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RESEARCH ARTICLE

Organic weed management approaches and their impact on weeds, *Rabi* fennel productivity, economic returns and soil fertility

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ABSTRACT

Eco-friendly weed management is crucial for enhancing crop productivity while preserving ecological balance. A field experiment was conducted at the Centre for Organic and Natural Farming Research, Sardarkrushinagar in loamy sand soil, during the *Rabi* seasons from 2019–20 to 2021–22 to evaluate different weed management strategies in organic *Rabi* fennel. A Randomized Block Design (RBD) with three replications was used. Eight weed management treatments were tested, *viz.* stale seed bed followed by (*fb*) hand weeding (HW) at 30 days after sowing (DAS); castor shell mulch 5 t/ha *fb* HW at 30 DAS, mustard straw mulch 5 t/ha *fb* HW at 30 DAS; sunn hemp mulch 5 t/ha *fb* HW at 30 DAS; wheat straw mulch 5 t/ha *fb* HW at 30 DAS; interculturing (IC) *fb* HW at 30 DAS and 60 DAS *fb* earthing up at 70 DAS; IC at 30 and 60 DAS *fb* earthing up at 70 DAS and weedy check. Among the eight treatments, IC *fb* HW at 30 and 60 DAS and earthing up at 70 DAS significantly improved fennel plant height, branch number, seed, and stalk yield followed by treatment with stale seed bed *fb* HW at 30 DAS, which also recorded the highest umbels per plant. IC *fb* HW at 30 and 60 DAS and earthing up at 70 DAS resulted in the lowest weed density and biomass at 50 DAS, with the highest weed control efficiency (66%). The lowest weed density at 25 DAS and weed index were observed in the stale seed bed *fb* HW at 30 DAS. Furthermore, organic carbon and available N, P, and K were highest under IC *fb* HW at 30 and 60 DAS and earthing up at 70 DAS, it was found at par with wheat straw mulch 5 t/ha *fb* HW. Economically, IC *fb* HW at 30 and 60 DAS and earthing up at 70 DAS also yielded the highest net return, while stale seed bed *fb* HW at 30 DAS had the highest benefit-cost ratio (2.49).

Keywords: Mulch, Earthing up, Fennel, Inter cultivation, Mulching Stale seedbed, Soil fertility, Organic weed management

INTRODUCTION

Fennel (*Foeniculum vulgare* Mill.) is a flowering plant species belonging to Apiaceae family. It is a hardy, perennial herb with yellow flowers and feathery leaves. Fennel is known for its licorice-like flavor, but it also has many health benefits, and it has long been used in natural remedies and it is cultivated extensively in the U.S.A., France, India and Russia. Medicinal and aromatic plants are major crops of domestic and industrial interest. Medicinal and aromatic plants are increasingly organically grown to enhance profitability. However, the presence of weeds may lead to a decrease in both yield and quality. Therefore, nonchemical methods of weed control are needed. Weed management in organic production systems must involve the use of many techniques and strategies, all with the goal of achieving economically acceptable weed control and crop yields. The cultural practices used in crop production (for instance, using transplanting, pre-emergent flaming of weeds, pre-germination of weeds) often provide crops with a competitive advantage in terms of nutrient and sunlight availability over weeds (Kolb and Gallandt 2012). Providing the crop a competitive advantage through organically acceptable techniques and subsequent hand weeding operations, the cost can be minimized. Stale seed bed technique (SSB) is one of the most important cultural management strategies that can be used before any crop to reduce the weed seed bank. This technique helps to provide an opportunity for crop emergence and growth before the next flush of weeds. Physical methods for weed suppression are the methods of integrated non-chemical weed management strategy and are very useful in organic farming. Mulches are commonly used in cultivation of vegetables and other spices and medicinal crops (Deka and Talukdar 2017) and are acceptable in organic farming as well as in any other crop production. Soil mulching with plant wastes or synthetic mulches is one of the management practices for reducing soil evaporation; it increases water retention, increasing water use

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efficiency (WUE) and weed control in crop fields (Awodoyin *et al*. 2007). With the decomposition of mulch, humus is added in to the soil which increases water holding capacity of soil. Thus, the application of mulch in the field offers dual benefits, *viz*. weed management through ecofriendly way and improvement of soil fertility. In light of this, the current study was carried out to assess the effect of organic weed management treatments on weed growth, fennel yield, yield, weeds and soil fertility status in organic *rabi* fennel.

MATERIAL AND METHODS

The experiment was conducted during the *Rabi* seasons of 2019-20, 2020-21, and 2021-22 at the Centre for Organic and Natural Farming Research, C.N.R.M., Sardarkrushinagar, Gujarat, India. The research field is located at 24°18' N latitude and 17°16' E longitude. The soil of the experimental field was classified as loamy sand, with a pH of 7.8. During the initial period of 2019-20, the organic carbon, available N, P, and K content in the soil were found to be 0.21% (low), 138.0 kg/ha (low), 31.52 kg/ha (medium), and 252.0 kg/ha (high), respectively. The experiment was laid out in a randomized block design (RBD) with three replications. The experiment consisted of eight treatments, *viz*. stale seed bed followed by (*fb*) hand weeding (HW) at 30 DAS; castor shell mulch 5 t/ha *fb* HW at 30 DAS; mustard straw mulch 5 t/ha *fb* HW at 30 DAS; sunn hemp mulch 5 t/ha *fb* HW at 30 DAS; wheat straw mulch 5 t/ha *fb* HW at 30 DAS; interculturing (IC) *fb* HW at 30 DAS and 60 DAS *fb* earthing up at 70 DAS; IC at 30 and 60 DAS *fb* earthing up at 70 DAS and weedy check. All standard packages of practices were followed throughout the growing season. Different straw mulches used in different treatments were spread after sowing as per the treatment. The organic manures [recommended dose of nutrients (RDN) [N, P and K kg /ha: 90-30-00] were applied using organic sources. Equivalent N of RDN was applied by 50% FYM + 25% vermi-compost + 25% castor cake) as per treatment directly in the furrow. The fennel variety Gujrat Fennel (GF) 12 was sown in the experimental field on November 11, 2019, November 03, 2020, and October 29, 2021, with a row-to-row spacing of 45 cm and a seed rate of 5-6 kg/ha. Manual weeding operations like IC and HW were carried out as per the treatments. The weed density was recorded at 25 and 50 DAS. Dry weight of weeds (weed biomass) was recorded at harvest. Weed index and weed control efficiency (WCE) were calculated. For economic analysis, the economic value of the entire output was expressed as gross returns, while net return and the benefit: cost (B:C) ratio were calculated using standard procedures. 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.

RESULTS AND DISCUSSION

Effect on crop

The fennel plant height and the number of umbels per plant were significantly influenced by different weed management treatments (**Table 1**). Among the treatments, IC *fb* HW at 30 DAS and 60 DAS *fb* earthing up at 70 DAS recorded maximum plant height which can be attributed to effective weed suppression during critical growth stages, resulting in minimized competition for vital resources such as nutrients, light, and water, allowing plants to grow taller. Conversely, the number of umbels per plant was highest with stale seedbed preparation *fb* HW at 30 DAS which is likely due to the stale seedbed technique that reduced the germination of weed seeds early in the growing season, thereby improving early weed control. Additionally, the HW at 30 DAS reduced competition during the critical reproductive phase, supporting the development of reproductive structures like umbels. However, plant height and the number of umbels per plant did not show significant differences among weed management treatments in individual years. Furthermore, weed management practices had no significant impact on fennel plant population at harvest, the number of branches per plant, or test weight during individual years or in the pooled analysis (**Table 1**).

Fennel seed and stalk yield

Among the treatments, significantly higher fennel seed yields and stalk yield were recorded with IC *fb* HW at 30 and 60 DAS *fb* earthing up at 70 DAS during study years (**Table 2**). During 2019–20, the seed yield with IC *fb* HW at 30 and 60 DAS *fb* earthing up at 70 DAS was statistically comparable to stale seedbed *fb* one HW at 30 DAS. Similar results were observed in the pooled analysis. The variation in climatic conditions, particularly rainfall and temperature likely contributed to the differential yield response of fennel under the same weed management practices across years. The superior seed and stalk yield under IC *fb* HW at 30 and 60 DAS + earthing up

at 70 DAS can be attributed to the combined effects of inter-culturing, which disrupted the weed root zone, and HW, which effectively removed weeds, thereby reducing competition for resources such as nutrients, water, and light. Additionally, earthing up at 70 DAS minimized weed regrowth and enhanced root development, contributing to improved plant Vigor and higher reproductive output as reported earlier by Rajender Kumar *et al.* (2019). The improved yields with stale seedbed *fb* HW at 30 DAS can be attributed to the depletion of the weed seed bank through stale seedbed preparation, which gave the crop a competitive advantage during early growth stages. Mulching treatments also contributed to increased yields by providing effective weed control, conserving soil moisture, and enhancing nutrient availability. The created favorable micro-environment likely enhanced photosynthesis and facilitated the translocation of photosynthates to various metabolic sinks, boosting growth and yield. Thakral *et al.* (2007) highlighted the role of integrated weed management practices in enhancing crop productivity by reducing weed competition and improving resource utilization.

Effect on weeds

Among the weed management treatments, IC *fb* HW at 30 DAS and 60 DAS *fb* earthing up at 70 DAS, recorded the lowest weed biomass during 2020-21, 2021-22, and in the pooled results (**Table 3**). The weedy check consistently recorded the highest weed biomass due to the absence of control measures, which allowed for the unrestricted growth of weeds (**Table 3**) as observed by Meena and Mehta (2009). The weed density recorded at 25 DAS was found to be non-significant in individual years, although it was significant in the pooled analysis (**Table 3**). The lowest weed density at 25 DAS was recorded with stale seedbed *fb* HW at 30 DAS. Nalayini *et al.* (2023) reported efficacy of stale seedbed in other crops. The lowest weed density at 50 DAS was recorded with IC *fb* HW at 30 DAS and 60 DAS *fb* earthing up at 70 DAS, whereas the highest weed density was observed under the weedy check (**Table 3**). Furthermore, weed control efficiency (WCE), calculated based on the weed biomass at harvest in the pooled analysis, further highlight the effectiveness of different treatments (**Table 3**). The maximum WCE (66%) was observed with IC *fb* HW at 30 DAS and 60 DAS *fb* earthing up at 70 DAS. In contrast, the minimum WCE was recorded with sunhemp mulch 5 t/ha *fb* HW at 30 DAS, which may be attributed to the gradual decomposition of the mulch and insufficient suppression of weeds over time. Additionally, weed index (%), calculated based on grain yield, varied significantly across treatments

Table 1. Effect of weed management treatments on fennel growth and yield attributes (pooled)

Treatment	Plant population (per meter row length)	Plant height (cm)	No. of branches/ plant	Test weight (g)	No. of umbels/ plant
Stale seed bed *fb* HW at 30 DAS	6.67	107.2	4.20	5.32	27.67
Castor shell mulch 5 t/ha *fb* HW at 30 DAS	7.00	99.25	4.09	5.03	25.56
Mustard straw mulch 5 t/ha *fb* HW at 30 DAS	6.33	97.69	3.73	4.94	24.44
Sunhemp mulch 5 t/ha *fb* HW at 30 DAS	7.00	100.1	3.98	4.98	22.33
Wheat straw mulch 5 t/ha *fb* HW at 30 DAS	6.67	102.4	3.89	5.02	23.89
IC *fb* HW at 30 DAS and 60 DAS *fb* earthing up at 70 DAS	7.00	111.2	4.22	5.37	27.00
IC twice at 30 and 60 DAS *fb* earthing up at 70 DAS	6.67	95.25	3.76	4.92	22.78
Weedy check	5.67	88.85	3.51	4.52	18.56
LSD (p=0.05)	NS	9.05	NS	NS	3.12

HW: hand weeding; DAS: days after seeding; IC: inter-cultivation; *fb:* followed by

Table 2. Effect of weed management treatments on fennel seed and stalk yield

Treatment	Fennel seed yield	Fennel stalk yield
	Pooled	Pooled
Stale seed bed *fb* 1 HW at 30 DAS	1344	3109
Castor shell mulch 5t/ha *fb* HW at 30 DAS	1201	2850
Mustard straw mulch 5t/ha *fb* HW at 30 DAS	1127	2805
Sunhemp mulch 5 t/ha *fb* HW at 30 DAS	1055	2683
Wheat straw mulch 5 t/ha fb HW at 30 DAS	1181	2753
Interculturing fb HW at 30 DAS and 60 DAS *fb* earthing up at 70 DAS	1423	3191
IC twice at 30 and 60 DAS *fb* earthing up at 70 DAS	1094	2712
Weedy check	554.9	2092
LSD (p=0.05)	152	336

***** *fb*: followed by; HW: hand weeding; DAS: days after seeding; IC: inter-cultivation; *fb:* followed by

(**Table 3**). The lowest weed index was observed with stale seedbed *fb* HW at 30 DAS. Conversely, the highest weed index was recorded under the weedy check, followed by sunhemp mulch 5 t/ha *fb* HW at 30 DAS.

Effect on soil

Soil amendment with straw alters the physical, chemical, and biological properties of soil, thereby influencing plant growth, soil microbial community structure, and abundance. However, in this study, there were no significant differences in EC, pH, organic carbon, or available nutrients such as N, P, and K across various weed management treatments (**Table 4**). Nonetheless, numerically higher levels of organic carbon and available N, P, and K were observed under the treatment involving inter-culturing *fb* HW at 30 DAS *fb* 60 DAS, combined with earthing up at 70 DAS. This treatment was statistically at par with the treatment involving wheat straw mulch applied at 5 t/ha *fb* HW at 30 DAS. Furthermore, microbial populations were found to be higher in mulched soils compared to un mulched soils as reported by (Tiquia *et al*. 2002). Zhang *et al*. (2018) noted that in soils amended with maize straw, there was an increase in microbial populations and enzymatic activities. These increases facilitated straw degradation, thereby enhancing soil organic carbon content and overall soil quality, which contributed to improved crop yield. Liu *et al*. (2017) further highlighted that the formation of macro-aggregates and crop yield were positively correlated with increasing soil organic carbon concentrations.

Correlation

The correlation analysis revealed significant relationships between plant height, yield, and weed parameters (**Table 6**). Plant height and yield exhibit a strong positive correlation (r = 0.91), indicating that taller plants are associated with higher yields supporting observations of Al-Kordy (2000), Bahmani *et al*. (2012) and Thakur and Sirohi (2009). Conversely, weed parameters, including weed density at 25 DAS, 50 DAS, and weed biomass at harvest, showed negative correlations with both plant height and yield (Table 6). For instance, the weed density at 50 DAS has a strong negative correlation with plant height (r = -0.95) and yield (r = -0.92), which suggest that higher weed infestation reduces both growth and productivity. Weed biomass at harvest also negatively correlates with yield (r = -0.89), emphasizing the detrimental impact of weed biomass on crop performance. Weed density, weed biomass and weed index was significantly highly negative correlated

Table 3. Effect of weed management treatments on weed parameters at harvest (pooled)

Treatment	Weed biomass at harvest (g/m^2)	Weed density (no./m^2)		Weed index (%)	Weed control efficiency (%)
		at 25 DAS	at 50 DAS		
Stale seed bed *fb* HW at 30 DAS	7.69(60.8)	4.73(23.1)	5.45(32.3)	5.55	66.19
Castor shell mulch 5 t/ha *fb* HW at 30 DAS	8.73(84.2)	6.00(37.0)	8.77(81.3)	15.60	50.33
Mustard straw mulch 5 t/ha *fb* HW at 30 DAS	10.41(112)	6.52(43.8)	7.88(64.1)	20.80	34.21
Sunhemp mulch 5 t/ha *fb* HW at 30 DAS	11.51(141)	6.15(41.0)	7.81(65.9)	25.86	17.01
Wheat straw mulch 5 t/ha *fb* HW at 30 DAS	9.26(90.0)	7.04(51.1)	7.66(60.3)	17.01	46.93
IC *fb* HW at 30 DAS and 60 DAS *fb* earthing up at 70 DAS	7.30(58.2)	5.97(37.7)	4.87(27.3)	0.00	63.63
IC twice at 30 and 60 DAS *fb* earthing up at 70 DAS	8.37(72.3)	6.90(49.8)	8.29(71.7)	23.12	57.39
Weedy check	12.63(170)	7.63(60.3)	10.67(117)	61.00	0.00
LSD (p=0.05)	2.05	1.37	1.85	-	-

Data subjected to ($\sqrt{x+1}$) transformation. Figures in parentheses are original values; ***** *fb* = followed by; HW = hand weeding; DAS = days after seeding; IC = inter-cultivation

Table 4. Effect of weed management treatments on EC, pH, OC, available N, P and K (kg/ha) after harvest of fennel (after three year)

Treatment	EC (1: 2.5) dS/m	pH (1:2.5)	OC%	Available (kg/ha)		
				N	P	K
Stale seed bed *fb* HW at 30 DAS	0.158	7.82	0.25	149.5	35.55	280
Castor shell mulch 5 t/ha *fb* HW at 30 DAS	0.176	7.77	0.25	143.5	34.50	272
Mustard straw mulch 5 t/ha *fb* HW at 30 DAS	0.183	7.89	0.25	147.5	34.83	278
Sunhemp mulch 5 t/ha *fb* HW at 30 DAS	0.164	7.83	0.25	145.8	34.83	276
Wheat straw mulch 5 t/ha *fb* HW at 30 DAS	0.167	7.85	0.26	156.4	38.17	293
IC *fb* HW at 30 DAS and 60 DAS + Earthing up at 70 DAS	0.176	7.71	0.26	157.2	38.83	314
Two IC at 30 and 60 DAS + earthing up at 70 DAS	0.169	7.77	0.24	141.5	33.75	269
Weedy check	0.172	7.87	0.24	139.7	33.05	265
LSD (p=0.05)	NS	NS	NS	NS	NS	NS
Initial Soil Analysis	-	-	0.212	138	31.52	252

***** *fb* = followed by; HW = hand weeding; DAS = days after seeding; IC = inter-cultivation

Table 5. Effect of weed management treatments on economics of fennel cultivation (pooled basis)

Treatment	Seed yield (kg/ha)	Total Cost of cultivation (₹/ha)	Gross return (₹/ha)	Net returns (₹/ha)	B: C Ratio
Stale seed bed *fb* HW at 30 DAS	1344	26417	65856	39439	2.49
Castor shell mulch 5 t/ha *fb* HW at 30 DAS	1201	31859	58849	26990	1.85
Mustard straw mulch 5 t/ha *fb* HW at 30 DAS	1127	41859	55223	13364	1.32
Sunhemp mulch 5 t/ha *fb* HW at 30 DAS	1055	29359	51695	22336	1.76
Wheat straw mulch 5 t/ha *fb* HW at 30 DAS	1181	41859	57869	16010	1.38
IC *fb* HW at 30 DAS and 60 DAS + earthing up at 70 DAS	1423	28229	69727	41498	2.47
Two IC at 30 and 60 DAS + earthing up at 70 DAS	1094	29633	53606	23973	1.81
Weedy check	554.9	21885	27190	5305	1.24

Fennel seed selling price: 49 Rs/kg; ***** *fb* = followed by; HW = hand weeding; DAS = days after seeding; IC = inter-cultivation

Table 6. The correlation matrix between fennel plant height, yield and weed parameters of in fennel (pooled basis)

	Plant height	Yield	Weed count at 25 DAS	Weed count at 25 DAS* converted	Weed density at 50 DAS	Weed density at 50 DAS converted	Weed biomass at Harvest	Weed biomass converted
Plant height	1							
Yield	0.908985077	1						
Weed count density at 25 DAS	-0.729528275	-0.770219067	1					
Weed density at 25 DAS converted	-0.739403763	-0.741850055	0.986179969	1				
Weed count density at 50 DAS	-0.947876501	-0.922017223	0.736244376	0.743927576	1			
Weed density at 50 DAS converted	-0.959881204	-0.89088863	0.72639531	0.753630978	0.989891444	1		
Weed biomass at Harvest	-0.741185885	-0.889714917	0.623579817	0.599459349	0.782121786	0.760865618	1	
Weed biomass converted	-0.758092264	-0.877896696	0.619902867	0.60843701	0.775999556	0.768797488	0.994448358	1

*DAS= days after seeding

with grain yield indicating serious reduction in grain yield supporting observations of Daniya *et al.* (2013) in sesame crop. These findings underscore the importance of effective weed management to enhance fennel growth and yield. The strong correlations highlight the critical interplay between plant traits and weed dynamics in agricultural systems.

Economics

The various weed management treatments had a significant impact on gross returns, net returns, and the benefit-cost (B:C) ratio across all years of experimentation (**Table 5**). Among the treatments, IC *fb* HW at 30 and 60 DAS + earthing up at 70 DAS, achieved the highest net returns with a B:C ratio of 2.47. This was closely followed by the stale seedbed preparation *fb* HW at 30 DAS. Notably, the highest B:C ratio (2.49) was observed under the stale seedbed *fb* HW at 30 DAS confirming the findings of Patel *et al.* (2019).

Conclusion

It is concluded that adopting stale seedbed preparation followed by hand weeding at 30 days after sowing, or inter-culturing followed by hand weeding at 30 and 60 days after sowing, along with earthing up at 70 days after sowing, is effective in managing weeds and ensures profitable fennel seed yield, along with better soil health, in *Rabi* fennel cultivation under organic farming.

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