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Performance of fennel (*Foeniculum vulgare* Mill.) under weed control measures and nutrient management

Pooja Kumari Meena*[1], R.C. Bairwa[2], Asha Kumari[3], Vikas Sharma[4], Rakhee Priya Baruah[5], Lalchand Kumawat[6], and Anuradha Yadav[7]

[1]*Department of Agronomy, Rajasthan College of Agriculture, Maharana Pratap University of Agriculture and Technology Udaipur, Rajasthan, India -313001*
[2]*Department of Agronomy, Swami Keshwanand Rajasthan Agricultural University, Bikaner, (Rajasthan), India -334006*
[3]*Department of Biotechnology, Junagadh Agricultural University, Junagadh, (Gujarat), India-362001*
[4]*Department of Biotechnology, Swami Keshwanand Rajasthan Agricultural University, Bikaner, (Rajasthan), India -334006*
[5]*Department of Agronomy, Assam Agricultural University, Jorhat, Assam, India- 785013*
[6]*Department of Agronomy, Maharana Pratap University of Agriculture and Technology Udaipur, Rajasthan, India -313001*
[7]*Department of Agronomy, Sri Karan Narendra Agriculture University, Jobner, Jaipur, Rajasthan, India -303329.*

ABSTRACT

A field experiment was conducted during the Rabi, 2021-22 at the Instructional Farm, College of Agriculture, SKRAU, Bikaner. The study was undertaken to identify the most effective weed control strategy and nutrient management practice for maximizing fennel productivity. There were 16 treatment combinations with four nutrient managements (control, 75% RDF, 100% RDF and 125% RDF) and four weed control measures (weed free, pendimethalin at 0.75 kg ha^{-1} (PE), Oxyfluorfen at 50 g ha^{-1} (PoE at 25 DAS) and weedy check) and were evaluated under factorial randomized design with three replications. The results revealed that among the weed control measures, pendimethalin at 0.75 kg ha^{-1} (PE) significantly reduced weed density and dry matter accumulation compared to the weedy check and was more effective than oxyflurfen at 50 g ha^{-1} (POE at 25 DAS). It reduced weed count by 83.95% and 85.32%, and weed biomass by 86.78% and 81.64% at 50 DAS and harvest, respectively, over the weedy check. The highest weed control efficiency (100%) and lowest weed index (0%) were observed in weed-free and pendimethalin at 0.75 kg ha^{-1} (PE) showed the next best treatment. The weed-free significantly enhanced crop growth and yield attributes, nutrient content and uptake, economic yield, biological yield (4595 kg ha^{-1}) and net return. However, pendimethalin at 0.75 kg ha^{-1} (PE) achieved the highest B: C ratio. Among nutrient management treatments, 125% RDF resulted in the maximum weed population and weed dry matter accumulation, while 100% RDF recorded superior growth and yield attributes and biological yield (3978 kg ha^{-1}) and economic returns. Challenges such as increased weed pressure under higher nutrient regimes and dependence on herbicides were noted. The study contributes to advancing integrated weed and nutrient management approaches for sustainable crop production.

Keywords: *Weed Control, Growth, Attributes, Pendimethalin, RDF, Biological Yield, Fennel, Nutrients, Oxyfluorfen, Weed index, Weed Dry Matter.*

Introduction

Fennel (*Foeniculum vulgare* Mill.) a significant seed spice crop belongs to the Umbelliferae (Apiaceae) family, with a diploid chromosome number of 2n = 22. The genus name "Foeniculum" originates from the Latin word *foenum*, meaning "hay," which refers to the plant's feathery foliage. Fennel is believed to have originated in the Mediterranean region and southern parts of Europe. Botanically, fennel is a robust, aromatic annual herb. Its seeds are nutritionally valuable, containing 9.5% protein, 10% fat, 42.3% carbohydrates, 18.5% fiber, and 13.4% mineral content (Meena *et al.*, 2023). Medicinally, fennel has been used in treating a variety of ailments such as asthma, colic, chest and spleen disorders, and kidney problems.

Corresponding Author: **Pooja Kumari Meena*

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The fruits are traditionally used to relieve flatulence, fever, intestinal colic, burning sensations, and constipation. Fennel is also incorporated into toothpaste formulations for the prevention of dental caries and periodontal diseases, and hot infusions of its fruits are used to manage amenorrhea (Jarlad and Jarlad, 2006)

India is the leading country in the production, consumption and export of fennel which is commonly known as "Saunf," and also referred to by various regional names across different parts of the country. Major producer states are Gujarat, Rajasthan, Karnataka, and Andhra Pradesh. Among these, Gujarat dominates the national fennel output contributing approximately 82% of the total production. Regarding its climatic preferences, fennel is a cool-season crop. Dry and cool weather during the seed development stage enhances both seed yield and quality. Considering the importance of fennel, its average productivity is very low. The reason for low productivity is due to a lack of ideal nutrient management and agronomic practices to control heavy weed infestation, lack of optimization of plant geometry, high sensitivity of pests and diseases at flowering and the non-availability of suitable varieties.

Fennel typically exhibits slow initial growth and takes a longer time to germinate, making it highly susceptible to weed infestation during the early stages of development (Gohil *et al.*, 2015). If not managed promptly, weeds can significantly hinder crop growth and may lead to yield losses as high as 91.4%, as reported by Mali and Suwalka (1987). Furthermore, weed competition can adversely impact the quality of essential oils in fennel (Abdallah *et al.*, 2021). Mechanical and cultural methods of weed control are often less effective and more costly, especially during labor shortages or when labor costs are high. In contrast, chemical weed control through herbicide application is generally more effective, economical and reliable. Herbicides have been shown to provide substantial increases in seed yield ranging from 43.2% to 86.9% and typically offer a three to fourfold return on investment compared to other weed control practices (Patel *et al.*, 2017). Maintaining a weed-free fennel field typically requires 3 to 4 rounds of manual weeding (Parthasarathy *et al.*, 2008). A weed-free environment throughout the crop cycle ensures maximum weed control efficiency (100%) and minimal yield loss contributing to optimal crop performance.

Efficient and balanced fertilizer application plays a crucial role in promoting proper plant growth, development and achieving higher yields (Kumar *et al.*, 2015). Macronutrients such as nitrogen (N), phosphorus (P) and potassium (K) are fundamental to the growth and development of all crops. Among essential nutrients, nitrogen is particularly important as it significantly influences vegetative growth, yield attributes, and seed quality (Chatzopoulou *et al.*, 2006). In plants, nitrogen predominantly exists in organic forms, including nucleic acids, certain vitamins, hormones, membrane constituents, coenzymes, and pigments. A deficiency of nitrogen can negatively impact leaf size and reduce the rate of photosynthesis (Lal *et al.*, 2016). Phosphorus is crucial for energy transfer within the plant, as it forms an integral part of adenosine triphosphate (ATP), nucleoproteins, genetic material, cellular membranes, and phosphorylated proteins. Potassium, on the other hand, acts as an essential activator or cofactor for numerous enzymatic reactions and plays a vital role in maintaining cellular osmotic balance and promoting water uptake (Waskela *et al.*, 2017)

Since, fennel is a commercial spice crop, its yield as well as quality is important and both can be achieved only by maintaining soil fertility through proper nutrient management practices and effective and economical weed control practices and managing the weeds at the critical stages of crop weed competition. Considering the above factors, the study was undertaken to identify the most effective weed control strategy and optimal nutrient management practice for enhancing the production of fennel.

Materials and Methods

The field study was carried out during the *rabi,* 2021–22 at the Instructional Farm of the College of Agriculture, Swami Keshwanand Rajasthan Agricultural University, Bikaner. The experimental site was located at 28.01° N latitude, 73.22° E longitude, with an elevation of 234.70 m above mean sea level. According to the 'Agro-ecological Region Map' developed by the National Bureau of Soil Survey and Land Use Planning (NBSS and LUP) location lied in Agro-ecological Region 2 (M_9E_1) which was part of the Hot Arid Eco-region. This area was characterized by deep sandy to coarse loamy desert soils, poor water-holding capacity and a hot, arid climate that receives 350–600 mm of annual rainfall. Based on agro-climatic classifications, Bikaner falls within Zone I-C (Hyper Arid Partially Irrigated Western Plain Zone) under the National Agricultural Research Project (NARP) and Zone XIV (Western Dry Region) as per the Planning Commission of India. The soil at the site was loamy sand in texture with a pH of 8.5, organic carbon content of 0.18%, low available nitrogen (121.4 kg ha^{-1}), medium phosphorus (19.08 kg ha^{-1}) and low potassium (191.42 kg ha^{-1}).

A factorial randomized block design (FRBD) with three replications was used. There were 16 treatment combinations with four nutrient managements (control, 75% RDF, 100% RDF and 125% RDF) and four weed control measures (weed free, pendimethalin at 0.75 kg ha^{-1} (PE), Oxyfluorfen at 50 g ha^{-1} (PoE AT 25 DAS) and weedy check). The treatment details are shown in (Table 1).

Table 1. Details of Total Treatments Combinations

S. No.	Treatment Combination	Symbol
1	Control + Weed-free	N_0W_0
2	Control + Pendimethalin at 0.75 kg ha^{-1} (PE)	N_0W_1
3	Control + Oxyfluorfen at 50 g ha^{-1} (PoE at 25 DAS)	N_0W_2
4	Control + Weedy check	N_0W_3
5	75% RDF* + Weed-free	N_1W_0
6	75% RDF + Pendimethalin at 0.75 kg ha^{-1} (PE)	N_1W_1
7	75% RDF + Oxyfluorfen at 50 g ha^{-1} (PoE at 25 DAS)	N_1W_2
8	75% RDF + Weedy check	N_1W_3
9	100% RDF + Weed-free	N_2W_0
10	100% RDF + Pendimethalin at 0.75 kg ha^{-1} (PE)	N_2W_1
11	100% RDF + Oxyfluorfen at 50 g ha^{-1} (PoE at 25 DAS)	N_2W_2
12	100% RDF + Weedy check	N_2W_3
13	125% RDF + Weed-free	N_3W_0
14	125% RDF + Pendimethalin at 0.75 kg ha^{-1} (PE)	N_3W_1
15	125% RDF + Oxyfluorfen at 50 g ha^{-1} (PoE at 25 DAS)	N_3W_2
16	125% RDF + Weedy check	N_3W_3

**RDF-Recommended dose of fertilizer (90 kg ha^{-1} N and 40 kg ha^{-1} P_2O_5)*

Fennel variety *RF-143* was grown at a spacing of 50 x 20 cm using a seed rate of 8 kg ha^{-1}. Herbicides were applied with a knapsack sprayer at both pre-emergence and post-emergence stages. Urea, SSP and MOP were used as sources of nutrients N, P and K, respectively and applied as per treatment details. Weed density and weed dry weights were measured from each plot at 50 DAS and at harvest using 1m^2 quadrate. The collected weed data were subjected to a square root transformation before statistical analysis. In order to evaluate the efficacy of various weed control treatments, the weed control efficiency of each treatment was calculated by using the following formula given by Kondap and Upadhyay (1985).

$$WCE(\%) = \frac{DWC - DWT}{DWC} X\ 100$$

Where, WCE = Weed control efficiency in per cent, DWC = Dry weight of weeds in weedy check plot and DWT = Dry weight of weeds in treated plot.

The weed index was worked out on the basis of that formula suggested by Gill and Kumar (1969).

$$\text{Weed Index } (\%) = \frac{YWF - YW}{YWF} X\ 100$$

Where, WI = Weed Index in per cent, YWF = Yield from weed free plot and YWT = Yield from treated plot.

The ratio of economic yield (seed yield) to biological yield was worked out and expressed in a percentage (Singh and Stoskopf, 1971).

$$\text{Harvest index } (\%) = \frac{\text{Economic yield}}{\text{Biological yield}} X\ 100$$

The data were analyzed statistically using Fisher's method of analysis of variance (ANOVA) as described by Fisher (1950). Duncan's Multiple Range Test was employed to determine at significant differences between treatment means at a 5% significance level ($p \le 0.05$).

Results and Discussion

Weed control measures

The study evaluated various weed control measures that exhibited significant variation in terms of weed density and weed dry matter accumulation. As expected, the weed-free treatment recorded zero weed population, whereas the weedy check showed the highest weed density at both 50 DAS and at harvest. Among the herbicide treatments, pendimethalin at 0.75 kg ha^{-1} (PE) was the most effective, reducing weed population by 83.95% and 85.32%, and weed dry matter accumulation by 86.82% and 81.64% at 50 DAS and harvest, respectively, over the weedy check. Similarly, oxyfluorfen at 50 g ha^{-1} (POE at 25 DAS) reduced weed population by 80.32% and 83.32%, and weed dry matter by 83.99% and 79.53% at corresponding stages compared to the weedy check (Table 2). Pendimethalin effectively suppresses root and shoot development of susceptible weed species, particularly during the crop's critical growth stage. This herbicidal action likely contributed to the observed reduction in weed density and biomass. These results align with the findings of Dutta *et al.* (2005), Kaur *et al.* (2022) and Singh (2023). In contrast, the continuous and unchecked growth of weeds in the weedy check plot resulted in a significant increase in weed population and dry matter accumulation. Similar trends of heavy weed infestation under unweeded conditions have been previously reported by Meena *et al.* (2013) and Fagaria *et al.* (2014) in fenugreek, Gohil *et al.* (2015) in fennel and Patel *et al.* (2016) in cumin.

The data presented in Table 3 reveal that weed-free exhibited the highest weed control efficiency (100%) and the lowest weed index (0%) indicating complete suppression of weed growth and no yield loss due to weed competition. Among the herbicidal treatments, pendimethalin at 0.75 kg ha^{-1} (PE) was the next best with WCE values of 86.87% at 50 DAS and 81.78% at harvest. This treatment also recorded a relatively low weed index of 13.47%, signifying effective weed suppression and minimal yield reduction when compared to the weedy check. The reduction in weed index (%) can be attributed to decreased crop-weed competition for essential resources such as light, nutrients and space which allowed the crop to more efficiently utilize available resources. This enhanced resource use efficiency ultimately contributed to improved crop growth and yield. Similar observations have been reported by Sagarka *et al.* (2005), Nagar *et al.* (2009), Patil *et al.* (2020) and Rathod *et al.* (2021) in coriander, Meena and Mehta (2010) and Mehriya *et al.* (2007) in cumin and Meena and Mehta (2009) in fennel.

Data from Tables 4 indicate that maintaining a weed-free environment throughout the crop season resulted in the most favorable yield attributes and overall productivity. This treatment recorded the highest values for umbel plant^{-1} (18.20), umbellate umbel^{-1} (20.63), and seeds umbel^{-1} (232.69) along with maximum biological yield (4595 kg ha^{-1}). The absence of weed competition throughout the growth period allowed the crop to fully utilize nutrients, moisture and sunlight, thereby enhancing growth and yield. Among the chemical control options, pre-emergence application of pendimethalin at 0.75 kg ha^{-1} proved most effective, followed closely by post-emergence application of oxyfluorfen at 50 g ha^{-1} at 25 DAS.

The primary mechanism of action of pendimethalin involves the inhibition of microtubule formation in the cells of susceptible monocot and dicot weeds. By disrupting microtubule assembly, it interferes with cell division, effectively halting mitosis. This disruption is linked to the inhibition of essential processes such as protein and nucleic acid synthesis, which are crucial for cell division and growth (Devine *et al.*, 1993). These treatments significantly improved yield components and yields compared to the weedy check. The weedy check experienced intense and continuous competition throughout the crop season due to unchecked weed growth which led to excessive depletion of soil nutrients and moisture by the weeds ultimately hindering crop development. The greater competitiveness of a mixed weed population observed in the field further supports that diverse weed species pose a stronger challenge to crop growth than a single-species infestation. Thus, season-long weed control played a crucial role in enhancing crop performance, supporting earlier findings by Thakral *et al.* (2007), Gohil *et al.* (2015) and Choudhary *et al.* (2021) in fennel, Patel *et al.* (2016) in cumin, Dhakad *et al.* (2017) and Patil *et al.* (2020) in coriander.

Effect of Nutrient management

In the present investigation, the application of 125% RDF resulted in the maximum plant height, branches plant^{-1} and dry matter accumulation which were statistically at par with 100% RDF. This enhancement can be attributed to increased nutrient availability in the soil, which led to better absorption and translocation of essential elements within the plant. These nutrients played a vital role in stimulating active cell division and elongation, ultimately supporting greater morphological development. Improved growth parameters likely contributed to larger canopy size and increased chlorophyll content, given the role of NPK in chlorophyll synthesis. The findings are strongly supported by earlier reports of Mehta *et al.* (2010) in fenugreek, Pariari *et al.* (2015), Waskela *et al.* (2017) and Kalasare *et al*. (2021) in fennel.

Yield attributes (Table 4) were significantly found higher with application of 100 % RDF by 31.22 %, 26.84%, 44.54%, 13.90% and 38.77% number of umbles plant^{-1}, umblets umble^{-1}, seeds umble^{-1}, test weight and seed yield, respectively, over control. These parameters were close to 125 % RDF. The yield attributes and yield were found to be higher due to higher nutrient availability under the recommended dose of fertilizer. The longer period of the reproductive phase due to higher nutrition (N, P and K) resulted in higher seed yield per hectare. The significantly highest biological yield, 3978 kg ha^{-1} also recorded under treatment 100 % RDF and the lowest, 2865 kg ha^{-1} under control, respectively. Biological yield was the total of total the dry matter accumulation and the seed yield. The dry matter accumulation depends on the photosynthetic activities of the plants under consideration. The nutrient-deficient environment resulted in the lowest biological yield, while sufficiency of nutrients (N, P and K), resulted in more photosynthesis. The results suggest that NPK fertilization improved both direct parameters, like dry matter accumulation and indirect traits such as branching and reproductive structures. These findings are in strong agreement with earlier studies conducted by Mehta *et al.* (2010) in fenugreek, Naruka *et al.* (2012) in ajwain, Singh and saxena (2013) in cumin, Pariari *et al.* (2015), Kumawat *et al.* (2015) , Kalasare *et al*. (2018), Kusuma *et al*. (2019) and Kumar *et al.* (2022) in fennel.

Table 2: Effect of weed control measures and nutrient management on number of weeds

Treatment	Numbers of weeds(m^{-2})		Weed dry matter accumulation ($g\ m^{-2}$)	
	At 50 DAS	At harvest	At 50 DAS	At harvest
Nutrient management				
Control	4.64 -31.67	4.16 -26.78	7.16	48.89
5% RDF	4.89 -34.71	4.5 -29.85	8.59	53.68
100 % RDF	4.96 -35.6	4.7 -32.61	9.61	59.53
125 % RDF	5.07 -37.57	4.9 -35.11	9.95	61.58
SEm±	0.042	0.06	0.35	1.46
CD (p=0.05)	0.12	0.18	1.01	4.2
Weed control measures				
Weed free	0.71 0	0.71 0	0	0
Pendimethalin at 0.75 Kg ha^{-1} PE	4.12 -16.5	3.78 -13.97	3.61	29.57
Oxyfluorfan at 50 g ha^{-1} (PoE at 25 DAS)	4.55 -20.23	4.03 -15.9	4.38	32.98
Weedy check	10.16 -102.82	9.73 -94.47	27.31	161.14
SEm±	0.04	0.06	0.35	1.46
CD (*p=0.05*)	0.12	0.18	1.01	4.2

**The original weed density per m2 is shown in parenthesis. A square root transformation of x + 0.5 were used*

Table 3: Effect of weed control measures and nutrient management on weed control efficiency and weed index

Treatment	Weed control efficiency (%)		Weed index (%)
	At 50 DAS	At harvest	
Weed control measures			
Weed free	100	100	0
Pendimethalin at 0.75 kg ha^{-1}PE	86.87	81.78	16.89
Oxyfluorfan at 50 g ha^{-1}(PoE at 25 DAS)	84.03	79.67	31.5
Weedy check	0	0	92.07
SEm±	-	-	-
CD (*p=0.05*)	-	-	-

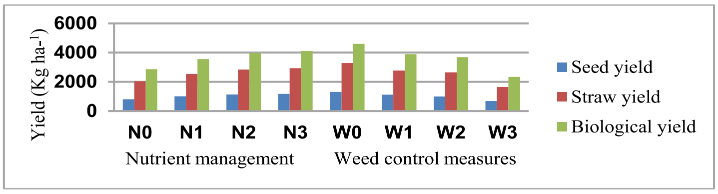

Fig. 1 Effect of nutrient management and weed control measures on yield

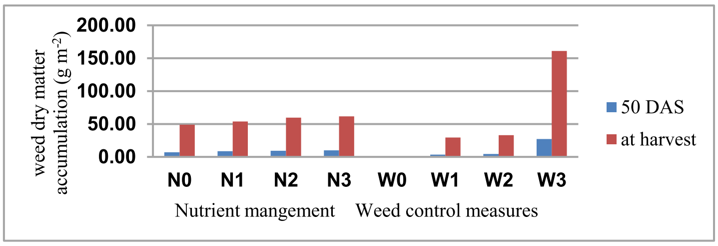

Fig. 2 Effect of nutrient management and weed control measures on weed dry matter accumulation

Table 4: Effect of weed control measures and nutrient management on yield attributes and yield of crop

Treatment	Yield attributes				Biological Yield (kg ha^{-1})	Harvest index (%)	
	Number of umbels plant^{-1}	Number of umbellate umbel^{-1}	Number of seeds umbel^{-1}	Test weight (g)			B: C ratio
Nutrient management							
Control	11.85	14.08	136.03	4.82	2865	29.64	2.19
75% RDF	14.18	16.74	174.3	5.23	3558	28.76	2.56
100 % RDF	15.55	17.86	196.63	5.49	3978	28.61	2.78
125 % RDF	15.99	18.21	199.89	5.65	4117	28.64	2.82
SEm±	0.39	0.39	5.78	0.14	67	0.71	0.06
CD (p=0.05)	1.12	1.13	16.69	0.4	192	NS	0.16
Weed control measures							
Weed free	18.2	20.63	232.69	5.62	4595	28.57	2.62
Pendimethelin at 0.75 kg ha^{-1} PE	14.58	16.69	191.41	5.39	3895	28.85	2.97
Oxyfluorfan at 50g ha^{-1} (PoE at 25 DAS)	13.61	15.75	171.11	5.56	3688	28.29	2.79
Weedy check	11.17	13.81	111.65	4.64	2340	29.95	1.98
SEm±	0.39	0.39	5.78	0.14	67	0.71	0.06
CD (*p=0.05*)	1.12	1.13	16.69	0.4	192	NS	0.16

Conclusion

The study concludes that weed control through pendimethalin at 0.75 kg ha^{-1} (PE) gave maximum growth and yield attributes, yield, net return and the highest B: C ratio with effective control of weeds after weed-free treatment in fennel crop. The season-long weed-free conditions and optimal nutrient management (100% RDF) are critical for maximizing fennel productivity and profitability. However, these results are only indicative and further experimentation is required to arrive at more consistent and definite conclusions for recommendation to the farmers.

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Conflict of Interest

The authors declare there is no conflict.

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