Indian Journal of Agronomy **67** (1): 67–72 (March 2022)

Research Paper

Performance of cultural and mechanical practices on weed-control efficiency, productivity and economics of Indian mustard (*Brassica juncea*) under organic production

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Received: December 2021; Revised accepted: March 2022

ABSTRACT

A field experiment was carried out during winter (*rabi*) season of 2017–18 and 2018–19 at the research farm of ICAR-Indian Institute of Farming Systems Research, Modipuram, Meerut, Uttar Pradesh, India, to study the effect of different weed-management practices on weed density, productivity and economics of Indian mustard under organic production. Eight cultural and mechanical weed-management practices, comprising hand-weeding, mechanical weeding, intercropping with chickpea (*Cicer arietinum* L.) (additive series), stale seedbed (SSB), reduced spacing, soil solarization using 25 μ transparent polythene sheet and mulching with different crop and weed residues area adopted. Among the different weed species, purple nut sedge (*Cyperus rotundus* L.) was dominant weed species and represented around 70% population of total weed density. At 20 days after sowing (DAS), the lowest weed density and the highest weed-control efficiency were found under soil solarization with 25 μ transparent polythene sheet + hand-weeding (HW) at 40 DAS, followed by SSB + reduced spacing (30 cm) + maize (*Zea mays* L.) straw mulching @ 5 t/ha + HW at 40 DAS treatment. An intercropping of Indian mustard with chickpea (1 : 1 additive series) also proved better for weed management with 6.8% weed-control efficiency as compared to the manual weeding. Yield attributes, viz. branches/plant (5.7), siliquae/plant (307), seeds/siliqua (14.6) and seed yield (3,527 kg/ha) were highest under application of Indian mustard oil cake @ 5 t/ha + HW at 40 DAS. The intercropping of Indian mustard + chickpea (1 : 1 additive series) improved the Indian mustard-equivalent yield by 92.0% as compared to 2 hand-weedings. The highest net returns (₹125,194/ha) and benefit: cost ratio (B : C) (6.6) were recorded under intercropping with Indian mustard + chickpea (1 : 1 additive series). Therefore, intercropping of fast-growing crops with wide-spaced crop could be an efficient strategy for weed management and higher profitability under organic crop production.

Key words: Intercropping, Indian mustard oil-cake, Mulching, Organic farming, Soil solarization, Weed-control efficiency

Application of agro-inputs such as fertilizers, herbicides and pesticides has increased considerably after post-green revolution. Due to health awareness among people, demand of pesticide-free product is increasing tremendously in recent time and popularity of organic farming is also increasing simultaneously. India is having the highest number of organic growers in the world. Moreover, India is at 8th position with respect to area cultivated under certified organic farming (Willer *et al.,* 2021). Among the states of India, Madhya Pradesh has covered the largest area under organic certification, followed by Rajasthan where oilseeds are major crops. India produced around 3.50 million tonnes of certified organic products which include all varieties of food products, namely oilseeds, fibre, sugarcane, cereals and millets, cotton, during 2020–21 (APEDA, 2021).

Simultaneously, organic growers are facing great difficulties under organic cultivation, especially during initial years of adoption. Among these, lower productivity, non-availability of quality organic inputs, poor marketing infrastructure and certification are the major challenge. Lack of awareness as well as technologies for nutrient and weed management under organic cultivation are the foremost factors responsible for lower productivity. Generally, farmers rely on manual weeding to keep their crop weed-free during critical stage. Manual weeding is very labour-intensive and requires wages of labour during peak period of

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different agricultural operation which make manual weeding uneconomical for organic grower. As a result, weeds compete with crop for different resources (nutrient, moisture, space and light) that are already not in pace of crop demand, resulting in lower yield (15–90%) and profitability (Mishra *et al.,* 2021). Improper management of weeds in crop sometimes may also lead to 100% crop failure (Hussain *et al*., 2020).

Different cultural and mechanical methods could be suitable alternative for manual weed management under organic farming. Mechanical weeding with the help of power-operated weeder, rotary weeder or wheel hoe in wide-row spaced crop can be reliably used during initial stage of crop growth (Sundaram *et al.,* 2021). Similarly, mulching with different crop and weed residue is very potent in management of weeds. Likewise, alteration of spacing with narrow row spacing, stale seedbed (SSB) preparation, mixed or intercropping with fast-growing crop (Paulsen *et al.,* 2006), soil solarization with transparent polythene sheet during summer season, application of allelo-chemicals (Blaise *et al.,* 2020) etc. are also promising techniques for weed management under organic crop production. Therefore, considering these practices in view, an experiment was conducted to study the effect of different weed management practices on weed density, productivity and economics of Indian mustard under organic production.

MATERIALS AND METHODS

A field experiment was conducted during winter (*rabi*) season of 2017–18 and 2018–19 at the research farm of ICAR-Indian Institute of Farming Systems Research, Modipuram, Meerut, Uttar Pradesh, India (29°04’38.8"N, 77°42’09.9"E, 237 m above mean sea-level). The climate of the location is semi-arid with dry hot summers and cold winters with an average annual rainfall of 747 mm, and 80% of which is received through south-west monsoon during July–September. The soil was sandy loam, having *p*H 7.8, 0.54% Walkley–Black carbon, 131.7 kg/ha available nitrogen, 15.8 kg/ha available phosphorus and 168.8 kg/ha available potassium.

The experiment was laid out in randomized complete-block design with 3 replications. Eight weed-management practices, viz. 2 hand-weedings (HW) each at 25 and 50 days after sowing (DAS), mechanical weeding at 25 DAS + HW at 50 DAS, intercropping of Indian mustard + chickpea (1 : 1 additive series), stale seedbed (SSB) + reduced spacing (30 cm) + maize (*Zea mays* L.) straw mulch @ 5 t/ha + HW at 40 DAS, water hyacinth (*Eichhornia crassipes* Mart.) mulch @ 4 t/ha + HW at 40 DAS, Indian mustard oil cake application @ 5 t/ha + HW at 40 DAS, soil solarization with 25 μ transparent polythene sheet + HW at 40 DAS, *Eucalyptus* leaves mulch @ 5 t/ha + HW at 40 DAS were adopted. Randomizations of treatments were done by using Fisher and Yates random number tables. ‘RH 749’ variety of Indian mustard was sown during the fourth week of October at 45 cm × 25 cm row and plant spacing. For nutrient management, FYM @ 8 t/ha (basal) and vermicompost @ 2.67 t/ha (25 DAS) were applied in all the treatments. The crop was irrigated twice during the crop season at 40 and 75 DAS.

Total weed density was recorded from 3 places in each plot with the help of 1 m^2 size quadrate. Places for weed count were selected by throwing quadrate in the plot. Species-wise different weeds were counted at 20 and 40 DAS before weeding operation and total weed density/m^2 was recorded. Weed-control efficiency under different weed-management practices at 20 DAS was calculated by using total weed density data of 2 HW at 25 and 50 DAS treatment.

Yield attributes, viz. branches/plant, siliqua/plant and seeds/siliqua, of 10 randomly selected Indian mustard plants in each treatment were recorded during both the years. Number of branches/plant was recorded by counting primary branches of each pre-selected plant. Selected plants were also used for counting number of siliquae/ plant. Randomly selected 20 siliquae from each selected plant were used for recording number of seeds/siliqua. The seed yield of Indian mustard was estimated at 8% moisture content. Likewise, straw yield was recorded by subtracting seed yield from the total biomass yield and expressed in kg/ ha. Indian mustard-equivalent yield (MEY) under intercropping with Indian mustard + chickpea (1 : 1 additive series) treatment was calculated as:

$$\text{MEY (kg/ha)} = \text{Mustard yield (kg/ha)} + \frac{\text{Chickpea yield (kg/ha)} \times \text{Price of chickpea (₹/kg)}}{\text{Price of mustard (₹/kg)}}$$

Total cost of cultivation (₹/ha) was calculated by summation of variable cost in different weed-management treatments. Gross and net returns (₹/ha) were calculated based on the seed yield and the prevailing market prices of Indian mustard in respective seasons. Benefit: cost ratio was also calculated.

Data recorded during study period were analysed statistically using the F–test. Data of total weed density were transformed to $\sqrt{X+0.5}$ and analysed statistically. The significant differences between treatments means were compared with the least significance at 5% level of probability.

RESULTS AND DISCUSSION

Weed density and weed-control efficiency

Total weed density was significantly affected by different organic weed-management practices at 20 and 40 days after sowing (DAS) of Indian mustard. Among the different weed species, purple nut sedge (*Cyperus rotundus* L.) was major dominant weed species representing around 70% population of total weed density during both the years. Other common weed species were white clover (*Trifolium repens* L.), black nightshade (*Solanum nigrum* L.), white seed clover (*Melilotus alba* Medik.), scarlet pimpernel (*Anagallis arvensis* L.), lamb's quarter (*Chenopodium album* L.), toothed dock (*Rumex dentatus* L.) and native gooseberry (*Physalis minima* L.). Among different organic weed-management practices, the lowest total weed density was recorded at 20 DAS under treatment soil solarization with 25 μm transparent polythene sheet + HW at 40 DAS, followed by stale seedbed (SSB) + reduced spacing (30 cm) + maize straw mulching @ 5 t/ha + HW at 40 DAS treatment (Table 1). Reduced spacing of Indian mustard might have increased the competition for nutrient, space etc. with weeds due to higher plant population of Indian mustard. However, significantly higher total weed density was recorded under application of Indian mustard oil cake @ 5 t/ha + HW at 40 DAS treatment. Total weed density at 20 DAS was 23.2–165.8% higher under application of Indian mustard oil cake @ 5 t/ha than the other treatments. At 40 DAS, total weed density was found lowest under mechanical weeding at 25 DAS + HW at 50 DAS and was statistically identical with 2 HW at 25 and 50 DAS, followed by soil solarization with 25 μm transparent polythene sheet + HW at 40 DAS, and the highest under application of Indian mustard oil cake @ 5 t/ha + HW at 40 DAS. Soil solarization is a hydrothermal method of weed management in which solar energy of sunlight is trapped under the transparent polyethylene sheet (Cohen *et al.,* 2019). The solar energy increases the temperature of the soil, and weed seed loses its viability. Soil solarization after 8 weeks could increase soil temperature up to 54ºC in top 5 cm soil depth and was capable in complete reduction of weed germination (Kapoor, 2020). Moreover, higher concentration of CO_2 in the soil during the solarization also induces the weed seed dormancy and control weed population (Khadka *et al.,* 2021). Similarly, under SSB weed seeds bank and species diversity in the cultivation layer was reduced by repeated tillage that stimulated emergence (Senthilkumar *et al.,* 2019; Shivran *et al.,* 2020). Monocot, dicot and total weeds were efficiently controlled using SSB + reduced spacing + wheat straw mulch @ 2 t/ha + HW at 25 DAS in soybean and gram under organic production (Chavan *et al.,* 2020).

Weed-control efficiency of different treatments was compared with 2 hand-weeding treatments at 20 DAS. Weed-control efficiency at 20 DAS was better among all the organic weed management treatments than 2 HW except application of Indian mustard oilcake @ 5 t/ha. The highest weed-control efficiency was registered under treatment of soil solarization with 25 μm transparent polythene sheet + HW at 40 DAS followed by SSB + reduced

Table 1. Effect of weed-management practices on total weed density and weed-control efficiency in Indian mustard

Treatment	Total weed density (No. m^2)						Weed-control efficiency at 20 DAS (%)		
	20 DAS			40 DAS					
	2017–18	2018–19	Pooled	2017–18	2018–19	Pooled	2017–18	2018–19	Pooled
2 HW at 25 and 50 DAS	16.2* (262)	15.3 (234)	15.8 (248)	10.0 (100)	8.2 (67)	9.1 (84)	–	–	–
Mechanical weeding at 25 DAS + HW at 50 DAS	16.7 (279)	15.5 (239)	16.1 (259)	9.1 (81)	8.8 (77)	8.9 (79)	–	–	–
Intercropping Indian mustard + chickpea (1 : 1 additive series)	15.5 (240)	14.9 (222)	15.2 (231)	14.8 (219)	13.2 (174)	14.0 (197)	8.1	5.4	6.8
SSB + reduced spacing + maize straw @ 5 t/ha + HW at 40 DAS	11.8 (139)	12.2 (147)	12.0 (143)	14.0 (196)	13.2 (174)	13.6 (185)	46.2	37.2	41.7
Water hyacinth @ 4 t/ha + HW at 40 DAS	13.8 (193)	14.4 (205)	14.1 (199)	15.7 (246)	13.7 (187)	14.7 (217)	24.4	12.4	18.4
Indian mustard oil cake @ 5 t/ha + HW at 40 DAS	19.4 (374)	16.3 (264)	17.8 (319)	19.1 (367)	15.0 (224)	17.1 (296)	-44.5	-12.5	-28.5
Soil solarization + HW at 40 DAS	11.2 (126)	10.7 (113)	10.9 (120)	12.1 (147)	9.9 (97)	11.0 (122)	50.9	51.6	51.3
Eucalyptus leaves @ 5 t/ha + HW at 40 DAS	14.8 (220)	14.5 (210)	14.7 (215)	15.1 (227)	14.0 (196)	14.5 (212)	15.3	10.2	12.8
SEm±	0.75	0.22	0.49	0.62	0.24	0.43	–	–	–
CD (P=0.05)	2.29	0.69	1.49	1.93	0.72	1.33	–	–	–

DAS, Days after sowing; HW, hand-weeding; SSB, stale seedbed

*Data in parentheses are original values, which were transformed to $\sqrt{X+0.5}$ and analysed statistically spacing (30 cm) + maize straw mulching @ 5 t/ha + HW at 40 DAS. Intercropping of Indian mustard + chickpea (1 : 1 additive series) also proved better with 6.8% weed-control efficiency. However, application of Indian mustard oil cake @ 5 t/ha + HW at 40 DAS was found inferior with respect to weed-control efficiency at 20 DAS as compared to 2 HW treatment. Application of Indian mustard oil cake might have provided additional nutrient as compared to the other treatments and resulted in higher total weed density and poor weed-control efficiency at 20 DAS.

Yield attributes

Yield-attributing characters of Indian mustard were significantly affected by the organic weed-management treatments. Number of branches/plant (5.7), siliquae/plant (307) and seeds/siliqua (14.6) were the highest under application of Indian mustard oil cake @ 5 t/ha + HW at 40 DAS, followed by soil solarization with 25 μ transparent polythene sheet + HW at 40 DAS and mechanical weeding at 25 DAS + HW at 40 DAS (Table 2). Application of Indian mustard oil cake in spite of the highest weed density has provided sufficient nutrients for crop as per its requirement and resulted in better yield-attributing characters than the other treatments. Improvement in yield attributes with the application of Indian mustard oil cake as sole nutrient source through faster nutrient availability was also reported in scented rice (Banerjee *et al.*, 2013) and wheat (Verma *et al.,* 2018). Yield-attributing characters of Indian mustard were found lowest under SSB + reduced spacing (30 cm) + maize straw mulch @ 5 t/ha + HW at 40 DAS. Lower yield attributes under reduced spacing might be due to higher intra-species competition for nutrient and space in Indian mustard due to higher plant population (Arif *et al.,* 2012).

Productivity

Seed and stover yields of Indian mustard were significantly affected by different weed-management practices under organic production. Seed yield (3,527 kg/ha) and stover yield (8943 kg/ha) were maximum with the application of Indian mustard oilcake @ 5 t/ha + HW at 40 DAS, followed by application of water hyacinth mulch @ 4 t/ha + HW at 40 DAS and the least under SSB + reduced spacing (30 cm) + maize straw mulch @ 5 t/ha + HW at 40 DAS (Table 3). Seed yield of Indian mustard was 139.3% higher under Indian mustard oilcake-applied treatment than 2 HW at 25 and 50 DAS. Faster release of nutrient from Indian mustard oil cake and higher absorption of nutrients, particularly nitrogen, supports the growth and development of crop plants which was responsible for higher yield (Banerjee *et al.*, 2013). The seed yield of Indian mustard was found statistically identical among 2 HW at 25 and 50 DAS, mechanical weeding at 25 DAS + HW at 50 DAS, intercropping with Indian mustard + chickpea (1 : 1), soil solarization + HW at 40 DAS and *Eucalyptus* leaves mulch @ 5 t/ha + HW at 40 DAS. Indian mustard-equivalent yield was highest under application of Indian mustard oil cake @ 5 t/ha + HW at 40 DAS, followed by intercropping with Indian mustard + chickpea (1 : 1 additive series). Additional yield from chickpea and suppression of weeds

Table 2. Effect of weed management practices on yield attributes and stover yield of Indian mustard

Treatment	Branches/plant			Siliquae/plant			Seeds/siliqua			Stover yield (kg/ha)		
	2017–18	2018–19	Pooled	2017–18	2018–19	Pooled	2017–18	2018–19	Pooled	2017–18	2018–19	Pooled
2 HW at 25 and 50 DAS	5.0	5.3	5.2	105	162	134	11.7	13.4	12.6	4,972	4,223	4,598
Mechanical weeding at 25 DAS + HW at 50 DAS	4.9	5.9	5.4	126	158	142	11.0	13.2	12.1	4,834	4,520	4,677
Intercropping Indian mustard + chickpea (1 : 1 additive series)	4.1	5.1	4.6	77	168	123	11.5	13.2	12.4	3,385 (1,523)	4,779 (1,964)	4,082 (1,744)
SSB + reduced spacing + maize straw @ 5 t/ha + HW at 40 DAS	4.9	3.7	4.3	147	135	141	11.4	11.7	11.6	4,890	4,395	4,643
Water hyacinth @ 4 t/ha + HW at 40 DAS	3.8	5.5	4.7	79	208	144	11.0	14.0	12.5	5,010	4,080	4,545
Indian mustard oil cake @ 5 t/ha + HW at 40 DAS	5.0	6.3	5.7	295	318	307	13.8	15.4	14.6	9,499	8,387	8,943
Soil solarization + HW at 40 DAS	5.9	4.8	5.4	197	138	168	11.9	13.3	12.6	5,917	4,620	5,269
Eucalyptus leaves @ 5 t/ha + HW at 40 DAS	4.9	5.5	5.2	243	158	201	10.9	14.3	12.6	3,926	4,704	4,315
SEm±	0.11	0.23	0.17	5.01	4.27	4.64	0.34	0.39	0.37	147.6	118.7	133.15
CD (P=0.05)	0.32	0.70	0.51	15.4	13.1	14.3	1.03	1.21	1.12	452.2	363.6	407.9

HW, Hand-weeding; DAS, days after sowing; SSB, stale seedbed
Figures in parentheses indicate straw yield of chickpea

Table 3. Effect of weed-management practices on productivity and economics of Indian mustard under organic management

Treatment	Seed yield (kg/ha)			Indian mustard -equivalent yield (kg/ha)	Cost of cultivation (₹/ha)	Gross returns (₹/ha)	Net returns (₹/ha)	Benefit: cost ratio
	2017–18	2018–19	Pooled					
2 HW at 25 and 50 DAS	1,251	1,696	1,474	1,474	19,880	77,364	57,484	3.9
Mechanical weeding at 25 DAS + HW at 50 DAS	1,290	1,795	1,543	1,542	17,880	80,976	63,096	4.5
Intercropping Indian mustard + chickpea (1 : 1 additive series)	1,102 (1,222)	1,748 (1,332)	1,425 (1,277)	2,830	22,380	148,574	126,194	6.6
SSB + reduced spacing + maize straw @ 5 t/ha + HW at 40 DAS	1,221	1,303	1,262	1,262	24,060	66,241	42,181	2.8
Water hyacinth @ 4 t/ha + HW at 40 DAS	1,604	2,083	1,844	1,843	18,880	96,775	77,895	5.1
Indian mustard oil cake @ 5 t/ha + HW at 40 DAS	3,592	3,461	3,527	3,527	117,280	185,157	67,877	1.6
Soil solarization + HW at 40 DAS	1,271	1,800	1,536	1,535	37,080	80,612	43,532	2.2
Eucalyptus leaves @ 5 t/ha + HW at 40 DAS	1,225	1845	1,535	1,535	18,880	80,605	61,725	4.3
SEm±	117.1	95.1	106.1	82.8	–	–	–	–
CD (P=0.05)	452.8	291.4	372.1	253.5	–	–	–	–

DAS, Days after sowing; HW, hand-weeding; SSB, stale seedbed
*Values in parentheses are intercrop (chickpea) grain yield (kg/ha)

significantly improved the Indian mustard-equivalent yield under intercropping of Indian mustard + chickpea (1 : 1) treatments as compared to the other treatments. Chavan *et al.* (2020) also reported higher productivity owing to intercropping in soybean and gram.

Economics

Application of mulching material and other inputs under different weed-management practices enhanced the cost of cultivation as compared to 2 HW at 25 and 50 DAS. Cost of cultivation was the maximum under application of Indian mustard oil cake @ 5 t/ha + HW at 40 DAS, followed by soil solarization with 25 µ transparent polythene sheet + HW at 40 DAS and SSB + reduced spacing (30 cm) + maize straw mulching @ 5 t/ha + HW at 40 DAS (Table 3). High market price of Indian mustard oil cake due to higher demand as animal feed was the major reason for higher cost of cultivation of Indian mustard oilcake-applied treatment. Similarly, soil solarization with 25 µ transparent polythene sheet also resulted in higher cost under this treatments. Gross returns were the highest under application of Indian mustard oil cake @ 5 t/ha + HW at 40 DAS followed by intercropping with mustard + chickpea (1 : 1 additive series). Higher seed yield under Indian mustard oilcake applied-treatments resulted in the highest gross returns as compared to the other weed-management treatments. However, net returns (₹125,194/ha) were the highest under intercropping of Indian mustard + chickpea (1 : 1 additive series), followed by application of water hyacinth mulch @ 4 t/ha + HW at 40 DAS. Similarly, highest benefit: cost ratio was found under intercropping with Indian mustard + chickpea (1 : 1 additive series) and the lowest under application of Indian mustard oil cake @ 5 t/ha + HW at 40 DAS. Significant improvement in crop productivity with marginal increase in cost of cultivation under intercropping with chickpea (1 : 1 additive series) treatment improved the net return and benefit: cost (B : C) ratio of the treatment. Improvement in net profit and B : C ratio owing to intercropping was also reported by Chavan *et al.* (2020).

Based on this study, soil solarization with 25 µ transparent sheet + HW at 40 DAS and SSB + reduced spacing (30 cm) + maize straw mulch @ 5 t/ha + HW at 40 DAS in Indian mustard is very effective in controlling total weed with higher weed-control efficiency than the manual weeding under organic production. However, crop productivity as well as profitability were significantly improved with substantial weed-control efficiency with intercropping of Indian mustard + chickpea (1 : 1 additive series) under organic management. Therefore, intercropping of fast-growing crops with wide-spaced crop could be efficient strategy for management of weed and higher profitability under organic crop production.

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