



Effect of Different Organic Sources on Seed Yield of *rabi* Fennel (*Foeniculum vulgare* P. Mill.) under Organic Farming

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The present study is titled "Effect of different organic sources on seed yield of *rabi* fennel (*Foeniculum vulgare* P. Mill.) under organic farming. It was carried out at Agronomy Instructional Farm of the Chimanbhai Patel College of Agriculture, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar, Gujarat during *Rabi* season of the year 2015-16, 2016-17 and 2019-20. *Foeniculum vulgare*, commonly known as fennel, is a widely recognized and essential medicinal and aromatic plant from the Apiaceae family. This study also examines the impact of organic sources in fennel cultivation, highlighting their potential to improve soil structure and microbial biomass. Organic sources, derived from both animal and plant sources, are considered eco-friendly alternatives with long term benefits. Results from the study indicate that for growing *rabi* fennel under organic farming application of 75% RDN (67.5 kg N/ha) either through castor cake or FYM at the time of sowing along with seed inoculation with *Azotobacter* and PSB @ 5 ml/kg seed for obtaining higher seed yield and net returns. These findings suggest the potential of organic manures to improve the growth and yield of fennel. In conclusion, this provides an extensive overview of fennel, addressing its botanical characteristics, chemical composition, pharmacological attributes, traditional uses, and agricultural practices. The experimental data highlights the positive impact of organic manures on fennel growth parameters, offering valuable insights for sustainable cultivation practices.

Keywords: Organic sources; castor cake; FYM; vermicompost; azotobacter; PSB and fennel.

1. INTRODUCTION

Foeniculum vulgare (Apiaceae) frequently accepted as fennel is an able-bodied accepted and important alleviative and ambrosial bulb broadly acclimated as carminative, digestive, lactagogue and diuretic and in alleviative respiratory and gastrointestinal disorders. Hanif et al. [1]. Phenolic compounds isolated from *F. vulgare* are advised to be amenable for its antioxidant action while the airy aroma compounds accomplish it an accomplished flavouring agent. The present assay is an abreast and absolute assay of the chemistry, pharmacology, acceptable uses and assurance of *F. vulgare* [2] Fennel is a cross-pollinated crop from the Apiaceae family. It is a diploid species with $2n=22$ chromosomes that originated in Europe [3]. Fennel is an herb with a slender, extendable, smooth stem that grows to be 100-180 cm tall. The inflorescence is terminal, with a complex umbel surrounded by bract involucre. Small, bisexual, complete, typical, and pentamerous flowers [4,5,6,7]. A schizocarp of two mericarps attached to a partitioning carpophore is the typical product known as the seed. A fully formed normal seed measures 4 to 8 mm in length. Fennel capital oil or its accustomed apparatus such as anethole characterize altered activities like antifungal, insecticidal, and antibacterial activity. Fennel possesses antioxidant property, antibacterial activity, anti-inflammatory effect, antiallergic and hepatoprotective action and antispasmodic

activity [8]. The seeds have a protein content of 9.5 percent, a fat content of 10.0 percent, a starch content of 42.3 percent, a rough fiber content of 18.5 percent, and a mineral content of 13.4 percent. The seeds contain a variable amount of oil, ranging from 2.5 to 6.5 percent, depending on the genotypes or organic kinds. Seed oil is used for scenting purifiers and flavoring cakes because it is unstable Bernath et al. [9]. The total area under cultivation is around 0.90 lakh hectares, with a yield of 1.57 lakh tonnes and a productivity of $1744.44 \text{ kg ha}^{-1}$ [10]. Organic manures in allegory of the actinic fertilizers accept lower comestible agreeable and are apathetic absolute but they are as able as actinic fertilizers over best periods of use Continuous acceptance of asleep fertilizer affects clay structure. Hence, amoebic manures can serve as another to mineral fertilizers for convalescent clay anatomy and microbial biomass. Organic fertilizers are acquired from beastly sources such as beastly admixture or bulb sources like blooming manure [11].

2. MATERIALS AND METHODS

The current field experiment was conducted during *Rabi* season of the year 2015-16, 2016-17 and 2019-20 at the Agronomy Instructional Farm of the Chimanbhai Patel College of Agriculture, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar, Gujarat. The experiment was laid out in RBD comprising 8 treatments and replicated four consists of T_1 : 50

% RDN through FYM + *Azotobacter* + PSB (PSB 10), T₂: 75 % RDN through FYM + *Azotobacter* + PSB (PSB 10), T₃:50 % RDN through Vermicompost + *Azotobacter* +PSB (PSB 10), T₄:75 % RDN through Vermicompost + *Azotobacter* PSB (PSB 10), T₅: 50 % RDN through Castor cake + *Azotobacter* + PSB (PSB 10), T₆:75 % RDN through Castor cake + *Azotobacter* + PSB (PSB 10) T₇:Seed treatment with *Azotobacter* and PSB (PSB 10) and T₈: Control (RDF: 90-30-00 NPK kg/ha). *Azotobacter* and PSB each was applied @ 5.0 ml/kg seed as seed inoculation. Experiment was conducted on fixed site in organically converted plot for treatments T₁ to T₇. Treatment T₈: Control (RDF: 90-30-00 kg NPK /ha) was conducted in conventional plot and site was changed every year. Manures were applied 15- 20 days before sowing. GF-12 variety of fennel was used for sowing. Spacing for crop is 45 cm and seed rate was 5 kg/ha. Crop management practices were followed as per the recommendation of the area. All over climatological data indicated that the weather conditions were observed normal and favourable for the satisfactory growth and development of the fennel during all years. Statistical analysis of the data of various characters studied in present investigation was carried out with the help of computer as per appropriate procedure suggested by Panse and Sukhatme [12] for the design of experiment.

3. RESULTS AND INTERPRETATION

3.1 Pooled (2015-16, 2016-17 and 2019-20)

The data summarized in Table 5 revealed that use of different sources of nitrogen along with biofertilizers had significant effect on seed and stalk yield of *rabi* fennel in pooled results of three years. Application of 75% RDN through castor cake along with seed inoculation of *Azotobacter* and PSB (T₆) registered significantly higher seed (1500 kg/ha) and stalk (4231 kg/ha) yields over rest of the treatments, which was found at par with treatments T₂ (75 % RDN through FYM + *Azotobacter* + PSB) and T₈ (Control: RDF: 90-30-00 kg NPK/ha) in case of seed yield and treatment T₂ with respect to stalk yield. When comparison made among different treatments received organic sources, treatment T₆ (application of 75% RDN through castor cake along with seed inoculation of *Azotobacter* and PSB) gave significantly higher seed as well as stalk yields as compared to rest of the treatments except treatment T₂ (75 % RDN through FYM + *Azotobacter* + PSB). Significantly the lowest

seed (1014 kg/ha) and stalk (3141 kg/ha) yields were registered under treatment T₇ (seed inoculation with *Azotobacter* and PSB).

3.2 Economics (pooled data)

The data on economics highlighted in Table 7 showed that maximum gross (Rs 99594/ha) and net return (Rs 58185/ha) with BCR of 2.41 was realized with application of 75% RDN through castor cake along with seed inoculation of *Azotobacter* and PSB (T₆) followed by treatments T₈ (Control: RDF: 90-30-00 kgNPK/ha) and T₂ (75 % RDN through FYM + *Azotobacter* + PSB) in pooled results. However, treatment T₇ (RDF *i.e.* control) recorded the lowest gross return (Rs 67481/ha) and net returns (Rs 34692/ha) and BCR (2.06) with treatment T₄ (75% RDN through vermicompost + seed inoculation with *Azotobacter* and PSB).

3.3 Microbial Study

The initial and final population of beneficial soil bacteria like *Rhizobium*, *Azotobacter* and PSB were evaluated in the field soil of *rabi* fennel using serial dilution and standard plating. The data on population of soil bacteria highlighted in Table 7 showed significant variation among the treatments under investigation during individual year as well as in pooled results of three years. The treatment T₆ [75% RDN through castor cake + *Azotobacter* + PSB (PSB10)] showed highest number of *Rhizobium*, *Azotobacter*, and PSB in the soil which was followed successively for the treatments T₂ (75% RDN through FYM + *Azotobacter* + PSB (PSB10)) and T₅ (50% RDN through castor cake + *Azotobacter* + PSB (PSB10)). However, the least bacterial populations of *Rhizobium*, *Azotobacter*, and PSB were reported in the treatment T₈(Control *i.e.* RDF: 90-30-00 kgNPK/ha) in which neither biofertilizers nor organic supplements were applied.

3.4 Effect on Uptake of Nutrients

3.4.1 Uptake of N, P and K by seed and stalk

Uptake of N, P and K by seed and stalk was influenced significantly due to different treatments during all the years of experimentations as well as in pooled analysis (Table 13). During first year, application of 75 % RDN through castor cake + *Azotobacter* + PSB (T₆) recorded significantly higher N uptake by seed as compared to other treatments but found

at par with treatments T₅, T₂, T₈ and T₄. Same treatment *i. e.* T₆ registered significantly higher N uptake as compared to other treatments but found on par with treatments T₅ and T₂ in second year and with T₂, T₈ and T₄ in third year and in pooled data.

In case of N uptake by stalk, treatment T₆ recorded the highest uptake, but it remained at par with T₂, T₅ and T₄ treatments in first year and second year and with T₂, T₄ and T₈ in third year. Significantly the highest removal of N by stalk was registered with treatment T₆ over rest of the treatments in pooled data.

The significant effect of different treatments on P uptake by seed and stalk was found during both the years and in pooled analysis (Table 14). Among different treatments, treatment T₆ registered significantly higher P uptake by seed as compared to treatment T₇ in first year. Same treatment *i. e.* T₆ also recorded significantly higher P uptake by seed as compared to other treatments except T₄, T₂ and T₅ treatment in second year and T₂, T₄ and T₈ treatments in pooled data. However during third year, treatment T₂ being at par with T₆, T₈ and T₄ treatments recorded significantly higher P uptake by seed over rest of the treatments.

During first year of study, treatment T₄ recorded significantly higher P uptake by stalk as compared to T₈ and T₇ treatments. However, treatment T₆ registered significantly higher removal of P by stalk over treatments T₁ and T₇ in second year and T₁, T₅ and T₇ in third year of experimentation. In pooled data, treatment T₆ registered significantly higher P uptake by stalk over rest of the treatments except T₄ and T₂ treatments.

The variation in K uptake by seed and stalk was significantly influenced due to different treatments (Table 15) during individual year as well as in pooled data. Among different treatments, an application of 75 % RDN through castor cake + *Azotobacter* + PSB (T₆) recorded significantly higher K uptake by seed as compared to T₈ and T₇ in first year and T₃, T₈ and T₇ in second year. However in third year, treatments T₂ being at par with T₆, T₈ and T₄ treatment recorded significantly higher K uptake by seed over rest of the treatments. In pooled data T₆ recorded significantly the highest K uptake by seed over rest of the treatments except T₂ and T₄ treatments. In case of K uptake by stalk, treatment T₂ recorded significantly

higher uptake as compared to T₈ and T₇ treatments in first and second year. However, treatment T₆ registered significantly higher K uptake by stalk over T₈ and T₇ treatments in third year. In pooled data, significantly the highest K uptake by stalk was noted under T₆ treatment over rest of the treatments except treatments T₂ and T₄.

3.4.2 Uptake of Fe, Mn, Zn and Cu by seed and stalk

The significant effect of different treatments was observed on Fe uptake by seed and stalk during all the years of study as well as in pooled analysis except Fe uptake by stalk in 2019-20 (Table 16). Significantly the highest uptake of Fe by seed was obtained under the application of 75 % RDN through castor cake + *Azotobacter* + PSB (T₆) over rest of the treatments except T₅ and T₂ treatments during first year of experimentation. Though the highest uptake of Fe by seed was recorded due to 75 % RDN through FYM + *Azotobacter* + PSB (T₂), it remained at par with T₁, T₆ and T₄ treatments in second year, T₆ in third year and T₆, T₄ and T₁ in pooled data. During first year of experimentation, treatment T₂ registered significantly higher removal of Fe by stalk over rest of the treatments except T₁, T₄ and T₆ treatments. However, the maximum removal of Fe by stalk was obtained with T₆, it remained at par with T₂, T₄ and T₅ in second year and with T₂ and T₄ in pooled data.

The uptake of Mn by seed and stalk was influenced significantly due to different treatments during all the years as well as in pooled data except Mn uptake by stalk in 2019-20 (Table 17).

An application of 75 % RDN through castor cake + *Azotobacter* + PSB (T₆) recorded significantly higher Mn uptake by seed as compared to T₇ in first year and T₈, T₃ and T₇ in second year. However, treatment T₂ registered significantly highest Mn uptake by seed over other treatments except treatments T₆, T₈ and T₄. Significantly the highest Mn uptake by seed was recorded due to T₆ treatment but, it remained at par with T₂ treatment in pooled data.

An application of 75 % RDN through FYM + *Azotobacter* + PSB (T₂) recorded significantly higher Mn uptake by stalk as compared to T₇ in first year and in pooled data and T₈ and T₇ in second year.

Table 1. Plant population of *rabi* fennel as influenced by different treatments

Treatments	Plant population at harvest (Gross plot)			
	2015-16	2016-17	2019-20	Pooled
T ₁ : 50 % RDN through FYM + <i>Azotobacter</i> + PSB (PSB 10)	233.5	243.0	243.3	239.9
T ₂ : 75 % RDN through FYM + <i>Azotobacter</i> + PSB (PSB 10)	231.0	244.8	242.3	239.4
T ₃ : 50 % RDN through Vermicompost + <i>Azotobacter</i> + PSB (PSB 10)	227.5	241.3	239.3	236.0
T ₄ : 75 % RDN through Vermicompost + <i>Azotobacter</i> + PSB (PSB 10)	236.0	243.0	244.0	241.0
T ₅ : 50 % RDN through Castor cake + <i>Azotobacter</i> + PSB (PSB 10)	225.5	238.5	232.0	232.0
T ₆ : 75 % RDN through Castor cake + <i>Azotobacter</i> + PSB (PSB 10)	225.0	237.0	230.0	230.7
T ₇ : Seed treatment with <i>Azotobacter</i> and PSB	227.5	246.0	244.3	239.3
T ₈ : Control (RDF: 90-30-00 kg NPK/ha)	224.0	241.8	235.8	233.9
S.Em. ±	9.79	9.22	9.51	5.01
CD (P= 0.05)	NS	NS	NS	NS
CV (%)	8.56	7.62	7.97	8.04
Y x T	-	-	-	NS

Table 2. Plant height and number of umbels per plant of *rabi* fennel as influenced by different treatments

Treatments	Plant height (cm)				Number of umbels per plant			
	2015-16	2016-17	2019-20	Pooled	2015-16	2016-17	2019-20	Pooled
T ₁ : 50 % RDN through FYM + <i>Azotobacter</i> + PSB (PSB 10)	109.1	119.3	125.2	117.9	7.75	7.85	8.25	7.95
T ₂ : 75 % RDN through FYM + <i>Azotobacter</i> + PSB (PSB 10)	112.8	124.0	133.7	123.5	8.60	8.65	10.90	9.38
T ₃ : 50 % RDN through Vermicompost + <i>Azotobacter</i> + PSB (PSB 10)	104.8	118.3	124.5	115.9	7.20	7.75	7.80	7.58
T ₄ : 75 % RDN through Vermicompost + <i>Azotobacter</i> + PSB (PSB 10)	109.1	119.1	130.5	119.6	7.98	8.25	8.25	8.16
T ₅ : 50 % RDN through Castor cake + <i>Azotobacter</i> + PSB (PSB 10)	115.6	126.4	136.7	126.2	8.50	9.93	9.55	9.33
T ₆ : 75 % RDN through Castor cake + <i>Azotobacter</i> + PSB (PSB 10)	120.3	130.0	143.3	131.2	10.18	10.58	11.50	10.75
T ₇ : Seed treatment with <i>Azotobacter</i> and PSB	96.0	100.5	113.9	103.4	6.85	7.03	7.10	6.99
T ₈ : Control (RDF: 90-30-00 kg NPK/ha)	111.6	119.5	128.8	120.0	8.18	8.10	8.75	8.34
S.Em. ±	5.09	5.38	5.71	2.86	0.41	0.44	0.51	0.27
CD (P= 0.05)	15.0	15.8	16.80	8.05	1.22	1.29	1.50	0.75
CV (%)	9.27	9.00	8.82	9.03	10.17	10.30	11.30	10.65
Y x T	-	-	-	NS	-	-	-	NS

Table 3. Number of umbelets per umbel and number of seeds per umbelet of *rabi* fennel as influenced by different treatments

Treatments	Number of umbelets per umbel				Number of seeds per umbelet			
	2015-16	2016-17	2019-20	Pooled	2015-16	2016-17	2019-20	Pooled
T ₁ : 50 % RDN through FYM + <i>Azotobacter</i> + PSB (PSB 10)	14.85	15.43	17.40	15.89	11.03	12.68	16.00	13.24
T ₂ : 75 % RDN through FYM + <i>Azotobacter</i> + PSB (PSB 10)	15.98	16.50	19.25	17.24	12.05	13.20	17.75	14.33
T ₃ : 50 % RDN through Vermicompost + <i>Azotobacter</i> + PSB (PSB 10)	13.88	14.70	17.40	15.33	10.45	12.05	14.50	12.33
T ₄ : 75 % RDN through Vermicompost + <i>Azotobacter</i> + PSB (PSB 10)	15.08	16.03	18.20	16.44	11.88	13.18	16.20	13.75
T ₅ : 50 % RDN through Castor cake + <i>Azotobacter</i> + PSB (PSB 10)	14.78	16.23	18.90	16.64	11.30	13.75	17.60	14.22
T ₆ : 75 % RDN through Castor cake + <i>Azotobacter</i> + PSB (PSB 10)	16.45	18.30	19.75	18.17	12.10	14.98	19.25	15.44
T ₇ : Seed treatment with <i>Azotobacter</i> and PSB	13.15	12.90	15.75	13.93	9.33	11.53	12.95	11.27
T ₈ : Control (RDF: 90-30-00 kgNPK/ha)	13.83	14.93	17.20	15.32	11.20	12.65	16.20	13.35
S.Em. ±	0.69	0.92	0.89	0.45	0.66	0.64	0.96	0.44
CD (P= 0.05)	2.02	2.70	NS	1.26	NS	1.87	2.84	1.23
CV (%)	9.29	11.76	9.89	10.39	11.83	9.79	11.84	11.39
Y x T	-	-	-	NS	-	-	-	NS

Table 4. Test weight and seed yield per plant of *rabi* fennel as influenced by different treatments

Treatments	Test weight (g)				Seed yield per plant (g)			
	2015-16	2016-17	2019-20	Pooled	2015-16	2016-17	2019-20	Pooled
T ₁ : 50 % RDN through FYM + <i>Azotobacter</i> + PSB (PSB 10)	5.95	6.13	5.93	6.00	7.35	9.36	11.99	9.57
T ₂ : 75 % RDN through FYM + <i>Azotobacter</i> + PSB (PSB 10)	6.26	6.37	6.14	6.26	7.85	9.87	14.03	10.58
T ₃ : 50 % RDN through Vermicompost + <i>Azotobacter</i> + PSB (PSB 10)	5.97	6.17	5.25	5.80	7.30	9.15	11.59	9.35
T ₄ : 75 % RDN through Vermicompost + <i>Azotobacter</i> + PSB (PSB 10)	6.34	6.30	5.61	6.08	7.80	9.72	13.93	10.48
T ₅ : 50 % RDN through Castor cake + <i>Azotobacter</i> + PSB (PSB 10)	6.48	6.36	5.95	6.26	8.00	9.59	13.98	10.52
T ₆ : 75 % RDN through Castor cake + <i>Azotobacter</i> + PSB (PSB 10)	6.59	6.60	6.21	6.47	8.60	10.87	16.12	11.86
T ₇ : Seed treatment with <i>Azotobacter</i> and PSB	5.95	5.38	5.05	5.46	6.40	7.87	9.74	8.00
T ₈ : Control (RDF: 90-30-00 kgNPK/ha)	6.30	6.11	5.32	5.91	7.50	9.41	13.37	10.09
S.Em. ±	0.26	0.30	0.27	0.16	0.44	0.55	0.57	0.42
CD (P= 0.05)	NS	NS	0.80	0.44	NS	NS	1.69	1.27
CV (%)	8.48	9.82	9.55	9.29	11.45	11.61	8.78	10.41
Y x T	-	-	-	NS	-	-	-	Sig (1.48)

Table 5. Volatile oil content and harvest index of *rabi* fennel as influenced by different treatments

Treatments	Volatile oil content (%)				Harvest index (%)			
	2015-16	2016-17	2019-20	Pooled	2015-16	2016-17	2019-20	Pooled
T ₁ : 50 % RDN through FYM + <i>Azotobacter</i> + PSB (PSB 10)	1.84	1.87	1.41	1.71	23.51	25.78	26.44	25.24
T ₂ : 75 % RDN through FYM + <i>Azotobacter</i> + PSB (PSB 10)	1.87	1.87	1.36	1.70	23.37	25.67	28.60	25.88
T ₃ : 50 % RDN through Vermicompost + <i>Azotobacter</i> + PSB (PSB 10)	1.97	1.93	1.36	1.75	25.38	24.59	25.15	25.04
T ₄ : 75 % RDN through Vermicompost + <i>Azotobacter</i> + PSB (PSB 10)	1.88	1.99	1.30	1.72	24.35	25.95	26.69	25.66
T ₅ : 50 % RDN through Castor cake + <i>Azotobacter</i> + PSB (PSB 10)	1.85	2.21	1.43	1.83	25.40	26.37	24.06	25.28
T ₆ : 75 % RDN through Castor cake + <i>Azotobacter</i> + PSB (PSB 10)	1.85	2.02	1.43	1.77	25.49	25.75	27.23	26.15
T ₇ : Seed treatment with <i>Azotobacter</i> and PSB	1.68	1.90	1.32	1.63	24.57	25.65	23.93	24.72
T ₈ : Control (RDF: 90-30-00 kgNPK/ha)	1.58	1.95	1.36	1.63	26.08	25.14	27.48	26.23
S.Em. ±	0.05	0.08	0.05	0.05	1.56	1.44	1.33	0.82
CD (P= 0.05)	0.15	NS	NS	NS	NS	NS	NS	NS
CV (%)	5.81	7.68	8.00	7.21	12.59	11.24	10.16	11.33
Y x T	-	-	-	Sig(0.17)	-	-	-	NS

Table 6. Seed and stalk yield of *rabi* fennel as influenced by different treatments

Treatments	Seed yield (kg/ha)				Stalk yield (kg/ha)			
	2015-16	2016-17	2019-20	Pooled	2015-16	2016-17	2019-20	Pooled
T ₁ : 50 % RDN through FYM + <i>Azotobacter</i> + PSB (PSB 10)	951	1216	1532	1233	3086	3494	4226	3602
T ₂ : 75 % RDN through FYM + <i>Azotobacter</i> + PSB (PSB 10)	1006	1308	1839	1384	3292	3795	4635	3907
T ₃ : 50 % RDN through Vermicompost + <i>Azotobacter</i> + PSB (PSB 10)	967	1151	1411	1176	2906	3529	4196	3544
T ₄ : 75 % RDN through Vermicompost + <i>Azotobacter</i> + PSB (PSB 10)	972	1298	1648	1306	3061	3713	4539	3771
T ₅ : 50 % RDN through Castor cake + <i>Azotobacter</i> + PSB (PSB 10)	1069	1365	1405	1280	3164	3838	4478	3827
T ₆ : 75 % RDN through Castor cake + <i>Azotobacter</i> + PSB (PSB 10)	1134	1463	1902	1500	3318	4234	5141	4231
T ₇ : Seed treatment with <i>Azotobacter</i> and PSB	794	1027	1221	1014	2443	3059	3921	3141
T ₈ : Control (RDF: 90-30-00 kgNPK/ha)	977	1185	1784	1315	2778	3532	4682	3664
S.Em. ±	53.2	62.8	89.6	63.5	150.6	205.8	274.3	118.2
CD (P= 0.05)	156.5	184.8	263.5	192.5	442.9	605.4	NS	332.7
CV (%)	10.82	10.04	11.25	11.01	10.02	11.28	12.25	11.65
Y x T	-	-	-	NS	-	-	-	NS

Table 7. Gross realization and cost of cultivation of *rabi* fennel as influenced by different treatments

Treatments	Gross realization (Rs/ha)				Total cost of cultivation (Rs/ha)			
	2015-16	2016-17	2019-20	Pooled	2015-16	2016-17	2019-20	Pooled
T ₁ : 50 % RDN through FYM + <i>Azotobacter</i> + PSB (PSB 10)	63358	80787	101693	81946	47532	47532	47704	47589
T ₂ : 75 % RDN through FYM + <i>Azotobacter</i> + PSB (PSB 10)	67036	86918	121853	91936	54802	54802	54974	54859
T ₃ : 50 % RDN through Vermicompost + <i>Azotobacter</i> + PSB (PSB 10)	64308	76580	93813	78234	51512	51512	51684	51569
T ₄ : 75 % RDN through Vermicompost + <i>Azotobacter</i> + PSB (PSB 10)	64711	86227	109390	86776	60902	60902	61074	60959
T ₅ : 50 % RDN through Castor cake + <i>Azotobacter</i> + PSB (PSB 10)	71067	90644	93564	85092	38522	38522	38694	38579
T ₆ : 75 % RDN through Castor cake + <i>Azotobacter</i> + PSB (PSB 10)	75369	97212	126201	99594	41352	41352	41524	41409
T ₇ : Seed treatment with <i>Azotobacter</i> and PSB	52832	68285	81326	67481	32732	32732	32904	32789
T ₈ : Control (RDF: 90-30-00 kgNPK/ha)	64894	78791	118301	87329	35637	35637	35809	35694

Table 8. Net realization and BCR of *rabi* fennel as influenced by different treatments

Treatments	Net realization (Rs/ha)				BCR			
	2015-16	2016-17	2019-20	Pooled	2015-16	2016-17	2019-20	Pooled
T ₁ : 50 % RDN through FYM + <i>Azotobacter</i> + PSB (PSB 10)	15827	33256	53990	34357	1.33	1.70	2.13	1.72
T ₂ : 75 % RDN through FYM + <i>Azotobacter</i> + PSB (PSB 10)	12235	32116	66879	37077	1.22	1.59	2.22	1.68
T ₃ : 50 % RDN through Vermicompost + <i>Azotobacter</i> + PSB (PSB 10)	12797	25068	42130	26665	1.25	1.49	1.82	1.52
T ₄ : 75 % RDN through Vermicompost + <i>Azotobacter</i> + PSB (PSB 10)	3809	25325	48316	25817	1.06	1.42	1.79	1.42
T ₅ : 50 % RDN through Castor cake + <i>Azotobacter</i> + PSB (PSB 10)	32546	52123	54871	46513	1.84	2.35	2.42	2.21
T ₆ : 75 % RDN through Castor cake + <i>Azotobacter</i> + PSB (PSB 10)	34018	55861	84677	58185	1.82	2.35	3.04	2.41
T ₇ : Seed treatment with <i>Azotobacter</i> and PSB	20100	35553	48422	34692	1.61	2.09	2.47	2.06
T ₈ : Control (RDF: 90-30-00 kgNPK/ha)	29257	43154	82492	51635	1.82	2.21	3.30	2.45

Table 9. Economics of *rabi* fennel as influenced by different treatments (Pooled data of 2015-16, 2016-17 and 2019-20)

Treatments	Yield (kg/ha)		Gross return (Rs/ha)	Cost of cultivation (Rs/ha)	Net return (Rs/ha)	BCR
	Seed	Stalk				
T ₁ : 50 % RDN through FYM + <i>Azotobacter</i> + PSB (PSB 10)	1233	3602	81946	47589	34357	1.72
T ₂ : 75 % RDN through FYM + <i>Azotobacter</i> + PSB (PSB 10)	1384	3907	91936	54859	37076	1.68
T ₃ : 50 % RDN through Vermicompost + <i>Azotobacter</i> + PSB (PSB 10)	1176	3544	78234	51569	26664	1.52
T ₄ : 75 % RDN through Vermicompost + <i>Azotobacter</i> + PSB (PSB 10)	1306	3771	86776	60959	25817	1.42
T ₅ : 50 % RDN through Castor cake + <i>Azotobacter</i> + PSB (PSB 10)	1280	3827	85092	38579	46513	2.21
T ₆ : 75 % RDN through Castor cake + <i>Azotobacter</i> + PSB (PSB 10)	1500	4231	99594	41409	58185	2.41
T ₇ : Seed treatment with <i>Azotobacter</i> and PSB	1014	3141	67481	32789	34692	2.06
T ₈ : Control (RDF: 90-30-00 kgNPK/ha)	1315	3664	87329	35694	51634	2.45

Rate of produce and inputs used in fennel

- (i) Seed : Rs 65.00/kg seed
- (ii) Stalk : Rs. 0.50/kg stalk
- (iii) Neem oil : Rs 475/lit
- (iv) *Azotobacter* : Rs150/lit
- (v) PSB : Rs 150/lit
- (vi) FYM : Rs1.50/kg
- (vii) Castor cake : Rs 6.0/kg (Rs 300/50 kg bag of castor cake)
- (viii) Vermicompost : Rs 4.0/kg
- (ix) Urea : Rs 6.00/kg (Rs 270/45 kg bag of urea)
- (x) DAP : Rs 24.0/kg (Rs 1200/50 kg bag of DAP)

Table 10. Microbial population in soil before sowing and after harvest of *rabi* fennel as influenced by different treatments

Treatment s	Population of microorganisms in soil (CFU/g of soil x 10 ⁴)											
	<i>Rhizobium</i>				<i>Azotobacter</i>				PSB			
	2015-16	2016-17	2019-20	Pooled	2015-16	2016-17	2019-20	Pooled	2015-16	2016-17	2019-20	Pooled
T ₁	84.4	92.3	102.4	93.0	103.5	115.5	117.3	112.1	97.4	106.6	109.2	104.4
T ₂	118.9	126.1	136.3	127.1	139.4	148.2	154.1	147.2	135.3	142.3	153.3	143.6
T ₃	78.6	86.2	97.4	87.4	97.5	108.6	111.8	105.9	91.6	99.5	104.3	98.4
T ₄	92.6	98.4	108.5	99.8	110.4	121.6	125.7	119.2	104.2	112.8	116.5	111.1
T ₅	99.3	105.7	114.5	106.5	117.4	127.1	132.3	125.6	112.3	118.7	121.5	117.5
T ₆	152.1	165.4	173.2	163.5	142.2	165.3	184.3	163.9	129.5	161.5	174.4	155.1
T ₇	71.4	83.1	92.6	82.3	93.3	101.4	105.3	100.0	84.2	82.5	89.7	85.5
T ₈	63.6	75.8	84.5	74.6	82.4	93.5	98.4	91.4	85.6	84.3	81.6	83.8
S.Em±	2.7	2.8	3.3	0.9	2.5	2.9	3.2	2.9	2.1	2.6	2.5	4.7
CD(P=0.05)	8.0	8.3	9.8	2.8	7.6	8.5	9.5	8.7	6.0	7.9	7.2	14.3
CV (%)	5.71	5.40	5.96	1.53	5.13	6.22	5.53	4.12	4.11	5.37	4.04	7.30
Initial												
i. Conventional plot	38.4	45.6	52.8		52.6	62.6	71.4		44.7	54.5	61.8	
ii. Organic plot	51.6	-	-		61.7	-	-		53.8	-	-	

Table 11. N uptake by seed and stalk of *rabi* fennel as influenced by different treatments

Treatments	N uptake (kg/ha) by seed				N uptake (kg/ha) by stalk			
	2015-16	2016-17	2019-20	Pooled	2015-16	2016-17	2019-20	Pooled
T ₁ : 50 % RDN through FYM + <i>Azotobacter</i> + PSB (PSB 10)	23.44	30.05	38.02	30.50	17.82	20.60	26.01	21.49
T ₂ : 75 % RDN through FYM + <i>Azotobacter</i> + PSB (PSB 10)	26.52	35.07	49.86	37.15	21.01	24.47	31.89	25.79
T ₃ : 50 % RDN through Vermicompost + <i>Azotobacter</i> + PSB (PSB 10)	24.05	28.76	36.16	29.66	17.76	21.91	25.27	21.64
T ₄ : 75 % RDN through Vermicompost + <i>Azotobacter</i> + PSB (PSB 10)	25.90	34.36	44.75	35.00	19.56	24.33	31.61	25.17
T ₅ : 50 % RDN through Castor cake + <i>Azotobacter</i> + PSB (PSB 10)	27.42	36.74	36.84	33.67	19.97	24.37	27.98	24.10
T ₆ : 75 % RDN through Castor cake + <i>Azotobacter</i> + PSB (PSB 10)	30.14	39.87	52.01	40.67	21.46	28.24	35.78	28.49
T ₇ : Seed treatment with <i>Azotobacter</i> and PSB	19.45	25.19	30.22	24.96	13.81	17.66	23.36	18.28
T ₈ : Control (RDF: 90-30-00 kgNPK/ha)	26.49	29.86	48.20	34.85	18.27	23.98	30.20	24.15
S.Em. ±	1.60	1.64	2.54	1.95	0.97	1.47	1.92	0.85
CD (0.05 %)	4.72	4.82	7.48	5.92	2.84	4.32	5.66	2.39
CV (%)	12.62	10.09	12.10	11.87	10.33	12.64	13.27	12.74

Table 12. P uptake by seed and stalk of *rabi* fennel as influenced by different treatments

Treatments	P uptake (kg/ha) by seed				P uptake (kg/ha) by stalk			
	2015-16	2016-17	2019-20	Pooled	2015-16	2016-17	2019-20	Pooled
T ₁ : 50 % RDN through FYM + <i>Azotobacter</i> + PSB (PSB 10)	4.07	5.43	7.20	5.57	2.14	2.87	3.67	2.89
T ₂ : 75 % RDN through FYM + <i>Azotobacter</i> + PSB (PSB 10)	4.61	6.13	8.96	6.57	2.50	3.27	4.48	3.42
T ₃ : 50 % RDN through Vermicompost + <i>Azotobacter</i> + PSB (PSB 10)	4.50	5.46	6.92	5.62	2.25	3.19	4.11	3.19
T ₄ : 75 % RDN through Vermicompost + <i>Azotobacter</i> + PSB (PSB 10)	4.61	6.28	8.33	6.40	2.55	3.41	4.59	3.51
T ₅ : 50 % RDN through Castor cake + <i>Azotobacter</i> + PSB (PSB 10)	4.39	5.98	6.01	5.46	2.16	3.06	3.66	2.96
T ₆ : 75 % RDN through Castor cake + <i>Azotobacter</i> + PSB (PSB 10)	4.93	6.62	8.95	6.83	2.40	3.50	4.75	3.55
T ₇ : Seed treatment with <i>Azotobacter</i> and PSB	3.22	4.46	5.17	4.28	1.59	2.25	3.19	2.34
T ₈ : Control (RDF: 90-30-00 kgNPK/ha)	4.27	5.52	8.58	6.12	2.03	3.01	4.31	3.12
S.Em. ±	0.29	0.30	0.46	0.36	0.17	0.21	0.27	0.12
CD (0.05 %)	0.86	0.87	1.36	1.08	0.48	0.62	0.80	0.35
CV (%)	13.48	10.37	12.35	12.29	15.15	13.67	13.27	14.11

Table 13. K uptake by seed and stalk of *rabi* fennel as influenced by different treatments

Treatments	K uptake (kg/ha) by seed				K uptake (kg/ha) by stalk			
	2015-16	2016-17	2019-20	Pooled	2015-16	2016-17	2019-20	Pooled
T ₁ : 50 % RDN through FYM + <i>Azotobacter</i> + PSB (PSB 10)	15.46	20.72	28.37	21.37	23.63	27.61	35.23	28.82
T ₂ : 75 % RDN through FYM + <i>Azotobacter</i> + PSB (PSB 10)	16.72	22.02	35.17	24.63	24.82	31.58	38.96	31.79
T ₃ : 50 % RDN through Vermicompost + <i>Azotobacter</i> + PSB (PSB 10)	15.83	18.96	26.19	20.33	21.87	26.88	34.81	27.85
T ₄ : 75 % RDN through Vermicompost + <i>Azotobacter</i> + PSB (PSB 10)	15.98	21.78	30.98	22.91	23.42	30.44	38.00	30.62
T ₅ : 50 % RDN through Castor cake + <i>Azotobacter</i> + PSB (PSB 10)	16.40	21.19	25.25	20.94	22.47	27.37	34.83	28.22
T ₆ : 75 % RDN through Castor cake + <i>Azotobacter</i> + PSB (PSB 10)	18.09	23.24	34.72	25.35	24.59	30.51	41.76	32.29
T ₇ : Seed treatment with <i>Azotobacter</i> and PSB	11.82	15.56	20.40	15.92	16.36	20.52	27.03	21.46
T ₈ : Control (RDF: 90-30-00 kgNPK/ha)	14.93	18.13	31.06	21.37	19.71	25.15	32.99	25.95
S.Em. ±	0.97	1.29	1.83	1.23	1.30	1.69	2.67	1.07
CD (0.05 %)	2.85	3.80	5.37	3.73	3.83	4.98	7.86	3.01
CV (%)	12.40	12.83	12.59	13.03	11.75	12.31	15.08	15.61

Table 14. Fe uptake by seed and stalk of *rabi* fennel as influenced by different treatments

Treatments	Fe uptake (g/ha) by seed				Fe uptake (g/ha) by stalk			
	2015-16	2016-17	2019-20	Pooled	2015-16	2016-17	2019-20	Pooled
T ₁ : 50 % RDN through FYM + <i>Azotobacter</i> + PSB (PSB 10)	66.40	119.81	169.03	118.41	320.73	395.12	506.34	407.39
T ₂ : 75 % RDN through FYM + <i>Azotobacter</i> + PSB (PSB 10)	80.53	136.32	208.76	141.87	345.68	430.90	562.19	446.26
T ₃ : 50 % RDN through Vermicompost + <i>Azotobacter</i> + PSB (PSB 10)	63.19	101.19	142.05	102.14	278.14	393.20	496.37	389.24
T ₄ : 75 % RDN through Vermicompost + <i>Azotobacter</i> + PSB (PSB 10)	73.48	114.20	173.39	120.35	310.75	414.96	539.50	421.40
T ₅ : 50 % RDN through Castor cake + <i>Azotobacter</i> + PSB (PSB 10)	83.13	106.81	134.63	108.19	291.00	407.96	505.89	401.44
T ₆ : 75 % RDN through Castor cake + <i>Azotobacter</i> + PSB (PSB 10)	96.46	115.99	191.80	134.75	308.64	457.86	584.76	450.42
T ₇ : Seed treatment with <i>Azotobacter</i> and PSB	49.93	74.27	112.41	78.87	221.45	316.52	438.93	325.63
T ₈ : Control (RDF: 90-30-00 kgNPK/ha)	70.45	80.74	157.97	103.05	245.06	361.53	522.49	376.36
S.Em. ±	5.85	9.50	11.21	8.20	17.50	19.36	35.45	13.98
CD (0.05 %)	17.20	27.93	32.97	24.88	51.47	56.95	NS	39.37
CV (%)	16.03	17.89	13.90	16.09	12.06	9.75	13.65	12.64

Table 15. Mn uptake by seed and stalk of *rabi* fennel as influenced by different treatments

Treatments	Mn uptake (g/ha) by seed				Mn uptake (g/ha) by stalk			
	2015-16	2016-17	2019-20	Pooled	2015-16	2016-17	2019-20	Pooled
T ₁ : 50 % RDN through FYM + <i>Azotobacter</i> + PSB (PSB 10)	64.67	90.60	114.71	89.99	69.47	85.06	102.88	85.80
T ₂ : 75 % RDN through FYM + <i>Azotobacter</i> + PSB (PSB 10)	74.22	103.31	144.55	107.36	77.29	95.72	118.61	97.21
T ₃ : 50 % RDN through Vermicompost + <i>Azotobacter</i> + PSB (PSB 10)	66.30	84.98	104.70	85.33	63.12	80.25	99.17	80.84
T ₄ : 75 % RDN through Vermicompost + <i>Azotobacter</i> + PSB (PSB 10)	66.15	96.30	124.17	95.54	67.13	85.61	109.22	87.32
T ₅ : 50 % RDN through Castor cake + <i>Azotobacter</i> + PSB (PSB 10)	70.50	98.58	103.16	90.75	66.18	84.25	100.21	83.55
T ₆ : 75 % RDN through Castor cake + <i>Azotobacter</i> + PSB (PSB 10)	76.46	107.95	139.58	108.00	71.32	94.18	117.60	94.37
T ₇ : Seed treatment with <i>Azotobacter</i> and PSB	50.67	71.57	86.55	69.59	48.20	63.93	86.71	66.28
T ₈ : Control (RDF: 90-30-00 kgNPK/ha)	63.86	84.99	129.17	92.67	56.53	75.86	100.66	77.68
S.Em. ±	4.38	6.68	7.16	3.82	3.97	5.19	7.68	3.10
CD (0.05 %)	12.90	14.48	21.05	10.76	11.68	15.27	NS	8.73
CV (%)	13.17	19.65	12.10	13.40	12.24	12.49	14.71	13.84

Table 16. Zn uptake by seed and stalk of *rabi* fennel as influenced by different treatments

Treatments	Zn uptake (g/ha) by seed				Zn uptake (g/ha) by stalk			
	2015-16	2016-17	2019-20	Pooled	2015-16	2016-17	2019-20	Pooled
T ₁ : 50 % RDN through FYM + <i>Azotobacter</i> + PSB (PSB 10)	28.43	36.82	50.03	38.43	40.92	47.07	67.44	51.81
T ₂ : 75 % RDN through FYM + <i>Azotobacter</i> + PSB (PSB 10)	30.41	41.64	61.63	44.56	44.42	54.76	76.25	58.47
T ₃ : 50 % RDN through Vermicompost + <i>Azotobacter</i> + PSB (PSB 10)	27.06	33.02	41.39	33.82	35.93	45.94	64.35	48.74
T ₄ : 75 % RDN through Vermicompost + <i>Azotobacter</i> + PSB (PSB 10)	27.80	38.65	52.32	39.59	38.81	49.32	70.75	52.96
T ₅ : 50 % RDN through Castor cake + <i>Azotobacter</i> + PSB (PSB 10)	28.22	36.88	39.72	34.94	37.35	48.10	65.20	50.22
T ₆ : 75 % RDN through Castor cake + <i>Azotobacter</i> + PSB (PSB 10)	30.34	40.11	56.61	42.35	38.74	54.10	76.55	56.46
T ₇ : Seed treatment with <i>Azotobacter</i> and PSB	19.30	26.12	31.07	25.50	26.77	35.74	52.11	38.21
T ₈ : Control (RDF: 90-30-00 kgNPK/ha)	24.44	31.08	47.07	34.20	32.05	44.14	68.10	48.10
S.Em. ±	1.88	2.46	2.88	2.26	3.06	3.43	5.17	2.17
CD (0.05 %)	5.54	7.22	8.47	6.86	9.01	10.09	NS	6.10
CV (%)	13.94	13.82	12.13	13.31	16.62	14.48	15.29	15.78

Table 17. Cu uptake by seed and stalk of *rabi* fennel as influenced by different treatments

Treatments	Cu uptake (g/ha) by seed				Cu uptake (g/ha) by stalk			
	2015-16	2016-17	2019-20	Pooled	2015-16	2016-17	2019-20	Pooled
T ₁ : 50 % RDN through FYM + <i>Azotobacter</i> + PSB (PSB 10)	10.01	15.94	21.20	15.71	20.91	26.29	42.35	29.85
T ₂ : 75 % RDN through FYM + <i>Azotobacter</i> + PSB (PSB 10)	10.88	16.82	25.72	17.80	23.79	29.47	47.49	33.59
T ₃ : 50 % RDN through Vermicompost + <i>Azotobacter</i> + PSB (PSB 10)	8.51	12.43	16.32	12.42	19.03	24.65	40.48	28.05
T ₄ : 75 % RDN through Vermicompost + <i>Azotobacter</i> + PSB (PSB 10)	8.71	14.04	19.57	14.11	20.55	26.91	44.93	30.79
T ₅ : 50 % RDN through Castor cake + <i>Azotobacter</i> + PSB (PSB 10)	8.62	13.64	15.44	12.57	19.88	25.71	39.80	28.46
T ₆ : 75 % RDN through Castor cake + <i>Azotobacter</i> + PSB (PSB 10)	9.78	15.48	21.95	15.74	21.45	29.50	49.46	33.47
T ₇ : Seed treatment with <i>Azotobacter</i> and PSB	5.68	9.95	12.18	9.27	15.33	18.99	27.60	20.64
T ₈ : Control (RDF: 90-30-00 kgNPK/ha)	7.17	11.60	18.39	12.38	17.31	22.87	36.47	25.55
S.Em. ±	0.61	0.98	1.70	0.73	1.53	1.68	3.85	1.47
CD (0.05 %)	1.80	2.87	5.01	2.06	4.51	4.94	11.31	4.15
CV (%)	14.13	14.21	18.09	17.27	15.51	13.15	18.72	17.91

Table 18. Organic carbon and available N content in soil after harvest of *rabi* fennel as influenced by different treatments

Treatments	Organic carbon (%)			Available N (kg/ha)		
	2015-16	2016-17	2019-20	2015-16	2016-17	2019-20
T ₁ : 50 % RDN through FYM + <i>Azotobacter</i> + PSB (PSB 10)	0.401	0.418	0.420	223.4	228.9	235.2
T ₂ : 75 % RDN through FYM + <i>Azotobacter</i> + PSB (PSB 10)	0.411	0.427	0.442	228.9	238.3	246.2
T ₃ : 50 % RDN through Vermicompost + <i>Azotobacter</i> + PSB (PSB 10)	0.397	0.420	0.432	225.8	233.6	237.2
T ₄ : 75 % RDN through Vermicompost + <i>Azotobacter</i> + PSB (PSB 10)	0.406	0.430	0.446	232.9	242.3	248.9
T ₅ : 50 % RDN through Castor cake + <i>Azotobacter</i> + PSB (PSB 10)	0.390	0.401	0.414	224.6	231.7	233.6
T ₆ : 75 % RDN through Castor cake + <i>Azotobacter</i> + PSB (PSB 10)	0.392	0.406	0.415	227.4	240.7	245.3
T ₇ : Seed treatment with <i>Azotobacter</i> and PSB	0.356	0.365	0.379	208.9	213.9	216.8
T ₈ : Control (RDF: 90-30-00 kgNPK/ha)	0.268	0.289	0.291	210.5	218.0	224.6
S.Em. ±	0.011	0.011	0.011	4.5	4.7	4.2
CD (0.05 %)	0.033	0.033	0.032	13.4	13.9	12.5
CV (%)	5.90	5.72	5.45	4.08	4.09	3.59
Initial						
i. Conventional plot	0.264	0.280	0.288	200.7	211.7	219.5
ii. Organic plot	0.353	-	-	207.0	-	-

Table 19. Available P₂O₅ and K₂O content in soil after harvest of *rabi* fennel as influenced by different treatments

Treatments	Available P ₂ O ₅ (kg/ha)			Available K ₂ O (kg/ha)		
	2015-16	2016-17	2019-20	2015-16	2016-17	2019-20
T ₁ : 50 % RDN through FYM + <i>Azotobacter</i> + PSB (PSB 10)	63.7	66.4	73.3	181.6	183.9	191.5
T ₂ : 75 % RDN through FYM + <i>Azotobacter</i> + PSB (PSB 10)	65.2	68.3	74.4	185.3	187.5	192.5
T ₃ : 50 % RDN through Vermicompost + <i>Azotobacter</i> + PSB (PSB 10)	67.9	71.4	75.6	179.4	183.5	187.1
T ₄ : 75 % RDN through Vermicompost + <i>Azotobacter</i> + PSB (PSB 10)	69.4	74.4	77.1	183.7	190.5	190.0
T ₅ : 50 % RDN through Castor cake + <i>Azotobacter</i> + PSB (PSB 10)	63.7	66.0	73.2	173.2	177.4	178.5
T ₆ : 75 % RDN through Castor cake + <i>Azotobacter</i> + PSB (PSB 10)	66.4	69.1	76.3	178.3	180.1	182.4
T ₇ : Seed treatment with <i>Azotobacter</i> and PSB	57.6	60.7	65.3	161.5	165.2	166.8
T ₈ : Control (RDF: 90-30-00 kgNPK/ha)	47.3	49.2	51.1	134.2	140.8	146.2
S.Em. ±	1.9	1.7	2.1	3.6	3.5	3.7
CD (0.05 %)	5.4	4.9	6.1	10.7	10.4	10.8
CV (%)	5.89	5.07	5.86	4.22	4.00	4.10
Initial						
i. Conventional plot	44.4	48.4	50.4	131.0	136.4	142.5
ii. Organic plot	54.2	-	-	157.3	-	-

The data given in Table 18 indicated that the different treatments had significant effect on Zn uptake by both seed and stalk during all the years as well as in pooled analysis except Zn uptake by stalk in 2019-20. Among different treatments, an application of 75 % RDN through FYM + *Azotobacter* + PSB (T₂) registered significantly higher Zn uptake by seed and stalk as compared to T₈ and T₇ in first year and second year and T₇ in third year and pooled data except Zn uptake by stalk in third year.

The data presented in Table 19 indicated that different treatments exerted their significant influence on Cu uptake by seed and stalk during all the years as well as in pooled analysis.

Significantly the highest Cu uptake by seed was obtained due to 75 % RDN through FYM + *Azotobacter* + PSB (T₂) over rest of treatments but it remained at par with T₁ and T₆ in first year and in third year, T₁, T₆ and T₄ in second year and T₆ in pooled data.

Same treatment *i. e.* T₂ also recorded significantly higher removal of Cu by stalk as compared to T₃, T₈ and T₇ in first year and T₅, T₃, T₈ and T₇ in pooled data.

An application of 75 % RDN through castor cake + *Azotobacter* + PSB (T₆) registered significantly higher uptake of Cu by stalk as compared to T₈ and T₇ treatments in second and third year.

3.4.3 Effect on organic carbon and available nutrients (N, P₂O₅ and K₂O) in soil

A perusal of data presented in Table 19 revealed that organic carbon content in soil significantly changed due to different treatments in all the year of study.

Among different organic treatments, an application of either 75 % or 50 % RDN through FYM or vermicompost or castor cake (T₂, T₄, T₆, T₁, T₃ and T₅) did not differed significantly with each other but registered significantly higher organic carbon content in soil after harvest of crop as compared to seed treatment with *Azotobacter* and PSB (T₇) in all years of study. The maximum value of organic carbon content in soil was found under T₂ treatment in first year whereas in second and third year, maximum value of organic carbon was noted under T₄ treatment.

Significant effect of different treatments on available N content in soil after harvest of crop

was found in all the years of experimentation. Among different organic treatments, all the treatments of organic sources *i.e.* T₁, T₂, T₃, T₄, T₅ and T₆ did not differ significantly with each other but recorded significantly higher available N content in soil as compared to seed treated with *Azotobacter* and PSB (T₇) in first and second years of study. However in third year, treatment T₄, T₂, T₆, T₃ and T₁ being at par with each other but recorded significantly higher available N content in soil as compared to T₅ and T₇ treatments (Table 18).

The data given in Table 19 showed that different treatments had significant effect on available P₂O₅ content in soil after harvest of crop during all the years of study. During first and third year of study, an application of 75 % RDN through vermicompost + *Azotobacter* + PSB (T₄) being at par with T₃, T₆, T₂, T₁ and T₅ and registered significantly higher available P₂O₅ content in soil as compared to seed treated with *Azotobacter* and PSB (T₇). During second year, same treatment *i. e.* T₄ also being at par with T₃, T₆ and T₂ treatments but recorded significantly higher available P₂O₅ content in as compared to T₁, T₅ and T₇ treatments.

Available K₂O content in soil varied significantly due to different treatments during all the three years of study (Table 19). Among different organic treatments, an application of 75 % RDN through FYM + *Azotobacter* + PSB (T₂) being at par with T₄, T₁, T₃ and T₆ recorded significantly higher available K₂O content in soil as compared to T₅ and T₇ treatments in first and third year. However in second year, treatment T₄ recorded significantly higher available K₂O content in soil as compared to T₆, T₅ and T₇ treatments but at par with T₂, T₁ and T₃ treatments.

This indicated that bio-fertilizers play significant role in increasing growth attributes of fennel at harvest. *Azotobacter* bacteria have the capacity to fix atmospheric nitrogen to soil and make it available to plant [13]. Phosphorus solubilizing microorganisms reserved in available form of readily hydrolyzes organic phosphate and degrade them in the soil through production of organic acids [14]. Seed inoculation with *Azotobacter* + PSB increased growth attributes [15].

The crop accumulates more amount of constituent and nutrients from organic manures (FYM + castor cake). Some beneficial

microorganisms (*Azotobacter*) fixed atmospheric nitrogen which readily available to plant and from this plant can easily uptake of nitrogen which results to stimulate the cell division in meristem tissue and an increase in the yield and yield attributes. This was confirmed with the findings of the findings are in agreement with those reported by Godara [16], Lal et al. [11] Increase in yield per plant at higher rate of CC and FYM or its combination with *Azotobacter* and PSB is might be due to balanced nutrition and favorable soil environment, better plant growth and ultimately photosynthesis increase which leads to maximum seed yield per plant. The increase in seed yield/plant of crop due to application of organic manure is not only because of improved nutrient availability, but also its beneficial effect on physical and biological environment. This has special reference in fennel crop as umbel setting and development take place in sub-surface soil and the crop is mainly grown in arid and semi-arid climate where water storage capacity plays vital role. These results are in agreements with earlier worker Mohamed et al. [17] and Singh et al. [18,19].

4. CONCLUSION

This study comprehensively analyzed the growth and yield parameters of *Foeniculum vulgare* (fennel) under various organic fertilizer treatments. The results revealed significant differences in growth, yield, yield attributes, microbial activity and soil parameters from application of 75% RDN (67.5 kg N/ha) either through castor cake or FYM at the time of sowing along with seed inoculation with *Azotobacter* and PSB @ 5 ml/kg seed. It means application of organic manures also maximization yield and net return. Such research contributes valuable insights into optimizing agricultural practices and enhancing crop productivity under organic farming for fennel.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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