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Influence of Different Nitrogen Levels and Spacing on Seed Yield and Economics of Fennel (*Foeniculum Vulgare* Mill.)

Preeti Yadav [a++], T. P. Malik [a#], Ram Mehar [a†*] and Sumit Deswal [a^]

[a] Department of Vegetable Science, CCS Haryana Agricultural University, Hisar-125004, Haryana, India.

Authors' contributions

This work was carried out in collaboration among all authors. Author PY participated in the experiment's execution, data collecting, study analysis, and publication preparation. Author SD assisted with the drafting, editing, data analysis and interpretation of the manuscript. Author TPM helped in the research work's planning, designing, and monitoring. Author RM contributed to the design of the project, its oversight, the analysis and interpretation of the data, and its final submission to the journal. The final version of the manuscript was authorized by all authors, who also agreed to take responsibility for every part of the work. All authors read and approved the final manuscript.

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ABSTRACT

The present study entitled, "Influence of nitrogen levels and spacing on seed yield and economics of fennel (*Foeniculum vulgare* Mill.)" was conducted during the Rabi *season* of 2021-22 with fennel

[++] Ph.D. Student;
[#] Professor and Head;
[†] PG Student;
^Assistant Scientist;
**Corresponding author: E-mail: rammeharsandhu1111@gmail.com;*

variety HF-143 using four different nitrogen levels (0, 25, 50 and 75 kg ha^{-1}) and three-row to row spacing (30x20 cm, 45x20 cm, and 60x20 cm). Sowing of the crop was done on 30th October 2021 in factorial randomized block design (RBD), and harvesting on 10th May 2022. The yield parameters, *i.e.,* number of umbels per plant, number of umbellate per umbel, seeds per umbels, and seed yield (per plot and hectare), were recorded with three replications of each treatment. The economics of each treatment was also calculated. The result revealed that 50 kg N ha^{-1} treatment with 45x20 cm spacing was best for obtaining higher seed yield. Fertilizing the fennel crop with 50 kg ha^{-1} nitrogen level and sowing at 45x20 cm is economical to obtain a high seed yield. Though seed yield increased with an increase in nitrogen fertilizer dose, the rise in the value of seed yield from 50-75 kg N ha^{-1} was found non-significant. From the present study, it can be concluded that the fennel crop produced a higher seed yield (18.23 q ha^{-1}), maximum net return (Rs. 1,14,670 ha^{-1}), and benefit-cost ratio *i.e.,* B: C (2.71) at 50 kg N with 45x20 cm spacing under the semi-arid, subtropical condition in sandy loam soil of Haryana.

Keywords: Fennel; nitrogen; spacing; seed yield and economics.

1. INTRODUCTION

Fennel is one of the most essential seed spice crop natives to Southern Europe and the Mediterranean region [1]. It is the annual herbaceous plant in the Umbelliferae family (Apiaceae). Fennel is cultivated for its economic, aromatic, and medicinal value. The dried seeds contribute to a pleasantly aromatic spice used in stews, cuisine, sweet bread, sausages, and cakes [2]. Mature fennel seeds are used as flavoring agents in food products such as pickles, liqueurs, and cheese [3]. Despite culinary and industrial uses, fennel seeds also have medicinal importance due to the presence of various chemicals, including trans-anethole, d-2 fenchone, 2-pinene, foenicullin, camphene, d-2 phellandrene, foenicullin, dipentenes, tri terpinene. Fennel seeds are estrogenic, having digestive, stimulative, appetizing, and carminative properties chewed as a remedy to prevent bad breath smell, and are used in cough, flatulence, dysentery, and diarrhoea [4]. Although the climatic conditions in India are favourable for fennel cultivation, it is grown in a limited area of Gujarat, Rajasthan, Madhya Pradesh, West Bengal, Uttar Pradesh, Maharashtra, Andhra Pradesh, and Punjab. In 2021, Gujrat contributes 71.67% to the total production followed by Rajasthan (24.86%), Madhya Pradesh (1.91%), West Bengal with 0.77% and other state 0.49%. Till date, it is an underutilized seed spice crop. This limited cultivation is due to less attention given in the past to its cultural aspects and, thus, the lack of knowledge among farmers about the cultural requirements for effective cultivation. Nitrogen fertilizer and spacing determine this crop's overall growth, yield, and economics.

Among the various factors which increase yield per unit area basis, applying nitrogen fertilizer is considered the most important in fennel [5]. It is an important constituent of various compounds of physiological importance such as nucleotides, phospholipids, vitamins, hormones, coenzymes, pigments, protein and chlorophyll and is involved in the metabolic process leading to the synthesis and transfer of energy. The application of nitrogen not only increases seed yield but can also improve oil content [6]. Nitrogen application positively affected plant height and seed yield of fennel [7,8]. Spacing is also a critical factor in determining growth and yield by defining the microenvironment in the field and interception of sunlight in the plant canopy. Thus, a suitable planting pattern is an important input that avoids interspacing competition, cooperative interaction and competitive interaction during the crop growing season. Adjustment in planting patterns creates favourable environmental conditions for better performance of all the physiological processes in plants, thus providing more fantastic opportunities to maximize yield. The wider spacing increases the yield and growth of fennel, while closer spacing increases competition within the crop plant, resulting in poor growth and yield by determining the microenvironment in the field. Proper optimization of these factors can lead to higher yield by favourably affecting the absorption of nutrients and exposing plants to light [9]. Even though the environmental conditions in Haryana are favourable for fennel cultivation but it is cultivated only in a limited area. Lack of awareness and knowledge among farmers about the cultural practice requirement for effective cultivation may be the reason behind this situation. Therefore, there is a need to develop agronomic as well as nutrient

management practices for increasing the productivity of this crop which could enhance the profit of growers. Hence, promising research on optimum nitrogen level and plant density will open new doors of wide scope to test the performance of fennel in semi-arid regions of Haryana by restructuring these inputs for optimum economic yields while sustaining soil health. Therefore, a study was conducted to check the effect of nitrogen levels and spacings on seed yield and economics of fennel.

2. MATERIALS AND METHODS

The experiment was conducted during the Rabi season of 2021-2022 at Research Farm, Department of Vegetable Science, Chaudhary Charan Singh Haryana Agricultural University, Hisar. The experimental field was 215.2 meters above mean sea level in the subtropics with coordinates of 29º 10' North latitude and 75º 46' East longitudes. The experiment consists of four nitrogen levels *viz.,* 0, 25, 50, and 75 kg ha^{-1} and three-row spacings *viz.,* 30, 45, and 60 cm. The treatments were evaluated in factorial randomized block design (RBD) with three replications to examine the main effect of both independent factors simultaneously. Sowing of the fennel variety HF-143 was done on 30th October 2021; half the dose of nitrogen was supplied as a basal dose and the rest half dose as a top dressing on 45 days of sowing. All recommended agronomic practices were followed timely for the successful raising of the crop. The crop was harvested after full maturity on 10th May 2022, and threshing was done after sun drying for 4-5 days in the field. Different yield parameters, *viz., several* umbels /plant, umbellate/umbel, seeds/ umbel, seed yield/plot, and seed yield/ha, were recorded on ten randomly selected plants. Observational plants were tagged from each plot. Boarder rows of plants were avoided for recording observations. The average of different recorded observations was subjected to statistical analysis as per the standard procedure given by Panse and Sukhatme [10]. The physico-chemical properties of soil of the experimental field are presented in Table 1.

3. RESULTS AND DISCUSSION

3.1 Effect of Nitrogen Fertilizer Level on Yield Attributes and Seed Yield

Nitrogen fertilizer significantly affected the yield attributes, *viz.,* number of umbels per plant, umbellate per umbel, seeds per umbel, and ultimately the seed yield. The inflorescence of fennel is called an umbel. Umbel contains an umbellate where seed setting takes place. The numbers of umbel were directly responsible for a good yield. More umbel per plant ensures more seed yield. Among different nitrogen levels tried, the number of umbels per plant (36.94) was observed to significantly maximum with nitrogen applied at 75 kg $ha^{-1,}$ which was statistically at par with nitrogen supplied at 50 kg ha^{-1} (36.23). It might be due to the greater availability of nutrients to the plant so that it could develop a more significant number of branches and reproductive structures, due to which a maximum number of umbels were produced on the plant. Whereas the minimum number of umbels per plant were recorded with control (21.10) treatment *i.e*., without the application of nitrogen fertilizer as few quantities of nitrogen remains in the soil.

It also proved the finding of Azizi et al. and Nath et al. [11 and 12] in Ajowain and Tehlan et al. [13] in coriander.At the same time, Kucha et al. [14] observed a significant maximum number of umbels per plant in fennel on applying 120 kg

Table 1. The physico-chemical properties of soil

Component	Values	Method
Sand (%) Silt (%) Clay (%)	59 23 18	International pipette method (Piper, 1966)
pH	8.10	pH meter with glass electrode in 1:2 Soil Water Suspension (Jackson, 1973)
EC (dS/m)	0.36	Conductivity Bridge Method (Richards, 1954)
Organic carbon (%)	0.35	Digestion Method (Walkley and Black, 1934)
Available nitrogen (kg/ha)	134.2	Alkaline Permanganate Method (Subbiah and Asija, 1956)
Available phosphorus (kg/ha)	22.00	Olsen's Method (Olsen et al., 1954)
Available potassium (kg/ha)	228	N NH_4OAC extraction and Flame photometry method, (Jackson 1973)

N $ha^{-1.}$ As the number of umbellate per umbel depends on the number of umbels per plant, the maximum number of umbellate per umbel was recorded at 75 kg N ha^{-1} (26.40), closely followed by 50 kg N ha^{-1} (26.11). At the same time, significantly, the lowest value was observed under the control treatment. The number of umbellets per umbel increased with an increase in nitrogen dose. Similarly, Mehta et al. and Singh and Amin [15 and 16] observed an increase in the number of umbellets per umbel with an increased nitrogen dose of up to 120 kg N ha^{-1} in fennel crop. It might be due to the greater availability of photosynthates, metabolites, and nutrients for the development of reproductive structures as nitrogen played an essential role in chlorophyll synthesis, which is the main absorber of light energy needed for photosynthesis and thus, increased photosynthates production and translocation in the plant. High nitrogen levels had positively affected seeds per umbel up to the moderate application dose. The maximum number of seeds per umbel was recorded at the highest nitrogen dose among all treatments, *i.e.,* at 75 kg N ha^{-1} (533.40), closely followed by nitrogen supplied at 50 kg ha^{-1} (526.07), which was statistically at par. Similar results were recorded by Mohammad et al. and Raj and Thakral [17 and 18] in fennel.

The greater availability of nutrients in the root zone led to increased metabolic activity at the cellular levels, thus increasing the number of seeds per umbel in fennel. Also, an increase in the number of seeds per umbel in fennel may be attributed to an improved number of umbellets per umbel and seeds per umbellet, ultimately resulting in higher seeds per umbel. The plot having the highest-yielding plants will subsequently possess the highest yield per plot. The data presented in Table3 showed that nitrogen levels significantly influenced seed yield per plot. Seed yield per plot (0.946 kg) was recorded as significantly maximum with the application of 75 kg ha^{-1} of nitrogen, which was statistically at par with nitrogen supplied at 50 kg ha^{-1} (0.943 kg), whereas the minimum seed yield per plot was recorded with control (0.733 kg). Seed yield per hectare means productivity is enhanced with increased nitrogen levels. This investigation showed that nitrogen levels significantly influenced seed yield. Maximum seed yield was recorded on applying 75 kg N ha^{-1} (17.55 q ha^{-1}), closely followed by nitrogen supplied at 50 kg ha^{-1} (17.54 q ha^{-1}). The higher seed yield in fennel may be attributed to improved yield components, which ultimately resulted in higher yield as growth and yield aspects showed a significantly positive correlation with seed yield. A significant increase in seed yield under higher nitrogen levels was due to solid sinks and source activity formation. The present findings are in close agreement with the results obtained by Bhardwaj and Kumar [19] and Meena et al. [20] that a positive corelation exists between nitrogen fertilizer dose and yield in fennel.

3.2 Effect of Spacing on Yield Attributes and Seed Yield

Row Spacing significantly affected the yield attributes, *viz.,* number of umbels per plant, umbellate per umbel, seeds per umbel, and ultimately the seed yield. From the present study, it can be concluded that number of umbels per plant are significantly affected by row spacing. A significant maximum number of umbels /plants was recorded at 60x20 cm spacing (33.28), statistically at par with 45x20 cm (32.38). In fennel, Waskela et al. [21] and Jakhar et al. ([22] recorded similar results and found that wide spacing resulted in higher nutrient absorption, profuse branching, and more significant biomass accumulation per plant. The profuse branching led to more flowering and an optimum supply of metabolites due to increased biomass per plant, which might have helped retain more umbels. At the same time, Singh and Amin (2015) [16] and Tamboli et al. (2020) [23] suggested that the spacing of 45 x 20 cm gave significantly more umbels per plant in fennel. The number of umbellate per umbel depends on the growth and nutrient status of the plant and is significantly affected by spacing. The number of umbellets per umbel was noticed to be significantly maximum at 60x20 cm spacing (24.54), closely followed by 45x20 cm (24.36), while the minimum number of umbellets per umbel was observed at 30x20 cm (23.85) spacing. Similar results were observed by Waskela et al. [21] and Jakhar et al. [22] in fennel. At the same time, Singh and Amin (2015) observed the maximum number of umbellets per umbel at 45x20 cm spacing in fennel and stated that the vigorous vegetative growth in the adequate space increased the biomass per plant to the appropriate supply of metabolites and, consequently, a maximum number of umbellets per umbel. The number of seeds per umbel positively correlates with metabolites production and source and sink relation. A significant maximum number of seeds per umbel was

recorded at 60x20 cm spacing (448.37), statistically at par with 45x20 cm (441.08).

In contrast, the minimum number of seeds per umbellet was observed at 30x20 cm (414.74) spacing. Similar results were recorded by Waskela et al. [21]. It might be due to the robust vegetative growth and higher biomass accumulation in widely spaced plants led to an increased supply of metabolites towards a reproductive structure that helped to get top seeds per umbel in fennel. Maximum seed yield (per plot and hectare) is the ultimate goal of any farmer, and it depends directly on growth and yield attributes. Seed yield is affected significantly by spacing as a factor of competition among plants, and the spacing which gives maximum yield is the optimum spacing. Seed yield was significantly maximum at 45 x 20 cm spacing (16.85 q ha^{-1}) followed by 60 x 20 cm (16.29 q ha^{-1}). Similar results were recorded by Singh and Amin [16] and Tamboli et al. [23] in fennel. This might be due to the availability of optimum space for individual plants, which has resulted in better utilization of resources, *viz.*, space, nutrients, moisture, carbon dioxide, and radiant energy to improve vegetative growth, reproductive growth, and seed yield. Also, close spacing led to competition among plants, while broader spacing led to a low plant population, resulting in lower seed yield. Thus, optimum spacing is best suited for seed yield.

3.3 Interaction Effect of Nitrogen Levels and Spacing

Interaction effects of nitrogen levels and spacing on the number of umbels per plant and seed yield (per plot and hectare) of fennel were found significant, whereas non-significant on the number of umbellate per umbel and seed per umbel. A significant maximum number of umbels per plant were found at treatment combination of (T_4S_3), *i.e.,* nitrogen applied at 75 kg ha^{-1} under 60x20 cm (38.30) spacing, which was statistically at par with T_4S_2 (37.86), T_3S_3 (37.67) and T_3S_2 (37.12). At the same time, the minimum number of umbels per plant was recorded with the treatment combination of T_0S_1 (18.22). An interaction effect was found non-significant for several umbellate and seeds per umbel. However, the maximum number of umbellets per umbel (26.68) and seeds per umbel (550.42) were found at the treatment combination of (T_4S_3), *i.e.,* nitrogen applied at 75 kg ha^{-1} under 60x20 cm spacing followed by T_4S_2 26.52 and 543.47 respectively. At the same time, the minimum number of umbellets per umbel was recorded with the treatment combination of T_0S_1 20.31 and 270.15, respectively. The interaction effect of nitrogen levels and spacings on seed yield (per plot and hectare) was significant. Maximum seed yield (per plot and hectare) was obtained with the treatment combination of T_4S_2 (0.980 kg) and (18.24 q ha^{-1}), *i.e.,* nitrogen applied at 75 kg ha^{-1} under 45x20 cm spacing which was statistically at par with T_3S_2 (0.977 kg) and (18.23 q ha^{-1}). In comparison, minimum seed yield per plot was recorded with a treatment combination of T_0S_1 (0.647 kg) and (12.05 q ha^{-1}), *i.e.,* at control under 30x20 cm spacing. This value signifies that application of nitrogen has a positive and economical on the seed yield. An increase in yield of about 6 q ha^{-1} could be achieved by fertilizing fennel with optimum fertilizer dose and sowing at proper spacing.

3.4 Economics

When deciding between adopting new technology, economics is the primary consideration of the farmer. Technology proves to be fruitful to a farmer if it minimizes his cost and maximizes his return. This can be estimated using the concept of B:C, which is the ratio of gross return to the total cost. Any higher B: C practice would be more advantageous than others. The data presented in Table 5 depicts the economics of the fennel. Among different treatments, the highest cost of cultivation (Rs. 67945 ha^{-1}) was incurred in fennel sown at higher nitrogen levels, *i.e.,* 75 kg ha^{-1} under different spacing. Among different treatments, the highest gross return of Rs. 182420 ha^{-1} was obtained at 75 kg N ha^{-1} with 45x20 cm spacing, closely followed by 50 kg N ha^{-1} with a spacing of 45x20 cm (Rs. 182315 ha^{-1}). While comparing the net returns and benefit-cost ratio, the highest net return (Rs. 114670 ha^{-1}) and B: C ratio (2.70) were reported at 50 kg N ha^{-1} under 45x20 cm spacing closely followed by the treatment 75 kg N ha^{-1} with 45x20 cm spacing (Rs. 114475 $ha^{-1}$and 2.68).

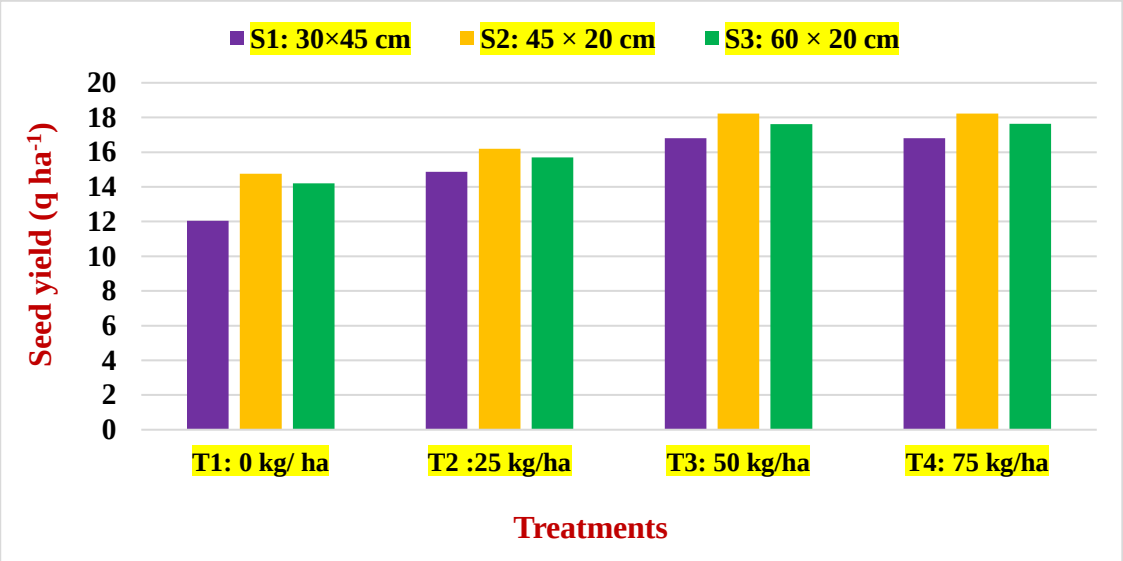

Fig. 1. Influence of nitrogen levels and spacings on seed yield per hectare on fennel

Table 2. Different treatment combinations of nitrogen levels and spacing

Treatments	Description
T_1S_1	Nitrogen @ 0 kg ha^{-1}under 30 x 20 cm spacing
T_1S_2	Nitrogen @ 0 kg ha^{-1}under 45 x 20 cm spacing
T_1S_3	Nitrogen @ 0 kg ha^{-1}under 60 x 20 cm spacing
T_2S_1	Nitrogen @ 25 kg ha^{-1}under 30 x 20 cm spacing
T_2S_2	Nitrogen @ 25 kg ha^{-1}under 45 x 20 cm spacing
T_2S_3	Nitrogen @ 25 kg ha^{-1}under 60 x 20 cm spacing
T_3S_1	Nitrogen @ 50 kg ha^{-1}under 30 x 20 cm spacing
T_3S_2	Nitrogen @ 50 kg ha^{-1}under 45 x 20 cm spacing
T_3S_3	Nitrogen @ 50 kg ha^{-1}under 60 x 20 cm spacing
T_4S_1	Nitrogen @ 75 kg ha^{-1}under 30 x 20 cm spacing
T_4S_2	Nitrogen @ 75 kg ha^{-1}under 45 x 20 cm spacing
T_4S_3	Nitrogen @ 75 kg ha^{-1}under 60 x 20 cm spacing

Table 3. Influence of nitrogen levels and spacing on yield parameters of fennel

Treatments	Umbels per plant	Umbellets per umbel	Seeds per umbel	Seed yield per plot (kg)	Seed yield per hectare (q/ha)
T_1 : Control	21.10	20.76	282.93	0.73	13.67
T_2: 25 kg/ha	30.61	23.71	396.53	0.83	15.59
T_3: 50 kg/ha	36.23	26.11	526.07	0.94	17.54
T_4: 75 kg/ha	36.94	26.40	533.40	0.95	17.55
Mean T	31.23	24.24	434.73	0.86	16.08
SE (m)	0.35	0.12	3.71	0.002	0.02
CD at 5%	1.05	0.37	10.05	0.005	0.07
S_1 : 30 × 20 cm	28.04	23.85	414.74	0.81	15.13
S_2 : 45 × 20 cm	32.38	24.36	441.08	0.90	16.85
S_3 : 60 × 20 cm	33.28	24.54	448.37	0.88	16.29
Mean S	31.23	24.24	434.73	0.86	16.08
SE (m)	0.31	0.10	3.21	0.001	0.02
CD at 5%	0.91	0.32	9.48	0.004	0.06

Table 4. Interaction effect of nitrogen levels and spacing on yield and yield parameters of fennel

Treatments	Umbels per plant	Umbellets per umbel	Seeds per umbel	Seed yield per plot (kg)	Seed yield per hectare (q/ha)
T_1S_1	18.22	20.31	270.15	0.65	12.05
T_1S_2	21.86	20.87	285.62	0.80	14.75
T_1S_3	23.23	21.10	293.02	0.76	14.21
T_2S_1	25.36	23.36	381.00	0.80	14.87
T_2S_2	32.67	23.81	400.85	0.87	16.20
T_2S_3	33.81	23.98	407.73	0.84	15.70
T_3S_1	33.90	25.71	501.51	0.91	16.80
T_3S_2	37.12	26.23	534.39	0.98	18.23
T_3S_3	37.7	26.41	542.30	0.95	17.61
T_4S_1	34.67	26.02	506.31	0.90	16.81
T_4S_2	37.86	26.52	543.47	0.98	18.24
T_4S_3	38.30	26.68	550.42	0.95	17.63
SE (m)	0.62	0.21	6.42	0.003	0.04
CD at 5%	1.82	NS	NS	0.01	0.12

Table 5. Economics of different treatment combinations of nitrogen levels and spacings

Treatments	Common cost	Treatment cost	Cost of cultivation	Yield kg/ha	Gross returns	Net returns	B: C
T_1S_1	67045	0	67045	1205.33	120533	53488	1.80
T_1S_2	67045	0	67045	1471.33	147633	80088	2.19
T_1S_3	67045	0	67045	1421.67	142167	75122	2.12
T_2S_1	67045	300	67345	1487.80	148700	81435	2.20
T_2S_2	67045	300	67345	1621.00	162100	94755	2.40
T_2S_3	67045	300	67345	1570.50	157000	89705	2.33
T_3S_1	67045	600	67645	1680.50	16800	100405	2.48
T_3S_2	67045	600	67645	1823.15	182315	114670	2.70
T_3S_3	67045	600	67645	1762.15	176215	108575	2.60
T_4S_1	67045	900	67945	1681.60	168160	100215	2.47
T_4S_2	67045	900	67945	1824.20	182420	114475	2.68
T_4S_3	67045	900	67945	1763.10	176310	108365	2.59

4. CONCLUSION

Nitrogen and spacing are the two major factors required for any crop's good production or yield. The increase in seed yield ultimately depends on good yield contributing characters, which results from a proper dose of fertilizers. The study was conducted to standardize the nitrogen application level and row spacing. From the result of the study, it could be concluded that treatment T_3S_2 was best for obtaining higher seed yield. Fertilizing the fennel crop with 50 kg ha^{-1} nitrogen level and sowing at 45x20 cm is economical to obtain a high seed yield. Though seed yield increased with increased nitrogen fertilizer dose, the rise in the value of seed yield from 50-75 kg N ha^{-1} was found non-significant. Only a numerical difference was observed in value. Statistically, they were at par, possibly due to environmental factors. Thus, as per the present findings, 50 kg nitrogen level and 45x20 cm spacing were most remunerative for fennel cultivation in semi-arid, subtropical conditions in the sandy loam soil of Haryana.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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