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Influence of weed control measures and nutrient management on growth of fennel (*Foeniculum vulgare* Mill.)

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Abstract
A study was carried out on loamy sandy soil during the *Rabi* season of 2021-22 at the Instructional Farm of SKRAU in Bikaner, Rajasthan. The objective of the study was to investigate the influence of weed control measures (weed-free, pendimethalin @ 0.75 kg ha^{-1} (PE), Oxyfluorfen @ 50 g ha^{-1} (POE at 25 DAS), and weedy check) and nutrient management (control (no fertilizer applied), 75% RDF, 100% RDF, and 125% RDF) on the growth and yield of fennel crop (*Foeniculum vulgare* Mill.). The experiment was conducted using a FRBD design with three replications. The results indicated that the weed-free treatment significantly improved crop growth attributes such as plant population, plant height, number of branches plant^{-1}, dry matter accumulation, CGR, and RGR and followed by pendimethalin @ 0.75 kg ha^{-1} (PE) and oxyfluorfen @ 50 g ha^{-1} (POE at 25 DAS) treatments and also showed a positive impact on crop growth attributes. Furthermore, among the various nutrient management treatments, the treatment with 100% recommended dose of fertilizer (RDF) exhibited significantly superior on growth parameters in fennel.

Keywords: Fennel, weed management, pendimethalin, oxyfluorfen, RDF

Introduction
Fennel (*Foeniculum vulgare* Mill.) is a highly significant seed spice crop that belongs to the *Umbelliferae* family. It is commonly known as *Saunf*. The fennel plant possesses a pleasant aroma, and all its parts, including leaves, bulbs, stalks, and seeds, are edible. Fennel seeds are characterized by their fragrant odor and delightful aromatic taste, which can be attributed to the presence of volatile oils such as Anethole and Fenchone. These seeds are commonly utilized in various culinary applications, including meals, meat and fish dishes, ice cream, alcoholic beverages, and herb blends. In terms of composition, the seeds contain approximately 9.5% protein, 42.3% carbohydrates, 18.5% fiber, 10.0% fat, and 13.4% minerals. The volatile oil content ranges from 0.7% to 6.0%, depending on the genotypes or botanical types (Bhunia *et al*., 2005) [2]. Fennel is believed to be native to the Mediterranean and Southern Europe. In India, fennel is primarily cultivated in the states of Gujarat, Rajasthan, Madhya Pradesh, Haryana, Maharashtra, Uttar Pradesh, and Punjab. In Rajasthan, fennel is grown on an area of 26.25 thousand hectares, yielding 25.62 thousand tonnes with an average yield of 976 kg ha^{-1} (Spice Board, India, 2019-20) [13]. The cultivation of fennel is concentrated in districts such as Tonk, Pali, Sirohi, and Jodhpur, with limited cultivation in Bharatpur, Bikaner, Kota, Jaipur, and Ajmer.

Weed and nutrient management practices are crucial factors in achieving a low fennel yield. The presence of macro nutrients, such as nitrogen, phosphorus, and potassium, is vital for the growth of all crops. Nitrogen, in particular, is the element that most significantly limits crop yields. It is an essential component of protein, chlorophyll, and various other compounds that play a crucial role in crop metabolism, including nucleotides, phospholipids, enzymes, alkaloids, hormones, and vitamins. Phosphorus, on the other hand, is essential for energy transfer compounds (such as ATP and other nucleoproteins), the genetic information system, cell membranes, and phospho-proteins. It contributes to shoot hardness, improves grain quality, regulates photosynthesis, governs physiochemical processes, and aids in cell enlargement and disease resistance. Additionally, potassium plays a major role in the transportation of water and nutrients throughout the plant via the xylem, and it enhances drought tolerance in plants.

Therefore, achieving balanced crop nutrition is crucial for maximizing crop yield and maintaining soil fertility. This requires considering the interaction of nutrients in a given soil and crop agro-climatic region.

Fennel typically requires a longer period of time for germination and also experiences slow initial growth, which often results in intense competition with weeds. The wide spacing and slow early growth of the crop contribute to the proliferation of weeds even before the crop emerges. Consequently, weeds emerge quickly and grow rapidly during the initial stages of the crop, posing a critical threat to the crop's access to essential growth resources such as nutrients, moisture, light, and space throughout its vegetative and early reproductive stages. Weeds also consume a significant amount of stored moisture and absorb substantial quantities of nutrients from the soil. Additionally, the presence of weeds diminishes the efficiency of photosynthesis, the production of dry matter, and the distribution of photosynthates to economically valuable parts of the crop, thereby negatively impacting the source and sink relationship. Therefore, it is crucial to control weeds in a timely manner; otherwise, the growth (both vegetative and reproductive) and yield of the crop will be significantly reduced when it becomes infested with weeds. In fact, if weeds are not effectively controlled, the seed yield can be reduced by as much as 50 percent (Gohil *et al*., 2015) [6].

Materials and Methods

The field experiment was conducted during the Rabi season of 2021-22 at the Instructional Farm of S.K. Rajasthan Agricultural University in Bikaner. The location of the farm is situated at 28.010 N latitude and 73.220 E longitudes, with an altitude of 234.70 meters above mean sea level. According to the National Agricultural Research Project (NARP), Bikaner falls within the Agro-climatic zone IC, which is classified as a Hyper Arid Partially Irrigated North Western Plain Zone. Bikaner experiences an arid climate, with an average annual rainfall of approximately 250 mm. The majority of this rainfall, more than 80 percent, is received during the kharif season (July-September) through the south-west monsoon. The maximum temperature during the summer can reach as high as 48 °C, while in the winter, it can drop as low as 0 °C. The National Planning Commission categorizes Bikaner under Agro-climatic zone XIV, which is known as the Western Dry Region of India. The analysis of the soil in the experimental field revealed that it has a loamy sand texture and a slightly alkaline pH. The soil is deficient in organic carbon and has low levels of available nitrogen, phosphorus, sulphur, and iron. However, it has medium levels of available potassium.

The experiment consisted of four treatments of nutrient management, namely control (no fertilizer applied), 75% recommended dose of fertilizer (RDF), 100% RDF, and 125% RDF, as well as four treatments of weed control measures, including weed-free, pendimethalin at 0.75 kg ha^{-1} (PE), oxyfluorfen at 50 g ha^{-1} (POE at 25 DAS), and weedy check. As a result, there were 16 treatment combinations that were arranged in a factorial randomized block design, using Fisher's random number table (Fisher, 1950), and replicated three times. The fennel cultivar 'RF 141' was sown using a standard package of practices, with sowing carried out through a *Deshi* plough at 50 cm row space, using 8 kg seed ha-1 at a depth of 2-3 cm on 31 October 2021. Fertilizers were applied in the experimental field according to the treatment. Half the dose of nitrogen and the full dose of phosphorus and potassium were drilled about 5-7 cm deep through a hand plough as basal at sowing, while the remaining dose of nitrogen through urea was applied in two equal splits with irrigation. Herbicides and hand weeding were carried out according to the treatment assigned to the experimental unit. The spray of pendimethalin and oxyfluorfen was done with a knapsack sprayer, keeping the spray volume at 700-800 liters ha^{-1}, and weeding was done manually according to the treatment. Recommended plant-protection measures were adopted to grow a healthy crop. At the maturity stage, the crop from the net area was harvested manually on 01.04.2022. The critical difference (CD) for the treatment comparisons was calculated wherever the variance ratio (F test) was found significant at the 5% level of probability.

Results and Discussion

Effect of weed control measures

The weed control treatments exhibited significant variations in their impact on the population of plants, height of plants, number of branches per plant, dry matter accumulation, CGR, and RGR (as shown in Table 1 to 3). All of the treatments resulted in a significant increase in the growth characteristics of fennel at all stages of the crop, compared to the weedy check. The treatment with no weeds recorded the highest plant population, plant height, number of branches per plant, dry matter accumulation, CGR, and RGR, with increases of 36.98%, 33.32%, 86.92%, 32.48%, 31.90%, and 6.58% respectively, compared to the weedy check at harvest. The treatment with pendimethalin at a rate of 0.75 kg ha^{-1} (PE) was found to be the next best and equally effective treatment in enhancing these characteristics of fennel. The improvement in growth attributes achieved by pendimethalin at a rate of 0.75 kg ha^{-1} (PE) was 32.06%, 31.26%, 67.43%, 29.10%, 28.48%, and 5.8% respectively, compared to the weedy check at harvest. This is because when there are fewer weeds and less weed dry matter accumulation, there is less competition for plant growth resources, allowing crop plants to produce more dry matter and grow taller when weed control measures are implemented. Similar results have been reported by Nagar *et al*. (2009) [11] and Kumar *et al*. (2021) [8] in fennel. Therefore, the availability of sufficient light, space, and a favorable soil and nutritional environment, along with improvements in the physiological and morphological characteristics of the plant in the rhizosphere, enhance photosynthetic efficiency and lead to greater dry matter accumulation under better treatments. In contrast, the continuous growth of weeds throughout the crop season in the weedy check hinders crop growth due to high competition between weeds and the crop. Hand weeding, carried out through hoeing, also improves the physical condition of the soil by increasing its friability and aeration. It is an effective method for preventing weeds from producing seeds, which can aid in the establishment and proliferation of roots and ultimately promote plant growth. The present findings align with the research conducted by Chovatia *et al*. (2009) [5], Bagri *et al*. (2014) [1] in the case of fenugreek, and Birla *et al*. (2016) [3], who reported the superior effects of herbicides on enhancing the growth of cumin.

Effect of nutrient management

The maximum plant height, number of branches plant^{-1} and dry matter accumulation, RGR and CGR (Table 1 to 3) were achieved with treatment 125% RDF but was uncountable after 100% RDF level which significantly increased 27.76 per cent plant height, 29.67 per cent number of branches plant^{-1} and 21.76 per cent dry matter accumulation over control at harvest. The enhancement of crop growth parameters can be attributed to the fulfillment of crop requirements, which has resulted in the creation of a favorable soil environment for crop growth. Waskela *et al*. (2017) [14] also supported these findings. The augmented endogenous levels of nitrogen, phosphorus, and potassium in plants, owing to their increased availability in the soil medium, have led to efficient absorption and translocation in growths through active cell division and elongation, resulting in greater plant height. These results have been substantiated by Mehta *et al*. (2010) [10] and Pariari *et al*. (2015) [12].

Table 1: Effect of weed control measures and nutrient management on plants population, plant height and number of branches of crop at harvest

Treatment	Plants population ha^{-1}	Plant height	Number of branches
Nutrient management			
Control	78061	93.45	5.56
75% RDF	80000	107.29	6.55
100% RDF	81654	119.40	7.21
125% RDF	82165	121.62	7.38
S.Em±	2111	2.81	0.18
CD (p=0.05)	NS	8.12	0.52
Weed control measures			
Weed free	90129	122.17	8.15
Pendimethalin @ 0.75 kg ha^{-1}PE	86892	120.28	7.30
Oxyfluorfan @ 50 g ha^{-1}PoE at 25 DAS	79062	107.70	6.90
Weedy check	65797	91.63	4.36
S.Em±	2111	2.81	0.18
CD (p=0.05)	6097	8.12	0.52

NS= Non-significant

Table 2: Effect of weed control measures and nutrient management on crop on dry matter accumulation

Treatment	Dry matter accumulation (g m^{-2})	
	At 50 DAS	At harvest
Nutrient management		
Control	31.29	289.49
75% RDF	37.64	341.96
100% RDF	41.92	378.05
125% RDF	42.38	382.10
S.Em±	1.04	8.29
CD (CD (p=0.05)	3.00	23.95
Weed control measures		
Weed free	45.49	396.52
Pendimethelin @ 0.75 kg ha^{-1}PE	40.55	377.64
Oxyfluorfan @ 50 g ha^{-1}PoE at 25 DAS	38.03	349.73
Weedy check	29.16	267.71
S.Em±	1.04	8.29
CD (p=0.05)	3.00	23.95

Table 3: Effect of weed control measures and nutrient management on crop growth rate and relative growth rate of crop

Treatment	CGR (g m^{-2} day^{-1})		RGR (mg g^{-1}day^{-1})
	0 - 50 DAS	50 DAS - at harvest	50 DAS - at harvest
Nutrient management			
Control	0.63	2.58	2.44
75% RDF	0.75	3.04	2.51
100% RDF	0.84	3.36	2.56
125% RDF	0.85	3.40	2.56
S.Em ±	0.02	0.08	0.01
CD (p=0.05)	0.06	0.24	0.03
Weed control measures			
Weed free	0.91	3.51	2.58
Pendimethelin @ 0.75 kg ha^{-1} PE	0.81	3.37	2.56
Oxyfluorfan @ 50 g ha^{-1} PoE at 25 DAS	0.76	3.12	2.52
Weedy check	0.58	2.39	2.41
S.Em±	0.02	0.08	0.01
CD (p=0.05)	0.06	0.24	0.03

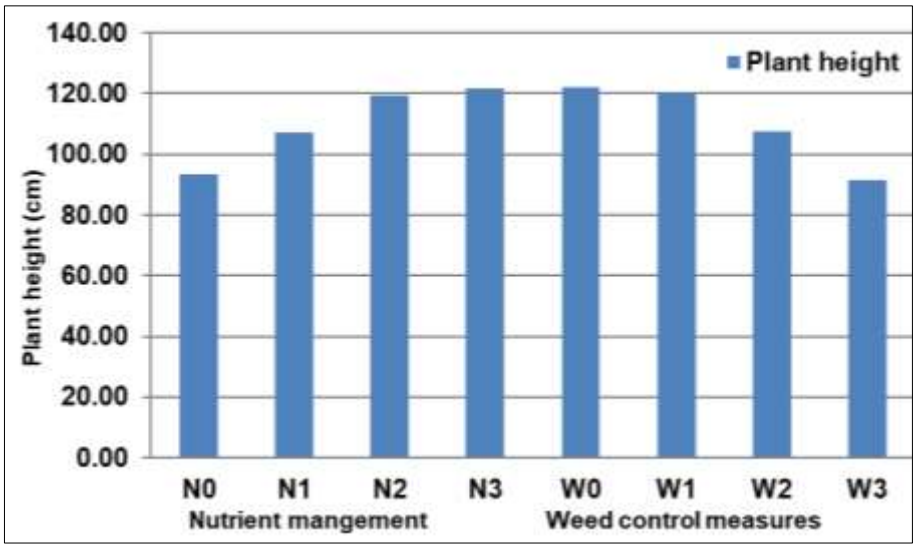

Fig 1: Effect of nutrient management and weed control measures on plant height

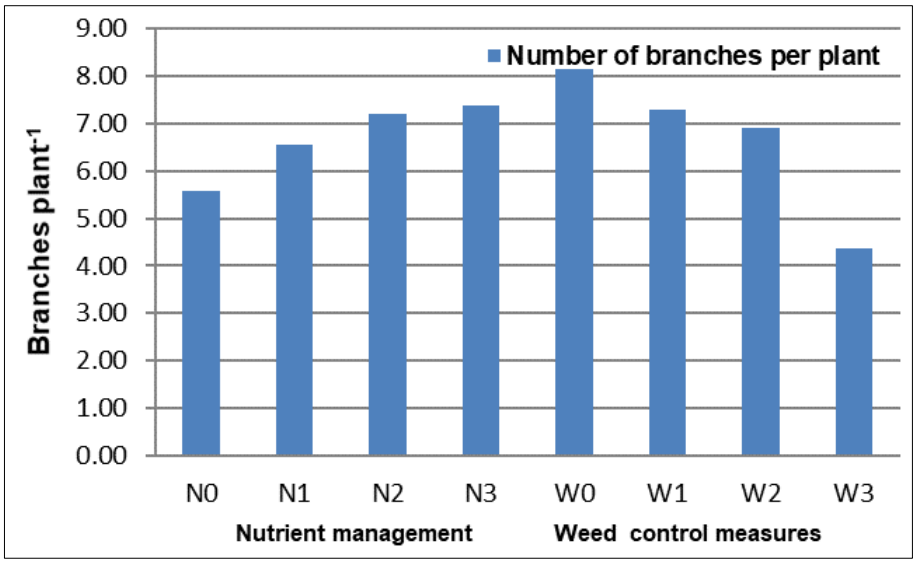

Fig 2: Effect of nutrient management and weed control measures on branches plant^{-1}

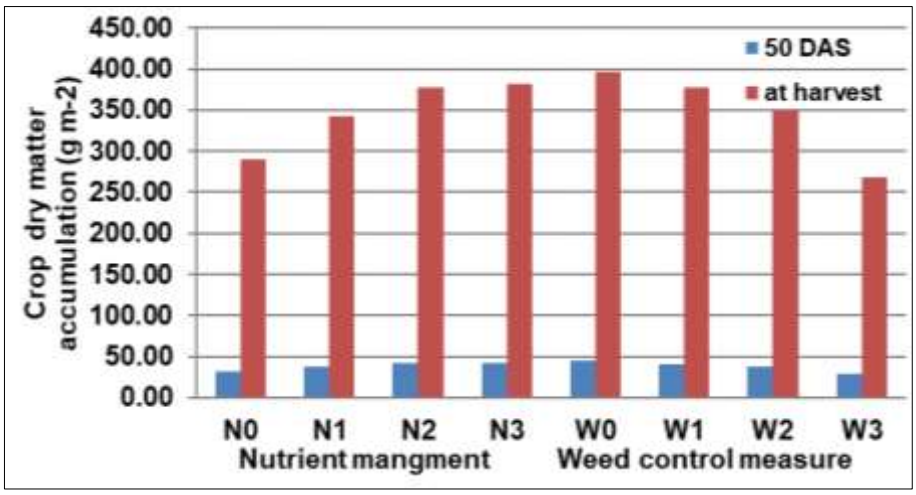

Fig 3: Effect of nutrient management and weed control measures on crop dry matter accumulation

Conclusion

It was concluded from the results that the weed-free treatment significantly improved crop growth and followed by pendimethalin @ 0.75 kg ha^{-1} (PE) and oxyfluorfen @ 50 g ha^{-1} (POE at 25 DAS) over control. Furthermore, among the various nutrient management treatments, the treatment with 100% recommended dose of fertilizer (RDF) exhibited significantly superior on growth of crop over rest of the treatments.

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