harvest stage was recorded with two hand weedings at 25 and 45 DAS. Pendimethalin @ 0.75 kg ha^{-1} as pre emergence controlled the weeds to the extent of 68.14 per cent at these stages and thus emerged the most effective herbicidal treatment.

The maximum oil content (41.07%) and oil yield (1029 kg ha^{-1}) was recorded in two HWs at 25 and 45 DAS treatment. Being at par with two HW at 25 and 45 DAS pendimethalin @ 0.75 kg ha^{-1} and one HW at 25 DAS were next better treatment with respect to oil content and oil yield in mustard crop. Favouravble effects of weed management using mechanical

Table 2: Effect of weed control and sulphur levels on plant stand, number of siliquae plant^{-1}, number of seeds siliqua^{-1}, Seed yield (kg ha^{-1}), 1000 seed weight (g), oil content (%) and oil yield (kg ha^{-1}) in mustard

Treatments	Plant stand	No. of silique plant^{-1}	No. of seeds siliqua^{-1}	Seed yield	1000 seed weight	Oil content	Oil yield
Weed control							
Weedy check	8.26	149.1	8.7	1367	4.66	36.92	508
One HW at 25 DAS	8.45	229.8	10.6	2127	5.63	40.39	864
Two HW at 25 and 45 DAS	9.02	257.8	11.6	2493	5.87	41.07	1029
Pendimethalin @ 0.75 kg ha^{-1} (PE)	8.92	234.0	11.9	2162	5.68	40.90	888
Isoproturon @ 1.0 kg ha^{-1} (PE)	8.53	200.4	9.6	1836	5.17	37.80	697
Oxyfluorfen @ 0.125 kg ha^{-1} (PE)	8.42	178.0	8.8	1584	4.76	37.13	592
Trifluralin @ 0.75 kg ha^{-1} (PPI)	8.67	210.3	9.8	1908	5.31	40.05	769
SEm±	0.18	4.11	0.2	41.34	0.07	0.61	18
CD (*p*=0.05)	NS	11.99	0.5	120.67	0.22	1.79	52
Sulphur levels (kg ha^{-1})							
0	8.36	154.7	7.4	1428	12.91	37.07	533
20	8.63	215.9	10.5	1995	10.87	38.75	782
40	8.69	230.1	11.2	2109	12.23	40.42	855
60	8.75	233.2	11.5	2167	12.27	40.47	885
SEm±	0.11	2.89	0.1	27.10	0.16	0.37	13
CD (*p*=0.05)	NS	8.13	0.3	76.21	0.46	1.04	35
Interaction (WxS)				NS		NS	Sig.

NS= Non significant

and herbicidal measures on protein and oil content of mustard have also been reported by Sewak et al. (2004) and Sah et al. (2013). Higher oil content coupled with higher seed yield further resulted into significantly higher yield of oil under these superior treatments.

Data showed (Table 5) that output energy (151500 MJ ha^{-1}), output input energy ratio (13.65), energy use efficiency (0.225kg MJ^{-1}) and energy balance (140430 MJ ha^{-1}) was obtained significantly maximum in two HW at 25 and 45 DAS. Among the herbicidal treatment output energy (132250 MJ ha^{-1}), maximum output input energy ratio (12.17), energy use efficiency (0.199 kg MJ^{-1}) and energy balance (121409) was obtained maximum with pendimthalin @ 0.75 kg ha^{-1} which was at par with one HW at 25 DAS. Maximum input energy was obtained in two HW at 25 and 45 DAS which was followed by pendimethalin @ 0.75 kg ha^{-1}.

3.2. *Effect of sulphur fertilization*

Results showed that increasing levels of S fertilization significantly increased the seed yield of mustard up to 40 kg ha^{-1} over lower levels (Table 3). Pooled results showed that application of sulphur at 40 kg ha^{-1} provided the seed yield 2109 kg ha^{-1} that was 5.7 and 47.7% more than obtained under 20 kg S ha^{-1} and control, respectively. However, it was found at par with 60 kg S ha^{-1} which also increased the seed yield by magnitude of 172 and 739 kg ha^{-1}over 20 kg ha^{-1} and control, respectively. The increase in attributes with increasing rate of sulphur is ascribed to its role in synthesis of protein and vitamins. Beneficial effect of sulphur on yield attributes might be due to better availability of N, K and S and their translocation which was reflected in terms of increased yield attributes of the crop. Thus, S fertilization stimulated seed setting and enhanced the siliquae bearing and seeds siliqua^{-1}. The improved growth and branching due to S fertilization coupled with increased photosynthates on one hand and greater mobilization of photosynthates towards reproductive structures on the other, might have been responsible for improvement in yield attributes of mustard. As sulphur is found in seed and siliqua in large amount which is considered essential for seed formation and boldness of seeds. As seed yield is primarily a function of cumulative effect of yield attributing characters, the higher values of these attributes can be assigned as the most probable reason for significantly higher seed yield. It is well evidenced from the positive correlation between crop dry matter and nutrient uptake by the crop. Piri and Sharma (2006), Kumar and Yadav (2007), Jat and Mehra (2007) Basumatary and Talukdar, 2011, Mohammad et al., 2012, Piri et al., 2012 and Singh et al., 2013 have also documented significant and positive influence of sulphur application on yield attributes and yield of mustard crop.,

Table 3: Combined effect of weed control and sulphur levels on oil yield (kg ha^{-1}) in mustard

Weed control	Sulphur levels (kg ha^{-1})			
	S_0	S_{20}	S_{40}	S_{60}
W_0=Weedy check	345	512	606	568
W_1=One HW at 25 DAS	577	958	943	979
W_2=Two HW at 25 & 45 DAS	714	1078	1116	1208
W_3=Pendimethalin @ 0.75 kg ha^{-1} (PE)	625	940	965	1022
W_4=Isoproturon @ 1.0 kg ha^{-1} (PE)	509	714	774	790
W_5=Oxyfluorfen @ 0.125 kg ha^{-1} (PE)	431	545	683	707
W_6=Trifluralin @ 0.75 kg ha^{-1} (PPI)	529	727	897	921
For S at same level of W				
SEm+				33
CD (p=0.05)				93
For W at same or different levels of S				
SEm±				34
CD (p=0.05)				96

Mustard crop also responded favourably to S fertilization in terms of crop dry matter production, CGR and RGR. Pooled results showed that every increase in level of sulphur brought about significant enhancement in dry matter up to 40 kg ha^{-1}over preceding levels at all the stages of crop growth during both the year of study. It increased the dry matter by margin of 7.9, 13.3 and 25.2% over 20 kg ha^{-1} and 21.1, 47.3 and 39.6% over control, respectively in pooled analysis at these three stages. However, it showed statistical equivalence with 60 kg ha^{-1}, wherein, the maximum dry matter of 28.2, 87.4 and 223.3 kg ha^{-1} at 30, 60 DAS and at harvest stages was recorded, respectively. Progressive increase in level of sulphur up to 40 kg ha^{-1} recorded significantly higher CGR values over preceding levels. It improved the CGR by margin of 7.80, 16.15 and 34.16% over 20 kg S ha^{-1} and 21.11, 64.10 and 34.46% over control during 0–30 DAS, 30–60 DAS and 60 DAS- at harvest stages, respectively. However, it was found at par with 60 kg S ha^{-1}. Resultsshowed (Table 2) that RGR exhibited an increasing trend with corresponding increase in levels of sulphur during 30–60 DAS period. Application of sulphur at 40 kg ha^{-1} recorded the mean RGR value of 37.28 mg g^{-1} day^{-1} and thus increased it by 5.5 and 17.5% over 20 kg ha^{-1} and control, respectively. However, it was found at par with 60 kg S ha^{-1}, wherein, maximum RGR of 37.37 mg g^{-1} day^{-1} was noted. On the other hand, during 60 DAS-at harvest, minimum RGR was noted at 20 kg S ha^{-1}. Being at par with each other, sulphur fertilization at 40 and 60 kg ha^{-1} increased it by 12.5 and 12.9%, respectively. As sulphur is one of the essential plant nutrients required for growth. Therefore, overall growth with the application of sulphur in deficient soil could be ascribed to its pivotal role in several physiological and biochemical processes which are of vital importance for development of the plants. The increase in these parameters could be ascribed to the overall improvement in plant vigour and production of sufficient photosynthates through increase in leaf area and chlorophyll content of leaves with applied sulphur (Tandon, 1991). 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. (These results are in agreement with the findings of Pachauri and Trivedi, 2012; Mohammad et al., 2012; Piri et al., 2012; Begum et al., 2012.

Pooled data showed that every increase in level of S resulted in significant higher oil content and oil yield up to 40 kg S ha^{-1} over lower levels. Application of sulphur at 40 kg ha^{-1} recorded the mean oil yield of 855 kg ha^{-1} which was higher by 9.3 and 60.4% over 20 kg S ha^{-1} and control. Maximum per cent oil content and oil yield (855 kg ha^{-1}) was achieved with 60 kg S ha^{-1} which was at par with 40 kg S ha^{-1}. The increase in oil content due to sulphur fertilization might be the outcome of better availability of nutrients owing to favourable environment created by sulphur application.As sulphur is an integral part of oil, the increased availability of it might have favourably influenced the synthesis of essential metabolites responsible for higher oil content.

3.2.1. Interaction

Data showed that weed control treatments differed significantly in providing oil yield in mustard under integration with different levels of sulphur fertilization (Table 3). In weedy check and trifluralin treatments, response to applied S was noted significant up to 40 kg ha^{-1}. Whereas in rest of the treatments, it was observed up to 20 kg S ha^{-1}. However, the maximum oil yield under all the treatments was obtained when they were integrated with 60 kg S ha^{-1}. Two hand weeding treatment combined with 60 kg S ha^{-1} (W_2S_{60}) recorded the maximum oil yield of 1208 kg ha^{-1}. However, it was found at par with W_2S_{40}. Being at par with each other, these two combinations increased the oil yield by 863 and 771 kg ha^{-1}, respectively over W_0S_0, wherein the lowest oil yield of 345 kg ha^{-1} was obtained.

Every increase in sulphur level output energy, output input energy ratio, energy use efficiency and energy balance significantly increases up to 40 kg S ha^{-1}. Maximum output energy (135918 MJ ha^{-1}), output input energy ratio (12.26), energy use efficiency (0.195 kg MJ^{-1}) and energy balance (124856 MJ ha^{-1}) was achieved with the sulphur

3.3. Response studies

Seed yield (Y) as a function of sulphur fertilization ($Y=b_0+b_1X+b_2X^2$)

To describe the relationship between seed yield and applied sulphur, multiple regression studies were undertaken (Table 4 and Figure 1). This relationship of type ($Y=b_0+b_1S+b_2S^2$) describing seed yield (Y) as a function of main effects of S levels showed a curvilinear trend expressed as a second degree polynomial in sulphur. The predicted yield work out from this

Table 4: Seed yield (Y) as a function of sulphur (S) fertilization ($Y=b_0+b_1.S+b_2.S_2$) (pooled mean of two years)

Study parameters	
1. Partial regression coefficients	
b_0	1448
b_1	30.72**
b_2	-0.317*
2. Coefficients of	
i. Determination (R^2)	0.977**
ii. Multiple correlation (R)	0.977**
3. Optimum level of S (kg ha^{-1})	48.28
4. Yield at optimum level (kg ha^{-1})	2192.25
5. Response of optimum level (kg ha^{-1})	744.25
6. Response per kg S at Optimum level	15.41
7. Response per kg S at S_{40} level	18.04

The yield, S levels, responses and intercepts are given in kg ha^{-1}; *: Significant at (p=0.05) level of significance; **: Significant at (p=0.01) level of significance

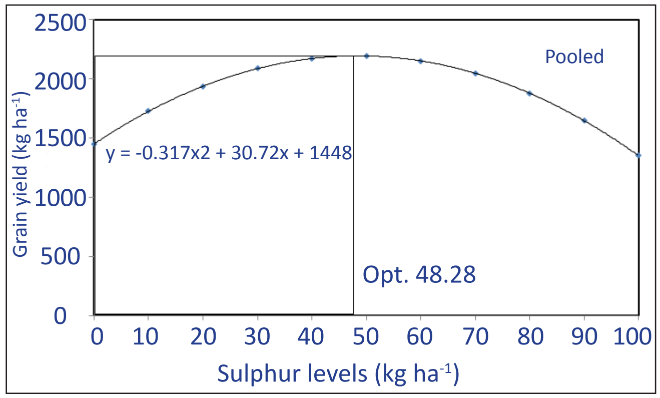

Figure 1: Seed yield of mustard (Y) as a function of sulphur fertilization

quadric function showed very high closeness to the observed data as evidenced from very high value of R^2 during both the years and in the mean data (0.977). The regression coefficient of second order function were fitted for two seasons. Mean data were found to be highly significant. A mean level of 48.28 kg S ha^{-1} was found to be optimum with seed yield of 2192.25 kg ha^{-1} and a mean response of 18.04 kg ha^{-1}.

Table 5: Effect of weed control and sulphur levels on energetics of mustard

Treatments	Output energy (MJ ha^{-1})	Input Energy (MJ ha^{-1})	Output input energy ratio	Energy Use efficiency (kg MJ^{-1})	Energy Balance (MJ ha^{-1})
Weed control					
Weedy check	89988	10505.3	8.55	0.130	79482
One HW at 25 DAS	131006	10787.9	12.11	0.197	120218
Two HW at 25 and 45 DAS	151500	11070.5	13.65	0.225	140430
Pendimethalin @ 0.75 kg ha^{-1} (PE)	132250	10840.6	12.17	0.199	121409
Isoproturon @ 1.0 kg ha^{-1} (PE)	116488	10700.2	10.86	0.171	105787
Oxyfluorfen @ 0.125 kg ha^{-1} (PE)	102388	10604.3	9.63	0.149	91783
Trifluralin @ 0.75 kg ha^{-1} (PPI)	118681	10727.8	11.03	0.177	107953
SEm+	2611	-	0.24	0.004	2611
CD (p=0.05)	7622	-	0.70	0.011	7622
Sulphur levels (kg ha^{-1})					
0	91118	10433.9	8.72	0.137	80685
20	122064	10643.4	11.44	0.187	111421
40	132214	10852.8	12.16	0.194	121361
60	135918	11062.2	12.26	0.195	124856
SEm+	1734	-	0.16	0.002	1734
CD (p=0.05)	4875	-	0.45	0.007	4875

4. Conclusion

Two HW at 25 and 45 DAS was more productive (2493 kg ha^{-1}) and remunerative as compared to another weed control treatment. Pendimethalin @ 0.75 kg ha^{-1} was next better management practice (2162 kg ha^{-1}). Sulphur level 60 kg ha^{-1} S ha^{-1} was more productive (2167 kg ha^{-1}) and remunerative management practice. Thus, for obtaining maximum production and profit pendimethalin @ 0.75 kg ha^{-1} along with 60 kg S ha^{-1} might be best managementpractice.

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