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Research Paper

Effect of plant geometry and weed management on growth and yield of fennel (*Foeniculum vulgare* Mill.) under semi-arid conditions of Rajasthan

MEENA CHOUDHARY[1], A.C. SHIVRAN[2], HANSA LAKHRAN[3], H.P. VERMA[4], SHEESHPAL CHOUDHARY[5] AND KIRAN DOODHWAL[6]

Sri Karan Narendra College of Agriculture, S.K.N. Agriculture University, Jobner, Jaipur, Rajasthan 303 329

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ABSTRACT

A field experiment was conducted on loamy sand soil the winter season (*rabi*) seasons of 2016–17 and 2017–18 at Agronomy Farm, Jobner, to study the influence of different plant geometries (50 cm × 20 cm, 50 cm × 25 cm, 60 cm × 15 cm and 60 cm × 20 cm) and weed-management measures [(weedy check, 2 hand-weedings (HW) at 25 and 50 days after sowing (DAS), pendimethalin @ 0.75 kg/ha pre-emergence (PE), oxadiargyl @ 75 g/ha (PE), pendimethalin @ 0.75 kg/ha (PE) + 1 HW at 30 DAS and oxadiargyl @ 75 g/ha (PE) + 1 HW at 30 DAS)] on growth, yield attributes and yield of fennel (*Foeniculum vulgare* Mill.) The fennel crop sown at wider plant geometry (60 cm × 20 cm) significantly improved the growth (except plant height) and yield attributes over the rest of the treatments. The highest seed (2.21 t/ha) and straw yields (7.45 t/ha) were obtained with plant geometry 60 cm × 20 cm. Among the weed-management practices, HW twice at 25 and 50 DAS significantly improved the growth, yield attributes, yield and net returns over the weedy check treatment. Results indicated that, HW twice at 25 and 50 DAS gave significantly highest seed (2.23 t/ha), straw yield (7.28 t/ha), net returns (₹99,945/ha) and benefit: cost ratio (4.31). The next best treatment in terms of these parameter pendimethalin @ 0.75 kg/ha (PE) + 1 HW at 30 days. The highest weed-control efficiency (86.75%) was shown by HW twice at 25 and 50 DAS.

Key words **:** Fennel, Plant geometry, Weed management, Pendimethalin, Oxadiargyl, Economics and yield

Fennel is grown primarily in Gujarat, Rajasthan and Uttar Pradesh states of India. It is consumed as condiment and culinary spice. Each part of the fennel (leaves, stalks, bulbs and seeds) is edible owing to its pleasant aromatic properties. Fennel seeds contain 1.4 to 4.0% essential volatile oil. Volatile oil of fennel possesses nematicidal, antimicrobial and detoxifying enzyme inducing activities (Yadav *et al*., 2017). In India, the crop is being cultivated on an area about 0.075 million ha, with an annual production of 1.27 million tonnes and productivity of 1,697 kg/ha (Commissionate of Agriculture, Jaipur, Rajasthan. 2020).

A significant non-monetary feature of crop production is the maintenance of optimum plant population which besides weed infestation, is directly influenced but plant geometry. Wider plant spacing not only contributes to excessive vegetative growth, but also accelerates the evaporative loss of water from the bare ground. Crop spacing may vary, depending on climatic conditions, soil fertility and cultivars adaptation to specific regions. Under wider spacing the plant is more vigorous in terms of leaf size, which could be due to less competition for light, nutrients and moisture as compared to closer spacing (Rai *et al.,* 2003). The proper plant spacing and management of weeds are particularly important among the different cultural practices in the semi-arid conditions of Rajasthan, with an appropriate plant population/unit of area.

Fennel is initially a slow-growing seed spice, and as a result it is more likely to prone to crop-weed competition. Therefore, field should be kept free of weeds at the initial stage of development by using appropriate weed-control methods. Initial slow crop growth leads to a substantial pressure from weed, which decreases both growth and yield up to 91.4% (Mali and Suwalka, 1987). For successful control of weeds during this stage, 1 hand-weeding (HW) at 25 and 30 days after sowing (DAS) is required,

[1]**Corresponding author Email**: meenac1191@gmail.com

[1,5]Ph.D. Scholar, [2]Professor, Department of Agronomy; Sri Karan Narendra Agriculture University, Jobner, Rajasthan 303 329; [3]Assistant Professor, College of Agriculture, (Agriculture University, Jodhpur) Nagaur, Rajasthan 341 001; [4]Technical Assistant, Mechanized Agriculture Farm, Agriculture University, Kota, Rajasthan 324 001; [6]Ph.D. Scholar, Department of Soil Science and Agricultural Chemistry, Rajasthan College of Agriculture, MPUAT, Udaipur, Rajasthan

but in view of scanty availability of labour and ever increasing wages, the manual weed control has become cumbersome, labour-intensive, time-consuming and costly. Therefore, it is essential to search out effective pre-emergence (PE) herbicide which can take care of early flush of weeds. The application of herbicide has, however, revolutionized weed-control and reduced production costs, but now the majority of farmers have been completely unaware of the proper doses, time of use and economy of herbicides, so that weed-control is back on their judicious use (Meena and Mehta, 2009). Appropriate planting patterns are important non-cash inputs that avoid intra-spacing competition, cooperation and competitive interaction; they are of crucial importance for sunlight interception by plant canopy (Singh and Amin, 2015). Since, maintenance of the optimal plant population is essential for intercepting the solar radiation without competing for nutrients, water and reducing the overall population of the weeds, an experiment was conducted with fennel in Jobner, Rajasthan.

MATERIALS AND METHODS

The field experiment was conducted during the winter (*rabi*) seasons of 2016–17 and 2017–18 at Agronomy farm, Sri Karannarendra College of Agriculture (26°05' N, 75°28' E and 427 altitude), Sri Karan Narendra Agriculture University, Jobner, Rajasthan to study productivity and profitability of fennel as influenced by plant geometries and weed-management. The agro-climate of the location is characterized by semi-arid conditions of climate with hot summer and severe cold winter. In Rajasthan, this region falls under agro-climatic zone-IIIA (Semi-Arid Eastern Plains). The soil was loamy sand, having low organic carbon (0.21%) and available N (128.6 kg/ha), medium in P (15.4 kg/ha) and K (148.6 kg/ha) and slightly alkaline (*p*H 8.2) with low moisture-retention capacity. The experiment was laid out in split-plot design with 4 sowing plant geometries [(50 cm × 20 cm (G_0), 50 cm × 25 cm (G_1), 60 cm × 15 cm (G_2) and 60 cm × 20 cm (G_3), in main plot and 6 weed-management measures [weedy check (W_0), 2 hand-weedings (HW) at 25 and 50 DAS (W_1), pendimethalin @ 0.75 kg/ha; pre-emergence (PE) (W_2), oxadiargyl @ 75 g/ha (PE) (W_3), pendimethalin @ 0.75 kg/ha (PE) + 1 HW at 30 DAS (W_4) and oxadiargyl @ 75 g/ha (PE) + 1 HW at 30 DAS (W_5)] in subplots with 3 replications. Each plot measured 4 m × 3 m (12 m^2) area. Fennel cultivar 'RF 205' was sown with standard package of practices. Sowing was done by *khera* method under rainfed condition in varying geometry as per treatment using a seed rate of 10 kg/ha at the depth of 2–3 cm. A uniform half dose of nitrogen and 40 kg P_2O_5 phosphorus were applied manually through diammonium phosphate DAP and urea at the time of sowing and the remaining nitrogen was applied at vegetative stage. Cumulative pan evaporation was taken as the sum of the daily pan evaporation from USWB class-A. Pre-emergence application of pendimethalin @ 0.75 kg/ha (PE) (Dost 30 EC) and oxadiargyl @ 75 g/ha (PE) (Raft 6 EC) were applied at day 2 after irrigation which was given immediately after sowing of the crop as per treatment. The spray of pendimethalin and oxadiargyl were done with knapsack sprayer, keeping spray volume of 700 to 800 litres/ha. In manual weed-control treatments, weeds were uprooted and removed at 25, 30 and 50 DAS with the help of *Kassi* as per treatment. Recommended plant-protection measures were adopted to grow a healthy crop. At maturity stage, 2 rows from either side of the plots and 2 plants from the proximal and distal ends of the rows of individual plots were harvested separately to eliminate the border effects for recording the yield attributes and yields. After complete sundrying, bundles harvested materials weighed to record biological yield. Thereafter, threshing was done by beating the plants with sticks. Fennel seeds were cleaned by manual winnowing and yield was recorded. Straw yield was obtained by subtracting seed yield from total biomass yield. Yield was expressed in t/ha. The harvest index was calculated by economic yield to biological yield and expressed in percentage. Net returns were calculated based on seed and straw yield and prevailing market price of fennel seed. All the data recorded during individual years as well as in pooled analysis were statistically analyzed for their test of significance using the *F*-test (Gomez and Gomez, 1984). The significance of difference between treatment means was compared with 't' critical difference at 5% level of probability.

RESULTS AND DISCUSSION

Plant geometry

Growth parameters: Plant height, branches/plant and dry-matter accumulation (DMA) were significantly influenced by different plant geometries (Table 1). Sowing of crop at plant geometry of 60 cm × 15 cm (G_2) resulted in the maximum plant height and proved significantly superior to rest of the treatments. The lowest plant height was recorded with the treatment G_3 at all the growth stages. Increase in plant height in narrow spacing might be due to stiff competition for mainly light which facilitated vertical growth by producing weak, lanky and taller plants. Similar results were also reported by Sharma *et al*. (2016) in coriander and Sharanya *et al*. (2018) in fenugreek. In contrast with this, the number of branches/plant was more in spacing of 60 cm × 20 cm (G_3) than spacing (60 cm × 15 cm). It may be ascribed to the better growth of plants under broader spacing of because it resulted in better vegetative growth owing to less plant population density and competition which result in more horizontal growth and plant

canopy area than those under narrow spacing. So, the branch-bearing capacity was increased, as also reported by Sharanya *et al*. (2018). Dry-matter accumulation of crop was significantly influenced by different plant geometries almost at all the growth stages. In the present study, plant geometry of 60 cm × 20 cm resulted in maximum crop dry matter because of availability of more ground area per plant which implied that, individual plant at wider plant geometry received higher resources like sunlight, water and nutrients with comparatively lower competition. Hence the higher photosynthetic activity/unit area produced more dry-matter in wider spacing (Meena *et al.,* 2016).

Yield attributes: Plant geometry revealed significant variations in various yield-determining characters of fennel, viz*.,* umbels/plant, umbellets/umbel, seeds/umbel and test weight (Table 2). The maximum umbels/plant, umbellets/umbel, seeds/umbel and 1,000-seed weight were registered under the plant geometry 60 cm × 20 cm (G_3) which may be attributed to better growth in terms of dry-matter and branches/plant and development of plants under 60 cm × 20 cm plant density which led to better source to sink relationship owing to availability of balanced and adequate nutrients and better light, space and moisture unlike in other spacing. Better utilization of available natural resources for growth and development of plant which may increase the shape and size of yield responsible organs resulting better development of yield attributes (Kumar *et al*., 2015). It is found due to own crop genetic features and gave the better results in this spacing.

Yield: The fennel seed, straw and biological yields (Table 3) were significantly affected by different plant geometries. Plant geometry of 60 cm × 20 cm resulted in production of significantly higher seed, strawand biological yields over rest of the plant geometries, the increase owing 11.31, 14.84 and 29.33% in seed yield; 11.55, 15.35 and 29.36% in straw yield; and 11.49, 15.24 and 29.35%, in biological yield, respectively, over low density planting at 50 cm × 25 cm, 50 cm × 20 cm and 60 cm × 15 cm. The main reason was dense plant population, which accelerated the competition within crop plant for space, light, nutrients and moisture. Thus, sowing of crop at 60 cm × 20 cm plant geometry emerged to be the best spacing for obtaining higher seed and straw yields. The higher yield in wider plant spacing might be owing to better development of yield attributes (Mehta *et al*., 2011; Bhardwaj *et al*., 2013).

Weed-control efficiency and weed competition index: Plant geometry could not bring variation in weed-control efficiency and weed-competition index to the level of significance (Table 4).

Economics: Plant geometry had significant effect on net returns and benefit: cost (B : C) ratio (Table 4). Plant geometry 60 cm × 20 cm gave the maximum net returns (₹98,962/ha) and B:C ratio of (4.28). The significantly higher net returns and B:C ratio accrued under the treatment G_3 was attributed to proportionately larger increase in grain and straw yields as compared to the cost involved which contributed to higher net returns/ha and B : C ratio. Our findings confirm the results of Yadav *et al*. (2017).

Weed management

Growth parameters: The weed management treatments differed significantly in their effect on plant height,

Table 1. Effect of plant geometry and weed management on plant height and branches/plant of fennel (pooled data of 2 years mean)

Treatment	Plant height (cm)	Branches/ plant	Dry-matter accumulation (g)/m^2
Plant geometry (cm × cm)			
G_0, 50 × 20	123.8	5.19	362.16
G_1, 50 × 25	123.3	5.37	372.88
G_2, 60 × 15	132.8	3.93	337.60
G_3, 60 × 20	69.7	6.08	401.13
SEm±	1.54	0.08	3.95
CD (P=0.05)	4.73	0.24	12.19
Weed management			
W_0, Weedy check	68.7	3.01	263.45
W_1, 2 HW at 25 and 50 DAS	132.4	6.04	421.14
W_2, Pendimethalin @ 0.75 kg /ha (PE)	127.9	5.80	408.40
W_3, Oxadiargyl @ 75 g/ha (PE)	84.8	4.15	285.11
W_4, Pendimethalin @ 0.75 kg /ha (PE) + 1 HW at 30 DAS	131.0	6.02	419.87
W_5, Oxadiargyl @ 75 g/ha (PE) + 1 HW at 30 DAS	129.5	5.85	412.70
SEm±	1.61	0.09	4.77
CD (P=0.05)	4.53	0.24	13.42

HD, Handing-weeding; DAS, days after sowing; PE, pre-emergence

branches/plant and crop dry-matter accumulation (Table 1). All the treatments significantly enhanced the growth characters of fennel at most of the stages as compared to the weedy check. Two hand-weedings done at 25 and 50 DAS recorded the highest plant height, significantly higher crop dry matter at harvesting stage as well as maximum number of branches/plant. Pendimethalin @ 0.75 kg/ha and 1 HW at 30 DAS, oxadiargyl @ 75 g/ha (PE) and 1 HW at 30 DAS and pendimethalin @ 0.75 kg/ha (PE) were the next better and equally effective treatments in improving these characters of fennel. Oxadiargyl @ 75 g/ha registered 23.52, 9.55 and 37.87% increase in plant height, crop dry-matter production and branches/plant over the weedy check treatment, respectively and thus was found as the least effective herbicidal treatment. Significant improvement in growth attributes was observed owing to 2 hand-weedings. However, Kumar *et al.* (2012) reported superiority of pendimethalin in fennel. Promising results of oxadiargyl in enhancing growth attributes of fennel were also obtained by Gohil *et al.* (2014).The improvement in growth attributes of fennel under the influence of different weed management treatments in present investigation could mainly be ascribed to the reduced weed count and dry weight of weeds. The greater plant height and maximum dry-matter production by crop plants under weed-management treatments is an ancillary effect on account of the least competition for plant growth inputs under reduced density and dry weight of weeds, plant gets sufficient space for optimum expression of leaves and umbels as early as possible (Yadav *et al.,* 2012). Thus, adequate availability of light, space as well as better edaphic and nutritional environment along with improvement in physiological and morphological characters of the plant in rhizosphere ameliorated the photosynthetic efficiency, thereby led to more accumulation of dry matter under better treatments. Contrary to this, incessant growth of weeds throughout the crop season in weedy check plots arrested the crop growth due to high degree of weed-crop competition. Hand-weeding (HW) done with hoeing also improved the physical condition of the soil by increasing its friability and aeration, and it is an effective method to it preventing weeds from producing seeds that might help in establishment and proliferation of roots and ultimately the plant growth. In addition of providing weed-free environment to crop, excellent growth observed under 2 HW and pre-emergence (PE) application of pendimethalin and oxadiargyl along with one HW treatments as compared to herbicides alone could be the another possible reason of getting higher values of growth parameters (Patel *et al*., 2017) in fennel, it was also reported effective weed control with 2 HW in comparison to chemical treatment alone.

Yield attributes: Two HW done at 25 and 50 DAS resulted in the maximum umbels/plant, umbellets/umbel, seeds/umbel and test weight (Table 3). Pre-emergence application of pendimethalin @ 0.75 kg/ha (PE) + 1 hand-weeding at 30 DAS, oxadiargyl @ 75 g/ha (PE) + 1 hand-weeding at 30 DAS and pendimethalin @ 0.75 kg/ha (PE) were found the next superior and equally effective treatments in enhancing yield attributes of fennel, as Since, 2 hand-weedings provided almost season long weed-free

Table 2. Effect of plant geometry and weed management on yield attributes of fennel (pooled data of 2 years mean)

Treatment	Yield attributes			
	Umbels/ plant	Umbellets/ umbel	Seeds/ umbel	Test weight (g)
Plant geometry (cm× cm)				
G_0, 50 × 20	20.71	24.7	339.49	5.44
G_1, 50 × 25	21.41	25.6	350.45	5.59
G_2, 60 × 15	18.92	22.5	254.47	4.30
G_3, 60 × 20	23.18	28.7	400.02	6.20
SEm±	0.33	0.38	5.06	0.08
CD (P=0.05)	1.01	1.17	15.58	0.24
Weed management				
W_0, Weedy check	16.50	19.5	230.16	4.15
W_1, 2 HW at 25 and 50 DAS	23.43	28.3	390.72	6.00
W_2, Pendimethalin @ 0.75 kg/ha (PE)	22.45	27.2	376.28	5.77
W_3, Oxadiargyl @ 75 g/ha (PE)	18.17	21.9	253.11	4.60
W_4, Pendimethalin @ 0.75 kg/ha (PE) + 1 HW at 30 DAS	23.20	27.9	388.07	5.92
W_5, Oxadiargyl @ 75 g/ha (PE) + 1 HW at 30 DAS	22.60	27.4	378.32	5.84
SEm±	0.35	0.42	5.64	0.09
CD (P=0.05)	1.00	1.17	15.86	0.25

HD, Handing-weeding; DAS, days after sowing; PE, pre-emergence

environment to excellent crop growth as reported by Bhullar *et al*. (2012).

Yield: Significantly higher values of seed, straw and biological yields of fennel were recorded under the 2 HW done at 25 and 50 DAS over the weedy check treatment. Two hand-weedings treatment provided almost season long weed-free environment hence resulted in appreciably higher yields over unweeded plots. However, it remained at par with application of pendimethalin @ 0.75 kg/ha (PE) + 1 hand-weeding at 30 DAS, oxadiargyl @ 75 g/ha (PE) + 1 hand-weeding at 30 DAS and pendimethalin @ 0.75 kg/ha (PE) (Table 3) and were found to be the next superior and equally effective treatments in enhancing yield of fennel. These treatments increased the seed yield by of 54.65, 52.32 and 51.33% over the unweeded control. The corresponding increase in straw yield was 50.52, 48.01 and 46.18% and biological yield was 51.46, 48.99 and 47.36%. Application of oxadiargyl @ 75 g/ha also gave the higher yield of fennel. This treatment gave 13.46% higher seed yield, 24.23% higher straw yield and 21.78% biological yield over the weedy check, but this was found inferior to above-described treatments. Because of differential growth habits of various weed species found in experimental field, it has been further established that for similar weed densities, a composite stand of weed species is always more competitive than solid stand of a single weed species. Two HW treatments ensued the long-period weed control and thus resulted in appreciably higher yields over to unweeded plots. These treatments kept the crop almost weed free up to 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 1 HW treatments, as this improved the soil tilth by making it loose and porous and thus facilitated the plants to effectively utilize water and air. All these favourable effects of weed-control treatments led to significant improvement in various yield-attributing characters of fennel by providing better source-sink relationship (Marmat *et al.*, 2003). On the other hand, relatively poor yield attributes and yield recorded under inferior treatments like oxadiargyl might be attributed to the poor crop growth due to phytotoxicity observed during the early growth stages that affected the yield-contributing traits. Furthermore, the most severe competition throughout the crop season due to unlimited weed growth under weedy check plots increased the removal of nutrients and moisture by weeds thereby negatively effecting the crop growth. It also blocks the porphyrin biosynthesis by inhibiting proto-porphyrinogen oxidase thus reduced the translocation of photosynthates towards seed formation having conflicting effect on yield characteristic parameters which in turn reduced the yield to the minimum level. Results obtained in this investigation strongly support by the findings of Mahmoudi *et al*. (2013) and Patel *et al*. (2016).

Table 3. Effect of plant geometry and weed-management on yield of fennel (pooled data of 2 mean)

Treatment	Yield			
	Seed yield (t/ha)	Straw yield (t/ha)	Biological yield (t/ha)	Harvest index (%)
Plant geometry (cm × cm)				
G_0, 50 × 20	1.93	6.45	8.38	22.92
G_1, 50 × 25	1.99	6.68	8.67	22.88
G_2, 60 × 15	1.71	5.76	7.47	22.84
G_3, 60 × 20	2.21	7.45	9.66	22.84
SEm±	0.14	0.36	0.48	0.35
CD (P=0.05)	0.40	1.04	1.41	NS
Weed management				
W_0, Weedy check	1.42	4.82	6.24	22.74
W_1, 2 HW at 25 and 50 DAS	2.23	7.28	9.51	23.47
W_2, Pendimethalin @ 0.75 kg/ha (PE)	2.15	7.04	9.19	23.36
W_3, Oxadiargyl @ 75 g/ha (PE)	1.61	5.98	7.59	21.17
W_4, Pendimethalin @ 0.75 kg/ha (PE) + 1 HW at 30 DAS	2.19	7.25	9.44	23.22
W_5, Oxadiargyl @ 75 g/ha (PE) + 1 HW at 30 DAS	2.16	7.13	9.29	23.26
SEm±	0.13	0.32	0.44	0.32
CD (P=0.05)	0.36	0.91	1.31	NS

HD, Handing-weeding; DAS, days after sowing; PE, pre-emergence

Weed-control efficiency and weed-competition index: The pooled data showed that, the highest weed-control efficiency recorded with 2 HW at 25 and 50 DAS (W_1) treatment was significantly superior to that of W_3 and remained at par with W_2, W_4 and W_5 treatments (Table 4). The variation in weed-control efficiency is directly associated with the amount of weed biomass accumulated under various treatments. Controlling two initial flushes of weeds by 2 HW at 25 and 50 DAS reduced the weed growth effectively for major part of the crop period. On the other hand, 1 HW at 30 DAS or using herbicides alone and along with HW, controlled weeds less effectively and resulted higher weed dry matter than above described treatments, though, it was significantly lower than weedy check (Nagar *et al*., 2009; Yadav *et al*., 2015). Weed-competition index also declined due to these treatments in comparison to the weedy check. The application of pendimethalin @ 0.75 kg/ha along with 1 HW at 30 DAS recorded the lowest mean competition index of 1.87% as against the maximum of 36.54% observed under weedy check. Application of oxadiargyl @ 75 g/ha + 1 HW at 30 DAS and pendimethalin @ 0.75 kg/ha were found as the next superior treatments that recorded weed competition indice. Use of oxadiargyl @ 75 g/ha (28.04%) was found lesser effective on weeds than the other treatments. The higher weed dry-matter accumulation and nutrient removal by weeds and corresponding reduction in seed yield is directly associated with variation in the weed-competition indices among different treatments (Nagar *et al.*, 2009) in coriander.

Economics: All the weed-management treatments resulted in significantly higher net returns and B : C ratio over the weedy check, obviously owing to higher seed yield under these treatments (Table 4). Two HW treatment fetched the maximum mean net returns of ₹99,945/ha with B : C ratio of 4.31, showeing increase in the net returns by margin of ₹47,349/ha over the weedy check. Pendimethalin @ 0.75 kg/ha (PE) + 1 HW at 30 DAS was the next better treatment which gave ₹97,627/ha with a B : C ratio of 4.23. However, it was found at par with oxadiargyl @ 75 g/ha (PE) + 1 HW at 30 DAS (₹95,718/ha and B : C ratio of 4.17) and pendimethalin @ 0.75 kg/ha (PE) (₹94,860/ha and B : C ratio of 4.14). Oxadiargyl @ 75 g/ha (PE) also fetched 22.19% greater returns than the weedy check with B : C ratio of 3.13. The highest net returns and B : C ratio recorded under these superior treatments can be explained easily with the corresponding higher seed yield. The higher B : C ratio (4.23) under pendimethalin along with 1 HW seems to be owing to lower cost of treatment application. The lowest seed yield due to unrestricted weed growth in weedy check treatment was eventually reflected in the lowest net returns (₹52,596/ha) and B : C ratio (2.74). Results of the present investigation are in cognizance with the finding of Patel *et al*. (2016).

Thus, sowing of fennel crop at plant geometry of 60 cm × 20 cm proved to be the most suitable plant geometry which brought out significantly higher growth, yield attributes, yield and economics of crop as compared to the other treatments. 2 hand-weedings at 25 and 50 DAS proved to be the most effective in fennel, resulting in the maximum seed, straw, biological yields and economics.

Table 4. Effect of plant geometry and weed-management on weed-control efficiency, weed-competition index, net returns and Benefit: cost ratio of fennel (pooled data of 2 mean)

Treatment	Weed-control efficiency (%)	Weed competition Index (%)	Net returns (₹/ha)	Benefit: cost ratio
Plant geometry (cm × cm)				
G_0, 50 × 20	70.91	12.28	82,239	3.72
G_1, 50 × 25	70.93	12.30	85,815	3.84
G_2, 60 × 15	70.90	12.27	69,659	3.31
G_3, 60 × 20	70.94	12.31	98,962	4.28
SEm±	0.81	0.20	1,577	0.05
CD (P=0.05)	NS	NS	4,858	0.15
Weed management				
W_0, Weedy check	-	36.54	52,596	2.74
W_1, 2 HW at 25 and 50 DAS	86.75	-	99,945	4.31
W_2, Pendimethalin @ 0.75 kg/ha (PE)	85.58	3.96	94,860	4.14
W_3, Oxadiargyl @ 75 g/ha (PE)	81.21	28.04	64,268	3.13
W_4, Pendimethalin @ 0.75 kg/ha (PE) + 1 HW at 30 DAS	86.18	1.87	97,627	4.23
W_5, Oxadiargyl @ 75 g/ha (PE) + 1 HW at 30 DAS	85.83	3.32	95,718	4.17
SEm±	0.95	0.31	1,907	0.06
CD (P=0.05)	2.67	0.86	5,368	0.18

The least weed competition index was observed under pendimethalin @ 0.75 kg/ha + 1 hand-weeding at 30 DAS and this was followed by oxadiargyl @ 75 g/ha + 1 hand-weeding at 30 DAS and pendimethalin @ 0.75 kg/ha. Under labour-scarce conditions pre-emergence application of pendimethalin @ 0.75 kg/ha + 1-hand weeding at 30 DAS, oxadiargyl @ 75 g/ha + 1 hand-weeding at 30 DAS and pendimethalin @ 0.75 kg/ha proved the best herbicidal treatment in achieving higher profitability under semi-arid eastern plan zone of Rajasthan, which was at par with 2 hand-weedings at 25 and 50 DAS.

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