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Research Paper

Effect of moisture conservation and sulphur sources on productivity and water use efficiency of Indian mustard (*Brassica juncea*) under rainfed conditions

J.P. TETARWAL[1], BALDEV RAM[2], D.S. MEENA[3] AND S.S. TOMAR[4]

Agricultural Research Sub Station of Maharana Pratap University of Agriculture & Technology, Aklera, Jhalawar, Rajasthan 326 033

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ABSTRACT

A field experiment was conducted during *rabi* 2008-09 and 2009-10 at Aklera, Jhalawar to find out the best moisture conservation practice and sulphur source for increasing productivity, profitability and water use efficiency (WUE) of Indian mustard [*Brassica juncea* (L.) Czern. & Coss] under rainfed conditions. Straw mulch @ 4 t/ha applied at 21 DAS + kaolin 6% spray at 60 DAS significantly increased the growth, yield attributes, seed (1.65 t/ha), oil yield (629.3 kg/ha), nutrients (NPS) uptake and net return (₹20,197/ha) compared to other moisture conservation practices. Amongst the sulphur sources, bentonite sulphur gave significantly higher growth, yield attributes, seed yield (1.50 t/ha), oil yield (568.3 kg/ha), nutrients (NPS) uptake, net return (₹18,948/ha) and B: C ratio (1.18) than other sources of sulphur. Maximum production and economic efficiencies, consumptive use (212 mm), rate of moisture use (1.55 mm/day) and water use efficiency (7.80 kg/ha-mm) were with straw mulch 4 t/ha + kaolin 6% spray over no mulch. Application of bentonite sulphur gave higher production and economic efficiencies, consumptive water use (208 mm), rate of moisture use (1.52 mm/day) and water use efficiency (7.22 kg/ha-mm) than to gypsum and wettable sulphur.

***Key words*:** Indian mustard, Moisture conservation, Sulphur sources, Water use efficiency.

Indian mustard is the most important *rabi* season oilseed crop of Rajasthan. It is grown in 2.21 million ha with a production of 2.91 million tonnes and 1316 kg/ha of average productivity (Anonymous, 2009-10). Due to changing of climatic conditions, number of rainy days has reduced, drastically along with total rainfall during the monsoon period (July to September). Mustard is mainly grown under limited availability of moisture at critical stages of crop growth with poor nourishment. Generally farmers shall not be interested to fallow their land during rainy season and take a short duration crop followed by mustard but rainfall pattern and duration plays a major role for success or failure of the next *rabi* season crop. Under such situations, moisture conservation is a prime factor for enhancing the mustard yield. There is a need to manage the limited available irrigation water and stored soil profile moisture through agronomic management practices, to harvest good yield. For efficient utilization of soil moisture under *vertisol* condition, moisture conservation practices plays a significant role in increasing the mustard productivity by economizing the use of limited irrigation or rain water as well as boosting use efficiencies of nutrients and water (Mahey *et al*. 1986). Organic mulches are poor conductor of heat that effectively reduces soil temperature and also maintain soil moisture in deeper layers for longer period (Vaidya *et al*. 1995), so that the production of mustard under rainfed condition may be enhanced by reducing the unproductive loss of soil moisture through surface evaporation and weed growth, which may be arrested by application of suitable moisture conservation practices. Use of anti-transpirant like kaolin (6%) can be a way in economizing water and making it more available to the plant for growth and reducing terminal heat stress at later stages of seed development.

Sulphur fertilization through various sources to mustard showed superiority in enhancing seed yield and other ancillary characters. Sulphur enhances the cellular activity, photosynthetic efficiency, meristamatic activity leads to tissue differentiation from somatic to reproductive and development of floral primordial, stimulated reproductive period and ultimately seed yield of mustard. Sulphur play a significant role in oilseed crops particularly where the

[1]**Corresponding author Email:** jptetarwal@gmail.com

[1,2&3]Assistant Professor (Agronomy), [4]Professor (Agronomy) & Zonal Director Research, Agricultural Research Station, Ummedganj, Kota (Rajasthan).

sink material is largely sulphur containing amino acids. It also has specific vital role in growth, development and quality of oilseed crops. Keeping this in view, a field experiment was conducted to find out suitable moisture conservation practice and source of sulphur for enhancing productivity and profitability of mustard.

MATERIALS AND METHODS

A field experiment was conducted during two consecutive *rabi* seasons (2008-09 and 2009-10) at Agricultural Research Sub-Station, Aklera, Jhalawar (Rajasthan) to find out the best moisture conservation practice and sulphur source for increasing productivity of mustard under rainfed conditions. The experiment was carried out in split plot design comprising six moisture conservation practices *viz*; no mulch (no hoeing/straw), straw mulch 4 t/ha, soil mulch (hoeing done at 30 DAS), *in-situ* mulching with weeds, kaolin 6% spray at 45 and 60 days after sowing (DAS) and straw mulch 4 t/ha + kaolin 6% spray (60 DAS) in main plots and three sulphur sources *viz*; gypsum, wettable sulphur and bentonite sulphur in sub-plots with three replications. The soil of the experimental field was clay loam, slightly alkaline in reaction (pH 7.4), medium in organic carbon (7.1 g/kg) and available phosphorus (27.7 kg/ha), high in available potassium (256.0 kg/ha) and low in available sulphur content (17.3 kg/ha). Indian mustard 'Pusa Jai Kishan (Bio-902)' was sown at 30 cm × 10 cm on 26 October, 2008 and 16 October, 2009 by adopting standard package of practices. The recommended dose of fertilizers (RDF) for rainfed mustard in south eastern parts of Rajasthan is 40 kg N, 20 kg P and 30 kg S/ha was given in the form of diammonium phosphate and urea before sowing. Sulphur was applied through gypsum (13% Agri grade), wettable sulphur (80%) and bentonite sulphur (90%) and drilled in earmarked plots before sowing. The total rainfall received during rainy season and crop growth period was 679 and 11 mm in 2008-09 and 677 and 86 mm in 2009-10, respectively. The treatment wise moisture conservation practices were done in earmarked plots i.e. soybean straw 4 t/ha (dry weight basis) was spread uniformly over the soil surface at 21 DAS as a mulch, soil mulch (breaking of capillaries with the help of narrow iron spade "kudali"), *in-situ* weed mulching at 30 DAS (uprooting of weeds and spread in between the rows and calculated their fresh biomass at the time of weeding, it was kept @ 3 kg/m^2 on fresh weight basis in all the three replications using *ex-situ* weeds namely *chenopodiun album, C. murale, A. tenuifolius, C. arvensis, Avena fatua* etc. Kaolin (6% suspension) was sprayed on crop foliage at 45 and 60 DAS as anti-transpirant (using knapsack sprayer fitted with holo cone nozzle). The crop was harvested at physiological maturity stage on 8 March, 2009 and 4 March, 2010.

Production indices like production, economic and water use efficiency were worked out to evaluate the crop and water efficiencies. Soil moisture was determined at 25 days interval in rainless period from three soil depths *viz;* 0-25, 26-50 and 51-75 cm commencing from sowing to harvesting with the help of tube auger. Seasonal consumptive use of water for the entire growing season of crop was estimated. Soil moisture percentage was determined by using gravimetric method after oven drying the samples at 105 ^{o}C for 24 hours. The consumptive use of water by the crop under different treatments was computed by formulae described by Dastane (1972). Similar results were obtained in both the years hence, pooled analysis was done. No significant interaction was found between moisture conservation practices and sulphur sources thus, interaction was not presented.

RESULTS AND DISCUSSION

Growth and yield attributes

Moisture conservation practices indicated significant differences for growth and yield parameters of mustard under rainfed conditions (Table 1). Straw mulch 4 t/ha + kaolin 6% spray at 60 DAS recorded significantly higher values of plant height, dry-matter accumulation, number of primary and secondary branches per plant compared to other moisture conservation practices. However, application of straw mulch 4 t/ha alone also proved significantly superior in growth parameters over no mulch, kaolin 6% spray and soil mulch but remained on par with *in-situ* mulch with weeds. It may be due to more availability of moisture during crop growth and high water status in the root zone. Application of sulphur 30 kg/ha in the form of bentonite sulphur recorded significantly higher plant height, dry-matter/plant, number of primary and secondary branches/plant over gypsum and wettable sulphur. It was increased to the tune of 6.94, 20.22, 19.48 and 14.31 over gypsum and 4.93, 11.87, 10.99 and 8.24 over wettable sulphur. This may be due to that after mixing in the soil, bentonite easily mixed with moisture and makes sulphur available to the plants for long durations, it helps in increasing the chlorophyll content and production of vitamin content in the plants. Sutar and Kumar (2012) reported that sulphur application through bentonite recorded significantly higher 100 grain weight and grain weight/cob of maize, mainly associated with higher uptake of primary nutrients (NPK) as a result of positive interaction with applied S through bentonite. However, application of sulphur in the form of gypsum or wettable sulphur found statistically on par with each other and wettable sulphur showed superiority compared to gypsum.

Moisture conservation practices enhanced all the yield

attributes of mustard over no mulch (Table 1). Significantly higher number of siliquae/plant, number of seeds/siliqua, length of siliqua and 1000-seed weight were recorded with application of straw mulch 4 t/ha + kaolin 6% spray at 60 DAS than other moisture conservation practices. The next best treatment was straw mulch 4 t/ha alone which was statistically on par with *in-situ* mulch with weeds. Singh and Rana (2006) also reported that moisture conservation through FYM + organic mulch + kaolin spray (6%) increased dry-matter accumulation, leaf-area index and length of siliqua in mustard. Amongst the sources of sulphur, bentonite sulphur recorded maximum and significantly higher siliquae/plant, seeds/siliqua, length of siliqua and 1,000-seed weight and per cent increase was 10.8 and 7.0, 19.9 and 14.4, 16.2 and 10.8, 14.6 and 9.6 over gypsum and wettable sulphur, respectively. This might be due to moisture holding capacity of bentonite in clay soils and maintained moisture for longer period in the crop root zone thus increased the yield attributes of mustard. Blake-kalff *et al*. (1998) reported that sulphur containing non-protein thiol compound help in protection of plant against varied environmental stresses.

Yield

Seed and stover yields of mustard were significantly influenced by moisture conservation practices (Table 2). Straw mulch 4 t/ha + kaolin 6% spray at 60 DAS recorded maximum seed and stover yield (769 and 1158 kg/ha higher over no mulch, respectively) and was significantly superior to rest of the moisture conservation practices. However, application of straw mulch 4 t/ha alone was the next best treatment of moisture conservation and recorded higher seed yield (592, 152 and 119 kg/ha over no mulch, kaolin spray and soil mulch, respectively) and was statistically on par with *in-situ* mulch with weeds. The increase in seed and stover yields were due to incremental increase in growth parameters and yield attributes thus enhanced higher production. This might be due to the combined effects of straw mulch i.e. slowed down the energy exchange at soil surface, thermal diffusion and provided temperature insulation, making uniform soil temperature that minimized evaporation losses (Vaidya *at al*., 1995) and kaolin (6%) spray i.e. effectively reducing the transpiration losses (Kaushik and Lal, 1997). These results are in agreement with the findings of Singh and Rana (2006). Amongst the sulphur sources, bentonite sulphur gave significantly higher seed (1.50 t/ha) and stover yield (3.59 t/ha) and registered increased to the tune of 262, 316 and 185 and 291 kg/ha over gypsum and wettable sulphur, respectively. This might be attributed to better growth and development of plant owing to higher moisture and biological solubility of S in bentonite sulphur thus, rapid spread of sulphur with large surface area and effective oxidation into sulphuric acid ultimately yielded higher values. Sutar and Kumar (2012) found that application of 40 kg S/ha through bentonite significantly increased grain yield of maize. Field studies conducted under AICRP of micro and secondary nutrients and results showed that bentonite-S significantly increased the yield over S control (Anonymous, 2010-11). Similarly, results at PAU, Ludhiana on station and farmers filed at Ropar and Hoshiarpur showed that 6% increased in mustard yield over S control.

Table 1. Effect of moisture conservation practices and sources of sulphur on growth and yield attributes of Indian mustard (Pooled data of two years).

Treatment	Plant height (cm)	Dry matter (g/plant)	Branches/plant		Siliquae/ Plant (No)	Seeds/ siliqua (No)	Length of siliqua (cm)	1,000-seed weight (g)
			Primary	Secondary				
Moisture conservation								
No mulch	147.7	37.2	3.8	9.1	219.3	11.9	3.7	5.0
Straw mulch 4 t/ha	172.9	48.2	5.0	11.7	258.8	15.5	4.9	5.9
Soil mulch	162.7	43.1	4.6	10.9	241.7	14.1	4.3	5.5
In-situ mulch with weeds	167.3	44.9	4.7	11.1	252.7	14.6	4.8	5.8
Kaolin 6 % spray	161.7	41.8	4.6	10.8	238.6	13.6	4.1	5.2
Straw mulch + Kaolin spray	183.6	53.5	5.4	12.6	281.6	16.9	5.4	6.3
SEm±	3.18	1.59	0.12	0.21	5.24	0.30	0.11	0.12
CD (P=0.05)	10.03	5.02	0.37	0.67	16.52	0.95	0.36	0.38
Sulphur sources								
Gypsum	161.2	41.0	4.3	10.3	237.4	13.4	4.3	5.4
Wettable sulphur	164.3	44.1	4.6	10.9	245.8	14.0	4.5	5.5
Bentonite sulphur	172.4	49.3	5.2	11.8	263.1	16.0	4.9	6.0
SEm±	2.23	1.68	0.12	0.17	3.17	0.24	0.08	0.06
CD (P=0.05)	6.51	4.90	0.34	0.50	9.24	0.69	0.24	0.17

Economics

Maximum and significantly higher net return (₹20,197/ha) and B: C ratio (1.14) was recorded with straw mulch 4 t/ha + kaolin 6% spray than rest of the treatments except benefit: cost ratio was found satistically on par with straw mulch 4 t/ha and *in-situ* mulch with weeds. It was registered increased net return to the tune of (₹12,864/ha) and ₹5,894/ha over no mulch and kaolin 6% spray, respectively. The next best treatment was straw mulch 4 t/ha which recorded ₹10,215/ha higher net return over no mulch while, it remained on par with *in-situ* mulch with weeds and soil mulch in terms of net return and B: C ratio. Higher net return might be due to higher yield and low cost of cultivation. Sulphur application in the form of bentonite sulphur gave maximum and significantly higher net return (₹18,948/ha) and B: C ratio (1.18) than gypsum and wettable sulphur except B: C ratio with gypsum was at par. It was registered higher to the tune of ₹3,752/ha and ₹7,721/ha over gypsum and wettable sulphur, might be probably due to lower cost of cultivation of bentonite sulphur and higher values of yield attributes and yield of mustard thus recorded maximum net return and B: C ratio.

Quality and nutrient uptake

Moisture conservation practices and different sources of sulphur influenced the oil content but could not being up to statistically significant whereas, oil yield was found statistically significant (Table 2). Significantly higher oil yield (629.3 kg/ha) was recorded with straw mulch 4 t/ha + kaolin 6% spray than rest of the moisture conservation practices and it was increased to the tune of 93.7 % over no mulch. The next best treatment was straw mulch 4 t/ha alone also recorded significantly higher oil yield (557.2 kg/ha) remained on par with *in-situ* mulch with weeds over no mulch, kaolin 6% spray and soil mulch, respectively. Amongst the sulphur sources, bentonite sulphur recorded maximum and significantly higher oil yield (568.3 kg/ha) of mustard and it was increased to the tune of 104.3 and 75.3 kg/ha over gypsum and wettable sulphur, respectively. Oil yield is a function of oil content and seed yield and both the parameters increased with different moisture conservation practices as well as sulphur sources, thus resulted in a significant increase in oil yield. Similar findings were given by Singh and Kumar (1996) and Singh and Meena (2004).

Moisture conservation practices enhanced the total N, P and S uptake of mustard (Table 2). Application of straw mulch 4 t/ha + kaolin 6% spray recorded significantly higher total N, P and S uptake over rest of the moisture conservation practices. Whereas, straw mulch 4 t/ha also recorded significantly higher total N, P and S uptake than no mulch, kaolin 6% spray, soil mulch and *in-situ* mulch with weeds. This could be attributed to higher seed and stover yields coupled with slight improvement in nutrient content and apparently due to increased availability of water to the plants. Singh and Rana (2006) reported that moisture conservation through organic mulch + kaolin 6% spray increased total nutrient uptake over no mulch of mustard. Appreciable improvement in nutrient uptake mustard was influenced by sources of sulphur (Table 2).

Table 2. Effect of moisture conservation practices and sources of sulphur on yield, economics, oil content and nutrient uptake of Indian mustard (Pooled data of two years).

Treatment	Yield (t/ha)		Net return ($\times 10^3$ ₹/ha)	B: C ratio	Oil content (%)	Oil yield (kg/ha)	Total nutrient uptake (kg/ha) by crop		
	Seed	Stover					N	P	S
Moisture conservation									
No mulch	0.88	2.78	7.33	0.58	36.8	324.9	35.6	10.4	7.1
Straw mulch 4 t/ha	1.48	3.58	17.55	1.09	37.8	557.2	64.5	17.4	12.3
Soil mulch	1.36	3.26	14.99	0.95	37.5	508.5	54.2	15.0	10.3
In-situ mulch with weeds	1.42	3.41	16.37	1.02	37.7	535.0	58.6	16.2	11.1
Kaolin 6 % spray	1.32	3.11	14.30	0.90	37.5	495.8	52.9	14.1	9.7
Straw mulch + Kaolin spray	1.65	3.93	20.20	1.14	38.0	629.3	76.7	20.5	14.3
SEm±	0.04	0.09	0.82	0.04	-	14.9	1.36	0.36	0.32
CD (P=0.05)	0.12	0.28	2.60	0.13	NS	46.8	4.27	1.12	1.02
Sulphur sources									
Gypsum	1.24	3.14	15.20	1.10	37.4	464.0	52.0	14.0	9.3
Wettable sulphur	1.32	3.30	11.23	0.57	37.4	493.0	55.5	15.2	10.5
Bentonite sulphur	1.50	3.59	18.95	1.18	37.8	568.3	63.7	17.6	12.6
SEm±	0.04	0.06	0.86	0.05	-	13.7	1.40	0.38	0.27
CD (P=0.05)	0.11	0.17	2.50	0.15	NS	40.1	4.09	1.11	0.80

Price:-Mustard seed: ₹22,000/t, Mustard stover: ₹500/t, Gypsum: ₹1.10/kg, Wettable sulphur: ₹160/kg, Bentonite sulphur: ₹75/kg, Kaolin ₹60/kg

Amongst the sulphur sources, bentonite sulphur recorded highest uptake of N, P and S to the tune of 11.77, 3.65 and 3.30 kg/ha over gypsum and 8.21, 2.39 and 2.16 kg/ha over wettable sulphur. Nutrient uptake by mustard is mainly a function of yield and nutrients concentration in seed and stover. It might be because of nutrient uptake is correlated with yield which in turns resulted in increase in dry matter and nutrient uptake. The concentration of S in seed and stover is also increased due to sulphur fertilization because it improved nutritional environment in rhizosphere and consequently plant system. The results confirm the findings of Singh and Meena (2004). Sutar and Kumar (2012) also recorded a higher uptake of N, P and K as a result of positive interaction with applied S through bentonite in maize.

Production and economic efficiency

Application of straw mulch 4 t/ha + kaolin 6% spray recorded highest production (12.07 kg/ha/day) and economic efficiency (₹147.43 /ha/day) which was 87.1 and 175.5% higher over no mulch, respectively (Table 3). The next best treatment was straw mulch 4 t/ha alone which was recorded significantly higher production (10.77 kg/ha/day) and economic efficiency (₹128.09 ha/day) than no mulch and kaolin 6% spray except *in-situ* mulch with weeds and soil mulch were found statistically on par. This might be due to higher seed and stover yield owing to increased production and economic efficiencies.

Bentonite sulphur gave significantly higher production and economic efficiency and per cent increase was to the tune of 21.2 and 24.7 and 14.2 and 68.8 over gypsum and wettable sulphur, respectively. Application of gypsum recorded higher economic efficiency due to its lower cost of cultivation but production efficiency was found at par with wettable sulphur. It could be ascribed to higher values of indices and lower cost of production in respect of treatments thus recorded higher production efficiencies.

Moisture use pattern

The maximum consumptive water use (212 mm), water use efficiency (7.80 kg/ha-mm) and rate of moisture use (1.55 mm/day) were observed under straw mulch 4 t/ha + kaolin 6% spray followed by straw mulch 4 t/ha (204 mm, 7.24 kg/ha-mm, 1.49 mm/day) and minimum with no-mulch (176 mm, 5.02 kg/ha-mm and 1.28 mm/day) (Table 3). The moisture conservation practices hold more moisture in soil profile due to reduction of evapotranspiration losses thus, increased the available soil moisture and water holding capacity which ultimately enhanced the crop growth and yield attributes. These results are in agreement with Singh and Rana (2006). Amongst sources of sulphur, application of bentonite sulphur recorded higher consumptive water use (208 mm), water use efficiency (7.22 kg/ha-mm) and rate of moisture use (1.52 mm/day) than gypsum and wettable sulphur. It owed due to binding capacity of bentonite-S and holds more moisture in the soil profile thus, increased crop parameters.

Moisture conservation practices markedly influenced the soil moisture extraction pattern in mustard grown under rainfed conditions (Table 3). Maximum soil moisture depletion (48.76%) was registered from top soil layer (0-25 cm) in no-mulch while, least (45.80%) was recorded

Table 3. Effect of moisture conservation practices and sources of sulphur on production & economic efficiency, water use efficiency and moisture extraction pattern of Indian mustard (Pooled data of two years).

Treatment	Production efficiency (kg/ha/day*)	Economic efficiency (₹/ha/day)	Consumptive use (mm)	Water use efficiency (kg/ha-mm)	Rate of moisture use (mm/day)	Moisture extraction pattern (%)		
						0-25 cm	26-50 cm	51-75 cm
Moisture conservation								
No mulch	6.45	53.52	176	5.02	1.28	48.76	29.45	21.79
Straw mulch 4 t/ha	10.77	128.09	204	7.24	1.49	46.95	30.38	22.67
Soil mulch	9.91	109.42	196	6.92	1.43	47.31	30.19	22.50
In-situ mulch with weeds	10.34	119.50	192	7.38	1.40	47.48	30.12	22.40
Kaolin 6 % spray	9.66	104.40	200	6.62	1.46	47.02	30.34	22.64
Straw mulch + Kaolin spray	12.07	147.43	212	7.80	1.55	45.80	30.06	23.14
SEm±	0.27	6.02	-	-	-	-	-	-
CD (P=0.05)	0.87	18.95	-	-	-	-	-	-
Sulphur sources								
Gypsum	9.04	110.92	180	6.88	1.31	47.88	30.45	21.67
Wettable sulphur	9.60	81.95	186	7.08	1.36	47.72	30.56	21.72
Bentonite sulphur	10.96	138.30	208	7.22	1.52	47.05	30.90	22.05
SEm±	0.28	6.26	-	-	-	-	-	-
CD (P=0.05)	0.81	18.28	-	-	-	-	-	-

*Mean crop duration 137 days

with straw mulch 4 t/ha + kaolin 6% spray. It might be due to slow canopy development which exposed soil surface to solar radiation leading to higher evaporation from top layer in no-mulch treatment. However, the reverse trend was observed in deeper soil layer from 26-50 and 51-75 cm and maximum depletion of soil moisture was recorded under straw mulch 4 t/ha + kaolin 6% spray (30.06 and 23.14%) followed by straw mulch 4 t/ha (30.38 and 22.67%) and least with no-mulch (29.45 and 21.79%). This was due to higher moisture available in the deeper soil layers under different moisture conservation treatments compared to no-mulch under rainfed conditions. These results corroborate the findings of Awasthi *et al*. (2007). Amongst the sulphur sources upper soil layer 0-25 cm did not exhibits the variation in extraction pattern but lower layers of 26-50 and 51-75 cm, bentonite sulphur showed higher values than gypsum and wettable sulphur, which was due to holding the more moisture by bentonite and makes available to the crop for longer period.

Thus, study suggests that mustard can be successfully grown under rainfed conditions by use of straw mulch 4 t/ha (21 DAS) + kaolin 6% spray at 60 DAS along with bentonite sulphur and harvest maximum productivity, profitability and water use efficiency.

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