Indian Journal of Agronomy **67** (1): 58–66 (March 2022)

Research Paper

Effect of planting density and weed management options on growth and productivity of Indian mustard

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Received: February 2021; Revised accepted: January 2022

ABSTRACT

A field experiment was conducted during the winter (*rabi*) season of 2018–19 and 2019–20 at Kalyani, West Bengal, to study the effect of various planting density and weed-management options on growth and productivity of Indian mustard [*Brassica juncea* (L.) Czern & Coss.]. The field experiment was conducted in split-plot design with 3 replications, having 30 treatments combinations including 3 planting densities in main-plot, viz. 30 cm × 15 cm, 30 cm × 20 cm and 30 cm × 25 cm; and 10 weed-management options in sub-plots which include pendimethalin @ 1.0 kg a.i./ha, oxadiargyl @ 0.08 kg a.i./ha, pendimethalin @ 1.2 kg a.i./ha, oxadiargyl @ 0.10 kg a.i./ha, pendimethalin @ 1.0 kg a.i./ha + 1 hoeing at 30 days after sowing (DAS), oxadiargyl @ 0.08 kg a.i./ha + one hoeing at 30 DAS, pendimethalin @ 1.2 kg a.i./ha + 1 hoeing at 30 DAS, oxadiargyl @ 0.10 kg a.i./ha + 1 hoeing at 30 DAS, weed free and control. Significantly lower weed density and dry-weight of weight observed with 30 cm × 20 and 30 cm × 15 cm plant spacing. Application of oxadiargyl @ 0.10 kg a.i./ha + 1 hoeing at 30 DAS and pendimethalin @ 1.20 kg a.i./ha + 1 hoeing at 30 DAS, greatly reduced different species of weeds and their dry weight. With various main-plot treatments, higher seed yield (1,838 kg/ha) of mustard was observed with the 30 cm × 20 cm planting and was statistically better than the other plant spacings. These treatments resulted in higher seed yield to the tune of 8.18 and 12.84% over the 30 cm × 15 cm and 30 cm × 25 cm plant spacings. Weed-free situation, resulted in the highest seed yield (2,230 kg/ha) and showed parity with pendimethalin @ 1.2 kg a.i./ha + 1 hoeing at 30 DAS and oxadiargyl @ 0.08 kg a.i./ha + 1 hoeing at 30 DAS. These treatments registered 93.5, 89.8 and 88.8% more seed yield over the control plots respectively. Economics revealed that, 30 cm × 25 cm plant spacing gave the maximum net returns (₹29,280/ha) with benefit: cost ratio of 1.70. The highest net returns (33,850/ha) were observed from the treatment of pendimethalin @ 1.2 kg a.i./ha + 1 hoeing at 30 DAS with a benefit: cost ratio of 1.74. This was closely followed by oxadiargyl @ 0.10 kg a.i./ha + 1 hoeing at 30 DAS.

Key words: Indian mustard, Oil, Plant spacing, Protein, Weed management, Yield

Among the 7 edible oilseeds cultivated in India, rapeseed-mustard group of crops contribute 28.6% in the total production of oilseeds (Shekhawat *et al*., 2012). The share of oilseeds is 14.1% out of the total cropped area in India; rapeseed-mustard accounts for 3% of it. Over the last 10 years, the oilseeds production in the country has increased from 24 million tonnes in 2007 to around 34 million tonnes in 2017 (Jat *et al*., 2017).

Indian mustard has a large number of alternative uses, mostly related to health (Mukherjee, 2015). The seed meal of Indian mustard contains proteins (35–40%), carbohydrates (14–15%), fibre (10–12%), ash (4–6%), minerals and vitamins (1.0–1.5%), glucosinolates (2–3%) tannin (1.6–3.1%), sinapin (1.0–1.5%) and phytic acid (3–6%) (Yadav *et al*., 2017). Considering the importance of Indian mustard, and the high level of imports, various rapeseed–mustard development schemes have been funded by the government to encourage its cultivation. Average yield of Indian mustard in India, though improved, is lower than world average and significantly lower than other major producing nations. As area under Indian mustard has been almost stagnant during the last decade, there is little scope for extension of area given the competing demands. Thus, yield rates need to be stepped up significantly in order to increase the production of oilseeds. It is one of the most important crops adopted by the farmers in the Indo-gangetic belt. This is a potential crop in winter (*rabi*) season owing to its wider adaptability and suitability to exploit residual moisture. Planting geometry on the other hand is a non-monetary input which affects canopy structure of

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crops and influences other physiological characteristics such as light interception and radiation-use efficiency. A uniform distribution of plants per unit area is a pre-requisite for yield stability (Mukherjee, 2014). The competitive ability of a Indian mustard plant depends greatly on the density of plants per unit area and weed-control efficiency. Yield losses due to crop-weed competition in mustard have been estimated to the tune of 31–52% depending upon the type, intensity and duration of competition (Singh *et al*., 2009). Competition by weeds at initial stages is a major limiting factor to its productivity. Manual weeding at 3–4 weeks after sowing, is the most common practice to control weeds in Indian mustard. But increasing wages and scarcity of labour compel to search for other alternatives. Herbicides are the dominant tool used for weed control in modern agriculture; they are highly effective on most weeds but are not a complete solution to the complex challenge that weeds present (Harker and Donovan, 2013). The competitive ability of a Indian mustard depends greatly on the density of plants per unit area and proper weed management options (Shekhawat *et al*., 2012). Cropping sequence with Indian mustard in the Indo-gangetic belt without proper weed management leading to fast depletion of soil fertility and crop productivity. An option of suitable crop-management practices with range of herbicide along with other management option become a good option for Indian mustard growers. At present, no recommended package of practices have been developed for cultivation of Indian mustard under system of crop intensification in new alluvial region of West Bengal. With this idea in mind, the present investigation was planned to find out the influence of different planting geometry and weed-management options on growth and yield of Indian mustard under new alluvial zone.

MATERIALS AND METHODS

The present experiment was conducted during the winter (*rabi*) season of 2018–19 and 2019–20, at Kalyani, West Bengal. The soil was sandy loam in texture, high in organic carbon (0.41%), available N (244.3 kg/ha), P_2O_5 (18.98 kg/ha) and K_2O (211.4 kg/ha) content with *p*H 7.2. The total rainfall recorded during crop-growth period was 19.1 and 11.7 mm, minimum temperature ranges from 10.7 to 16.5 and 11.3 to 17.4, and maximum temperature 21.1 to 36.4 and 18.3 to 34.2ºC during winter 2018–19 and 2019–20, respectively. The field experiment was conducted in split-plot design with 3 replications, having 30 treatments combinations including 3 planting methods in main-plot, viz. 30 cm × 15 cm, 30 cm × 20 cm and 30 cm × 25 cm, and 10 cm weed-management options in sub-plots which include pendimethalin @ 1.0 kg a.i./ha, oxadiargyl @ 0.08 kg a.i./ha, pendimethalin @ 1.2 kg a.i./ha, oxadiargyl @ 0.10 kg a.i./ha, pendimethalin @ 1.0 kg a.i./ha + 1 hoeing at 30 days after sowing (DAS), oxadiargyl @ 0.08 kg a.i./ha + 1 hoeing at 30 DAS, pendimethalin @ 1.2 kg a.i./ha + 1 hoeing at 30 DAS, oxadiargyl @ 0.10 kg a.i./ha + 1 hoeing at 30 DAS, weed-free and the control. The recommended dose of fertilizer (RDF) 60 kg N + 17.5 kg P + 33.3 kg K/ha was used. Primary nutrients were supplied through urea, single superphosphate and muriate of potash. Indian mustard cultivar NRCHB 101 was shown on 10 October 2018 and 12 October 2019. The variety was developed by the ICAR-Directorate of Rapeseed–Mustard Research, Bharatpur, Rajasthan, and released for cultivation under timely and late-sown irrigated conditions. The plants are of medium height and mature in 105 to 135 days under diverse agroclimatic situations. Full amount of phosphorus and potash and half amount of nitrogen were applied at the time of sowing, while the remaining dose of nitrogen was top dressed at the pre-flowering stage. The irrigation was given and other recommended packages of practice were adopted during the crop growth period in both the years. Five randomly selected plants from each plot were uprooted and later cleaned and observations like plant height and leaf area at peak growth stage, i.e. 60 DAS, were recorded and averaged. The yield attributes were recorded at harvesting time to assess the contribution to yield. The branches of 5 randomly selected plants were counted and reported as number of branches/plant. Similarly, the total siliqua of 5 sample plants were counted and expressed as number of siliqua/plant. Weight of 1,000-seeds was recorded as 1,000-seed weight. The seed and stover yields were computed from the harvest of net plot and expressed in tonne/ha. Plant and soil samples were analyzed for uptake of nitrogen, phosphorus and potash as per standard laboratory procedures (Jackson, 1973). Available phosphorus was determined by Olsen's method as outlined by Jackson (1973), using spectrophotometer (660 nm wave length). Available potassium was extracted with neutral normal ammonium acetate and the content of K in the solution was estimated by flame photometer (Jackson, 1973). Oil per cent in the seed was determined by Soxhlet apparatus using petroleum ether (60–80ºC) as an extractant (AO.A.C., 1960). The experimental data were analyzed statistically by applying the technique of analysis of variance (ANOVA) prescribed for the design to test the significance of overall difference among treatments by the F-test and conclusions were drawn at 5% probability level. The effect of treatments was evaluated on pooled analysis basis on growth, yield attributes and yields. Cost of cultivation (/ha) was calculated considering the prevailing charges of agricultural operations and market price of inputs involved. Gross returns were obtained by converting the harvest into monetary terms at the prevailing market rate during the course of studies. Benefit: cost ratio (B : C) was obtained by dividing the gross income with cost of cultivation.

RESULTS AND DISCUSSION

Growth characters

Data presented in Table 1 indicates that the plant height was affected significantly, with various main and sub-plot treatments. The highest plant height observed with the 30 cm × 20 cm plant spacing and showed parity only with 30 cm × 25 cm. The marked variation in growth could be ascribed to more response of plant to nutrient availability, which helped to exploit available resources for growth and development. Significantly more plant height (69.13 cm) was observed with the weed-free treatments and was at par (67.23 cm) only with the oxadiargyl @ 0.08 kg a.i./ha + 1 hoeing at 30 DAS and pendimethalin @ 1.0 kg a.i./ha + 1 hoeing at 30 DAS. Leaf-area index (LAI) and branches/plant failed to produce any statistical difference under various planting geometry; however, these parameters were found more with the 30 cm × 25 cm spacing. Various weed management option revealed that, noteworthy response with different treatments observed with respect to LAI, and it was highest with pendimethalin @ 1.2 kg a.i./ha + 1 hoeing at 30 DAS and was at par with oxadiargyl @ 0.08 kg a.i./ha, oxadiargyl @ 0.10 kg a.i./ha and oxadiargyl @ 0.10 kg a.i./ha + 1 hoeing at 30 DAS.

Weeds

The weed flora in the experimental field consisted of mixed population of grasses, viz. *Cynodon dactylon, Elusine indica;* broad-leaf weeds, viz. *Chenopodium album, Physalis minima, Rumex spinosus, Vicia hirsuta, Melilotus indica, Anagallis arvensis, Cichorium intybus, Convolvulus arvensis, Fumaria parviflora, Spergula arvensis* and sedges such as *Cyperus* sp. etc.

Table 1. Effect of planting methods and weed-management on growth, yield attributes and yield of Indian mustard (pooled data of 2 years)

Treatment	Plant height at 60 DAS (cm)	LAI at 60 DAS	Branches/ plant	Siliqua/ plant	Seed/ siliqua	1,000-seed weight (g)	Seed yield (kg/ha)	Stover yield (kg/ha)	Harvest index (%)
Planting methods (cm × cm)									
30 × 15	58.24	0.34	9.44	82.5	8.59	3.96	1,688	3,832	30.58
30 × 20	67.13	0.36	10.01	116.64	9.11	4.11	1,838	4,124	30.83
30 × 25	67.06	0.39	9.19	108.35	10.05	4.32	1,602	4,499	26.26
SEm±	1.02	0.02	0.38	2.63	0.32	0.16	19.05	25.44	0.61
CD (P=0.05)	3.49	NS*	NS	8.35	0.92	NS	58.18	73.31	1.72
Weed-management									
Pendimethalin @ 1.0 kg a.i./ha	57.11	0.30	8.92	98.33	7.33	3.93	1558	3,858	28.77
Pendimethalin @ 1.2 kg a.i./ha	63.89	0.35	9.83	106.11	8.52	4.11	1,611	3,039	34.65
Pendimethalin @ 1.0 kg a.i./ha + 1 hoeing at 30 DAS	66.81	0.35	9.39	89.21	10.58	4.44	1,640	3,758	30.38
Pendimethalin @ 1.2 kg a.i./ha + 1 hoeing at 30 DAS	64.25	0.40	9.91	101.25	9.25	4.32	2,187	4,965	30.58
Oxadiargyl @ 0.08 kg a.i./ha	61.04	0.38	9.86	111.31	9.86	4.16	1,438	3,853	27.18
Oxadiargyl @ 0.10 kg a.i./ha	65.23	0.39	10.00	93.19	9.31	4.26	1,645	4,611	26.29
Oxadiargyl @ 0.08 kg a.i./ha + 1 hoeing at 30 DAS	67.23	0.36	9.80	103.66	9.23	3.98	1,458	3,702	28.26
Oxadiargyl @ 0.10 kg a.i./ha + 1 hoeing at 30 DAS	66.41	0.38	9.54	124.25	10.21	4.56	2,175	5,221	29.41
Control	60.29	0.33	8.06	69.28	7.59	3.33	1,152	3,162	26.7
Weed-free	69.13	0.40	10.05	128.33	10.66	4.32	2,230	5,017	30.77
SEm±	0.83	0.03	0.31	3.24	0.41	0.19	24.54	31.36	0.51
CD (P=0.05)	2.41	0.08	0.92	9.15	1.16	0.55	70.54	90.32	1.38

DAS, Days after sowing; LAI, leaf-area index; NS, non-significant

The results revealed that, plant spacing and application of different herbicides either alone or in combination with cultural practices significantly influenced the weed density. Population of grassy weeds, mainly *Eleusine indica* was lower with crop spacing of 30 cm × 15 cm, and significantly lower to the other plant spacings (Table 2). However, density of *Cynodon dactylon* was the least with the plant spacing of 30 cm × 20 cm and was comparable only with 30 cm × 15 cm. Use of pendimethalin @ 1.2 kg a.i./ha + 1 hoeing at 30 DAS caused significantly lower density of *Eleusine indica* and was comparable with the pendimethalin @ 1.0 kg a.i./ha + 1 hoeing at 30 DAS, oxadiargyl @ 0.10 kg a.i./ha + 1 hoeing at 30 DAS and pendimethalin @ 1.2 kg a.i./ha. Density of *Cynodon dactylon* was the least with the pendimethalin @ 1.2 kg a.i./ha + 1 hoeing at 30 DAS and was comparable with the pendimethalin @ 1.0 kg a.i./ha + 1 hoeing at 30 DAS and pendimethalin @ 1.2 kg a.i./ha, and considerably lower to all other treatments. Density of *Cynodon dactylon* was found notably low with the pendimethalin @ 1.2 kg a.i./ha + one hoeing at 30 DAS and was comparable with the pendimethalin @ 1.0 kg a.i./ha + 1 hoeing at 30 DAS, pendimethalin @ 1.2 kg a.i./ha.

Broad-leaf weeds (BLW) population was recorded appreciably less with the 30 cm × 15 cm plant spacing and was comparable only with the 30 cm × 20 cm for *Chenopodium album* and with 30 cm × 25 cm for *Physalis minima* density (Table 2). Moreover, density of *Vicia*

Table 2. Effect of planting methods and weed-management on major weed species at 60 days after sowing DAS (no./m^2) (pooled data of 2 years)

Treatment	Grasses		Broad leaf weeds (BLW)					Sedges	
	Eleusine indica	*Cynodon dactylon*	*Chenopodium album*	*Physalis minima*	*Vicia hirsuta*	*Rumex spinosus*	Other minor BLW	*Cyperus difformis*	*Cyperus iria*
Planting methods (cm × cm)									
30 × 15	2.93 (8.06)	4.13 (16.58)	3.43 (11.25)	3.14 (9.33)	2.2 (4.33)	2.65 (6.54)	5.73 (32.36)	3.59 (12.36)	3.14 (9.35)
30 × 20	3.46 (11.45)	3.4 (11.06)	3.69 (13.11)	4.09 (16.22)	1.86 (2.96)	2.27 (4.66)	4.88 (23.32)	3.53 (11.99)	3.89 (14.66)
30 × 25	4.14 (16.66)	4.57 (20.48)	4.74 (21.96)	3.43 (11.25)	3.12 (9.23)	3.29 (10.33)	6.44 (41.02)	3.99 (15.43)	4.13 (16.54)
SEm±	0.16	0.25	0.18	0.13	0.15	0.13	0.18	0.16	0.17
CD (P=0.05)	0.46	0.76	0.52	0.40	0.44	0.40	0.53	0.43	0.49
Weed-management									
Pendimethalin @ 1.0 kg a.i./ha	3.3 (10.36)	4.02 (15.73)	3.69 (13.09)	5.2 (26.55)	3.14 (9.36)	3.44 (11.36)	6.48 (41.44)	4.36 (18.55)	4.1 (16.31)
Pendimethalin @ 1.2 kg a.i./ha	2.93 (8.11)	3.58 (12.30)	3.44 (11.36)	3.29 (10.32)	1.61 (2.09)	2.61 (6.33)	5.67 (31.65)	3.04 (8.77)	3.98 (15.33)
Pendimethalin @ 1.0 kg a.i./ha + 1 hoeing at 30 DAS	2.74 (7.00)	3.27 (10.20)	3.88 (14.55)	2.01 (3.54)	2.48 (5.66)	3.08 (8.97)	5.42 (28.91)	3.66 (12.92)	3.25 (10.09)
Pendimethalin @ 1.2 kg a.i./ha + 1 hoeing at 30 DAS	2.61 (6.30)	3.19 (9.71)	3.19 (9.65)	2.68 (6.66)	2.99 (8.44)	1.31 (1.21)	4.07 (16.05)	2.95 (8.21)	1.91 (3.13)
Oxadiargyl @ 0.08 kg a.i./ha	5.16 (26.16)	4.6 (20.72)	5.44 (29.11)	4.44 (19.25)	2.25 (4.56)	3.29 (10.33)	6.7 (44.36)	4.69 (21.54)	4.73 (21.88)
Oxadiargyl @ 0.10 kg a.i./ha	3.39 (10.98)	4.49 (19.74)	3.49 (11.69)	2.44 (5.44)	1.87 (3.00)	2.35 (5.01)	5.63 (31.15)	4.1 (16.33)	4.18 (16.96)
Oxadiargyl @ 0.08 kg a.i./ha + 1 hoeing at 30 DAS	3.82 (14.08)	4.47 (19.51)	4.08 (16.11)	4.39 (18.77)	2.95 (8.18)	3.14 (9.36)	4.57 (20.35)	3.87 (14.44)	3.49 (11.66)
Oxadiargyl @ 0.10 kg a.i./ha + 1 hoeing at 30 DAS	2.63 (6.44)	3.79 (13.93)	3.42 (11.2)	3.17 (9.56)	1.25 (1.07)	2.04 (3.67)	3.95 (15.11)	2.05 (3.69)	1.94 (3.25)
Control	5.63 (31.16)	6.28 (39.00)	6.09 (36.54)	4.76 (22.12)	3.68 (13.01)	3.97 (15.25)	9.7 (93.55)	5.33 (27.89)	5.19 (26.44)
Weed-free	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)
SEm±	0.14	0.20	0.21	0.17	0.19	0.16	0.21	0.22	0.17
CD (P=0.05)	0.43	0.53	0.58	0.49	0.55	0.46	0.60	0.61	0.48

DAS, Days after sowing; data analysed after square-root transformation $\sqrt{(\times + 0.5)}$; figures in parentheses are original values *hirsuta* was the least with the 30 cm × 20 cm spacing and was significantly superior to the other plant spacings. Population of *Rumex spinosus* observed least with the 30 cm × 20 cm and was at par only with the 30 cm × 15 cm plant spacing and considerably better to other treatments. Other minor broad-leaf weed (BLW) population revealed that, significantly lower population was observed with the 30 cm × 20 cm crop spacing and was remarkably better to the other options. Combined use of pendimethalin @ 1.2 kg a.i./ha with 1 hoeing at 30 DAS showed significantly lower density of *Chenopodium album* and comparable with the oxadiargyl @ 0.10 kg a.i./ha + 1 hoeing at 30 DAS, pendimethalin @ 1.2 kg a.i./ha and oxadiargyl @ 0.10 kg a.i./ha. Population of *Physalis minima* was observed least with the pendimethalin @ 1.0 kg a.i./ha + 1 hoeing at 30 DAS and was comparable only with the oxadiargyl @ 0.10 kg a.i./ha, and significantly better to all weed-management options except weed-free situation. Further observation with respect to density of *Vicia hirsuta* revealed that, population of this weed was least with the oxadiargyl @ 0.10 kg a.i./ha + 1 hoeing at 30 DAS and was comparable only with the pendimethalin @ 1.2 kg a.i./ha and considerably better to the other options of weed management. Density of *Rumex spinosus* was lower with pendimethalin @ 1.2 kg a.i./ha + 1 hoeing at 30 DAS and statistically better than all the other weed management

Table 3. Effect of planting methods and weed-management on weed dry-matter in Indian mustard at 60 days after sowing (g/m²) (pooled data of 2 years)

Treatment	Grasses		Broad leaf weeds (BLW)					Sedges	
	Eleusine indica	*Cynodon dactylon*	*Chenopodium album*	*Physalis minima*	*Vicia hirsuta*	*Rumex spinosus*	Other minor BLW	*Cyperus difformis*	*Cyperus iria*
Planting methods (cm × cm)									
30 × 15	1.88* (3.02)**	2.93 (8.09)	3.16 (9.51)	3.41 (11.11)	1.79 (2.70)	2.7 (6.77)	3.89 (14.65)	3.32 (10.54)	3.37 (10.86)
30 × 20	1.91 (3.13)	3.3 (10.37)	3.57 (12.23)	2.97 (8.33)	2.41 (5.32)	2.13 (4.04)	3.44 (11.32)	3.25 (10.08)	3.59 (12.36)
30 × 25	3.16 (9.46)	4.42 (19.07)	3.84 (14.25)	3.77 (13.71)	2.75 (7.05)	2.71 (6.85)	4.68 (21.36)	3.66 (12.89)	4.45 (19.33)
SEm±	0.14	0.12	0.16	0.13	0.10	0.14	0.16	0.17	0.12
CD (P=0.05)	0.39	0.33	0.46	0.38	0.3	0.41	0.39	NS	0.34
Weed-management									
Pendimethalin @ 1.0 kg a.i./ha	2.05 (3.69)	3.52 (11.92)	4.01 (15.61)	3.54 (12.03)	1.86 (2.96)	2.97 (8.33)	4.92 (23.66)	3.8 (13.96)	4.66 (21.25)
Pendimethalin @ 1.2 kg a.i./ha	2.33 (4.95)	3.55 (12.11)	3.19 (9.66)	3.13 (9.32)	1.84 (2.89)	1.76 (2.59)	3.4 (11.04)	3.29 (10.33)	4.16 (16.77)
Pendimethalin @ 1.0 kg a.i./ha + 1 hoeing at 30 DAS	2.00 (3.52)	3.03 (8.66)	3.57 (12.27)	2.82 (7.44)	1.69 (2.36)	2.36 (5.08)	3.8 (13.96)	3.62 (12.61)	4.74 (21.98)
Pendimethalin @ 1.2 kg a.i./ha + 1 hoeing at 30 DAS	2.27 (4.66)	3.47 (11.54)	2.98 (8.36)	3.54 (12.01)	2.62 (6.36)	2.75 (7.05)	3.26 (10.12)	3.14 (9.35)	3.61 (12.51)
Oxadiargyl @ 0.08 kg a.i./ha	1.90 (3.11)	3.01 (8.55)	3.24 (9.99)	4.2 (17.13)	2.04 (3.66)	2.96 (8.25)	3.94 (15.06)	4.23 (17.36)	4.3 (18.03)
Oxadiargyl @ 0.10 kg a.i./ha	1.69 (2.35)	2.8 (7.34)	2.97 (8.33)	3.24 (9.98)	2.77 (4.66)	2.59 (6.21)	3.72 (13.33)	3.96 (15.19)	3.69 (13.11)
Oxadiargyl @ 0.08 kg a.i./ha + 1 hoeing at 30 DAS	2.04 (3.66)	3.12 (9.22)	3.68 (13.06)	3.28 (10.25)	2.46 (5.55)	2.41 (5.33)	4.54 (20.14)	3.51 (11.85)	3.76 (13.65)
Oxadiargyl @ 0.10 kg a.i./ha + 1 hoeing at 30 DAS	2.15 (4.12)	3.55 (12.11)	3.24 (10.01)	2.93 (8.07)	1.69 (2.36)	2.7 (6.78)	3.12 (9.22)	3.22 (9.85)	2.6 (6.25)
Control	4.75 (22.11)	6.66 (43.89)	5.75 (32.56)	4.96 (24.11)	4.48 (19.55)	3.08 (8.99)	6.46 (41.25)	3.45 (11.42)	4.32 (18.15)
Weed-free	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)
SEm±	0.09	0.11	0.13	0.14	0.08	0.13	0.06	0.12	0.09
CD (P=0.05)	0.25	0.31	0.38	0.40	0.21	0.32	0.19	0.34	0.26

DAS, Days after sowing; data analyzed after square root transformation √ (x + 0.5); figures in parentheses are original values; NS, non-significant options except weed-free situation. Other minor BLW population was significantly less with the treatment oxadiargyl @ 0.10 kg a.i./ha + 1 hoeing at 30 DAS and was comparable only with pendimethalin @ 1.2 kg a.i./ha + 1 hoeing at 30 DAS.

Density of sedges varied significantly with various treatments, being minimum of *Cyperus difformis* with the plant spacing of 30 cm × 20 cm and was statistically at par only with 30 cm × 15 cm (Table 2). Population of *Cyperus iria* was the least with plant spacing of 30 cm × 15 cm and significantly better to all the other crop geometry options. With various weed-management practices oxadiargyl @ 0.10 kg a.i./ha + 1 hoeing at 30 DAS checked the density of *Cyperus difformis* and was significantly better to the other options except weed-free situations. Further, density of *Cyperus iria* was lower with the pendimethalin @ 1.2 kg a.i./ha + 1 hoeing at 30 DAS and was comparable only with the oxadiargyl @ 0.10 kg a.i./ha + 1 hoeing at 30 DAS and statistically better than all the other weed-management options except weed-free situation.

Dry weight of weeds was significantly influenced by different crop geometry and weed management options (Table 3). Weed biomass of grassy weeds, mainly *Eleusine indica* was observed lower with plant spacing of 30 cm × 15 cm and 30 cm × 20 cm and was statistically superior to the other options. Dry weight of *Cynodon dactylon* was found least with the 30 cm × 15 cm and notably better than other spacings. Use of oxadiargyl @ 0.10 kg a.i./ha resulted in significantly lower weed biomass of *Eleusine indica* and was comparable only with oxadiargyl @ 0.08 kg a.i./ha, and considerably better than the other weed-management measures. Further, weed biomass of *Cynodon dactylon* was appreciably lower with the oxadiargyl @ 0.10 kg a.i./ha and was comparable with the oxadiargyl @ 0.08 kg a.i./ha and pendimethalin @ 1.0 kg a.i./ha + 1 hoeing at 30 DAS.

Biomass of BLWs was significantly lower with the plant spacing of 30 cm × 20 cm for *Chenopodium album* and *Physalis minima;* however, this was significantly comparable only with 30 cm × 15 cm for *C. album* (Table 3). Dry weight of *Vicia hirsuta, Rumex spinosus* and other minor BLWs were significantly least with the 30 cm × 20 cm spacing and was better than the other weed-control options. The lowest dry weight of *Chenopodium album* was observed with the oxadiargyl @ 0.10 kg a.i./ha and showed parity with oxadiargyl @ 0.10 kg a.i./ha + 1 hoeing at 30 DAS, oxadiargyl @ 0.08 kg a.i./ha, pendimethalin @ 1.2 kg a.i./ha + 1 hoeing at 30 DAS, and pendimethalin @ 1.2 kg a.i./ha, and statistically better to other subplot treatments. Biomass of *Physalis minima* was the least with the pendimethalin @ 1.0 kg a.i./ha + 1 hoeing at 30 DAS and was comparable only with the oxadiargyl @ 0.10 kg a.i./ha + 1 hoeing at 30 DAS, and significantly better to all the other weed-management options except weed-free situation. Further observation revealed that, dry weight of *Vicia hirsuta* was the least with the oxadiargyl @ 0.10 kg a.i./ha + 1 hoeing at 30 DAS and was comparable with the pendimethalin @ 1.2 kg a.i./ha, pendimethalin @ 1.2 kg a.i./ha and pendimethalin @ 1.0 kg a.i./ha, and significantly better than the other options of weed management. *Rumex spinosus* density was found lower with pendimethalin @ 1.2 kg a.i./ha and statistically better than all the other weed-management options except weed-free situation. Population of other minor BLWs was significantly less with the oxadiargyl @ 0.10 kg a.i./ha + 1 hoeing at 30 DAS and was at par only with pendimethalin @ 1.2 kg a.i./ha + 1 hoeing at 30 DAS and significantly better than that of other subplot treatments.

Weed biomass of sedges varied significantly with different treatments; however, spacing failed to produce any statistical difference with *Cyperus difformis.* Plant spacing of 30 cm × 15 cm produced significantly low biomass of *Cyperus iria* and showed parity only 30 cm × 20 cm. With various weed-management practices, pendimethalin @ 1.2 kg a.i./ha + 1 hoeing at 30 DAS checked total biomass of *Cyperus difformis* and was significantly better than that of the other options except weed-free situation. Further, density of *Cyperus iria* was observed lower with the oxadiargyl @ 0.10 kg a.i./ha + 1 hoeing at 30 DAS and statistically better than all theother weed- management options except weed-free situation.

Total weed density was found higher with the 30 cm × 25 cm plant spacing, being significantly less than that of 30 cm × 15 cm and 30 cm × 20 cm; however, the latter were at par with each other (Table 4). Further, with various weed-control options, the lowest weed population was observed with oxadiargyl @ 0.10 kg a.i./ha + 1 hoeing at 30 DAS, being significantly better than that of all the other treatments. Weed dry weight was found the lowest with the 30 cm × 20 cm and was at par with 30 cm × 15 cm spacing and significantly better than the other crop geometry. Amongst the weed-control options, the least weed biomass was observed with the oxadiargyl @ 0.10 kg a.i./ha + 1 hoeing at 30 DAS and was at par with pendimethalin @ 1.2 kg a.i./ha + 1 hoeing at 30 DAS, and oxadiargyl @ 0.10 kg a.i./ha and statistically better than the other treatments. Nutrient uptake by weeds varied significantly with various treatments, least total nutrient uptake was observed with the 30 cm × 25 cm plant spacing which was at par with 30 cm × 15 cm (Table 4). Further observation revealed that, nutrient uptake was the least with pendimethalin @ 1.20 kg a.i./ha + 1 hoeing at 30 DAS, which showed parity only with oxadiargyl @ 0.10 kg a.i./ha + 1 hoeing at 30 DAS.

Table 4. Effect of planting methods and weed-management on total weed population, dry weight and nutrient uptake by weeds infesting Indian mustard (pooled data of 2 years)

Treatment	Total weed population (at 60 DAS) (No./m^2)	Total weed dryweight (at 60 DAS) (g/m^2)	Nutrient uptake by weeds (kg/ha)			Total uptake by weeds (kg/ha)
			N	P	K	
Planting methods (cm × cm)						
30 × 15	10.77*	8.93	10.14	2.93	8.11	21.18
	(115.47)**	(79.25)				
30 × 20	9.98	8.81	8.1	2.87	7.21	18.18
	(99.14)	(77.18)				
30 × 25	12.97	11.07	13.24	5.09	13.08	31.41
	(167.79)	(121.97)				
SEm±	0.59	0.22	0.63	0.23	0.56	1.81
CD (P=0.05)	1.56	0.64	1.86	0.71	1.61	5.92
Weed-management						
Pendimethalin @ 1.0 kg a.i./ha	12.77	10.06				
	(162.70)	(113.41)	12.13	4.01	10.11	26.25
Pendimethalin @ 1.2 kg a.i./ha	10.64	8.95	11.25	4.13	9.46	24.84
	(112.61)	(79.66)				
Pendimethalin @ 1.0 kg a.i./ha	10.84	9.40				
+ 1 hoeing at 30 DAS	(117.07)	(87.88)	9.98	3.43	9.36	22.77
Pendimethalin @ 1.2 kg a.i./ha	7.97	9.08	8.25	2.08	4.98	15.31
+ 1 hoeing at 30 DAS	(63.12)	(81.96)				
Oxadiargyl @ 0.08 kg a.i./ha	14.09	10.02	13.94	4.94	12.78	31.66
	(197.89	(99.93)				
Oxadiargyl @ 0.10 kg a.i./ha	10.90	9.07	9.25	3.12	8.05	20.42
	(118.36)	(81.71)				
Oxadiargyl @ 0.08 kg a.i./ha	11.12	9.66	12.74	4.31	11.39	28.44
+ 1 hoeing at 30 DAS	(123.24)	(92.71)				
Oxadiargyl @ 0.10 kg a.i./ha	8.01	8.32	9.01	3.03	7.11	19.15
+ 1 hoeing at 30 DAS	(63.65)	(68.77)				
Control	17.48	14.92	18.31	7.31	21.36	46.98
	(304.96)	(222.03)				
Weed-free	0.00	0.00	0.00	0.00	0.00	0.00
SEm±	0.76	0.28	0.56	0.19	0.73	1.39
CD (P=0.05)	2.22	0.79	1.42	0.56	2.01	4.63

DAS, Days after sowing; data analysed after square-root transformation $\sqrt{(\times + 0.5)}$; figures in parentheses are original values

Yield attributes

Different treatments combinations either in main or sub-plots statistically influenced all yield-attributing characters (Table 1). Branches/plant failed to show any significant variation with different plant spacings; however this parameter was showed higher values with the 30 cm × 20 cm spacing. Moreover, branches/plant were observed higher with the oxadiargyl @ 0.10 kg a.i./ha and were at par with treatments, viz. weed-free, oxadiargyl @ 0.10 kg a.i./ha + 1 hoeing at 30 DAS, oxadiargyl @ 0.08 kg a.i./ha + 1 hoeing at 30 DAS and pendimethalin @ 1.2 kg a.i./ha + 1 hoeing at 30 DAS. Number of siliqua/plant was higher with 30 cm × 20 cm and showed parity with 30 cm × 25 cm spacing. Application of oxadiargyl @ 0.10 kg a.i./ha + 1 hoeing at 30 DAS resulted in more siliqua/plant and significant only with weed free, which had highest number of siliqua/plant. Further, seeds/siliqua were observed more with the 30 cm × 25 cm plant spacing and statistically superior to the other main-plot treatments. The higher values of yield attributes is the result of higher plant spacing that resulted in better growth and more translocation of photosynthates from source to sink (Tripathi *et al*., 2010). Of the various weed-management options, use of pendimethalin @ 1.0 kg a.i./ha + 1 hoeing at 30 DAS produced more seed/siliqua and notably similar with weed-free, oxadiargyl @ 0.10 kg a.i./ha + 1 hoeing at 30 DAS and oxadiargyl @ 0.08 kg a.i./ha. Test weight failed to show any statistical difference with plant spacing; however, more test weight was observed with the 30 cm × 25 cm plant spacing. Use of oxadiargyl @ 0.10 kg a.i./ha + 1 hoeing at 30 DAS ensued higher test weight and was at par with all other subplot treatments except thecontrol, oxadiargyl @ 0.08 kg a.i./ha

+ 1 hoeing at 30 DAS and pendimethalin @ 1.0 kg a.i./ha.

Yield

Significant yield variation was observed with various main and subplot treatments. Adequate plant spacing along with proper weed-control measures increased the seed and stover yields by improving the setting pattern of siliquae on branches, siliquae/plant, and other yield attributes (Mukherjee, 2014). Amongst the main-plot treatments, higher seed yield of Indian mustard was found with the 30 × 20 cm (1,838 kg/ha) and was statistically better than the other plant spacings. These treatments evolved more seed yield to the tune of 8.18 and 12.84% over the 30 cm × 15 cm and 30 cm × 25 cm. The seed yield is the cumulative sum of all the yield components. Therefore, with marked variation in planting geometry, improved seed yield could be achieved, as it enhanced all the yield components significantly (Table 1). Amongst various subplot treatments, the highest seed yield was observed with the weed-free situation (2,230 kg/ha), and was statistically better than all the other treatments except pendimethalin @ 1.2 kg a.i./ha + 1 hoeing at 30 DAS and oxadiargyl @ 0.08 kg a.i./ha + 1 hoeing at 30 DAS (Table 1). These treatments revealed 93.5, 89.8 and 88.8% more seed yield than the control plots, respectively. Maximum stover production was recorded with plant spacing of 30 cm × 25 cm and was considerably better than the other main plot treatments. This treatment registered 17.4 and 9.7% more stover production compared to 30 cm × 15 cm and 30 cm × 20 cm plant spacing respectively. Further Table 1 revealed that field treated with various chemical doses, maximum stover yield was obtained with the application of oxadiargyl @ 0.10 kg a.i./ha + 1 hoeing at 30 DAS and was statistically superior to all the other treatments. This was followed by weed-free and pendimethalin @ 1.2 kg a.i./ha + 1 hoeing at 30 DAS. Significant response with respect to harvest index was observed with various treatments and it was the highest with the plant spacing of 30 cm × 20 cm, being statistically similar to 30 cm × 15 cm. Amongst various weed-management options, higher harvest index was found with the pendimethalin @ 1.2 kg a.i./ha and was notably superior to other subplot treatments. Interaction effects among spacing and weed-control measures for various growth and yield attributes and yield were found to be non-significant.

Nutrient uptake

Nutrient uptake by crop was significantly influenced by various treatments, the highest NPK uptake was noted with the 30 cm × 20 cm plant spacing and was notably better than all the other planting geometry (Table 5). Further, vari-

Table 5. Nutrient uptake and economics of Indian mustard as influenced by planting density and weed-management options (pooled data of 2 years)

Treatments	Total nutrient uptake (kg/ha)			Oil content (%)	Protein content (%)	Economics (×10³ ₹/ha)		
	N	P	K			Gross returns	Net returns	Benefit : cost ratio
Planting methods (cm × cm)								
30 × 15	97.61	41.06	72.54	38.65	12.11	69.09	24.43	1.55
30 × 20	116.81	49.54	87.22	38.45	13.41	71.05	29.28	1.70
30 × 25	92.03	37.12	70.44	37.92	14.52	59.23	20.61	1.53
SEm±	3.48	0.92	1.23	0.57	0.22			
CD (P=0.05)	10.33	2.55	4.14	NS	0.60			
Weed-management								
Pendimethalin @ 1.0 kg a.i./ha	88.33	36.54	72.54	39.75	11.31	56.75	21.73	1.62
Pendimethalin @ 1.2 kg a.i./ha	91.03	40.12	80.02	39.86	12.32	62.29	25.51	1.69
Pendimethalin @ 1.0 kg a.i./ha + 1 hoeing at 30 DAS	95.83	42.12	86.33	38.54	13.71	67.97	24.61	1.57
Pendimethalin @ 1.2 kg a.i./ha + 1 hoeing at 30 DAS	138.87	53.34	94.56	37.51	14.14	79.64	33.85	1.74
Oxadiargyl @ 0.08 kg a.i./ha	76.13	32.41	51.37	38.54	12.25	56.62	20.94	1.59
Oxadiargyl @ 0.10 kg a.i./ha	101.13	48.09	87.87	36.25	14.21	62.86	23.31	1.59
Oxadiargyl @ 0.08 kg a.i./ha + 1 hoeing at 30 DAS	80.11	34.45	61.99	37.41	13.51	60.97	18.26	1.43
Oxadiargyl @ 0.10 kg a.i./ha + 1 hoeing at 30 DAS	131.41	51.54	90.36	39.32	15.21	78.93	33.07	1.72
Control	69.13	24.21	43.04	36.36	12.11	46.86	13.01	1.38
Weed-free	149.11	60.54	97.62	39.58	15.24	92.86	33.54	1.57
SEm±	4.56	1.19	1.32	0.63	0.27			
CD (P=0.05)	.14.07	4.10	4.22	1.87	0.77			

ous weed-management options revealed that, the highest NPK uptake was found with the weed-free situation and was at par only with pendimethalin @ 1.2 kg a.i./ha + 1 hoeing at 30 DAS for nitrogen and potassium uptake, and significantly better than all other treatments.

Quality parameters

The quality of Indian mustard seeds was measured in the term of oil and protein contents which were markedly influenced by the different treatments (Table 5). Plant spacing did not show in any significant variation in oil percentage. Similar result was observed by Yadav *et al.* (2017). Wider spacing (30 cm × 25 cm) resulted in significantly higher protein content compared to the other crop geometries. This is owing to higher nitrogen content which is precursor of protein synthesis in seed. Charak *et al*. (2006) and Kaur and Sindhu (2006) also reported recorded the variability amongst crop geometry of Indian mustard with respect to oil and protein content. With various weed-management options, more oil content was found under the weed-free situation and was at par with all other treatments except pendimethalin @ 1.2 kg a.i./ha + 1 hoeing at 30 DAS, oxadiargyl @ 0.08 kg a.i./ha + 1 hoeing at 30 DAS and the control. Further, protein content was found higher with the weed-free situation and significantly superior to all other treatments.

Economics

Net profitability (₹/ha) and benefit: cost ratio (B: C) from all the different planting densities and weed-management options increased progressively up to certain extent (Table 5). Economics revealed that, 30 cm × 25 cm plant spacing gave maximum net returns (29,280 ₹/ha) with B : C ratio of 1.70 (Table 3). Various subplot treatment revealed that, the highest net returns (33,850 ₹/ha) was observed with the pendimethalin @ 1.2 kg a.i./ha + 1 hoeing at 30 DAS with B:C ratio of 1.74. This was closely followed by oxadiargyl @ 0.10 kg a.i./ha + 1 hoeing at 30 DAS. The best performance was revealed by plant spacing of 30 cm × 20 cm coupled with application of pendimethalin @ 1.2 kg a.i./ha + 1 hoeing at 30 DAS.

It was concluded that, plant spacing of 30 × 20 cm resulted in significantly higher values for all of yield attributes (siliquae/plant, seeds/siliqua and 1,000-seed weight) over other spacings. Weed-management either with pendimethalin @ 1.2 kg a.i./ha + 1 hoeing at 30 DAS or oxadiargyl @ 0.10 kg a.i./ha + 1 hoeing at 30 DAS, was found optimum for irrigated timely sown Indian mustard in order to gain higher net returns and benefit : cost ratio under alluvial zone of West Bengal.

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