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Research Paper

Integrated nutrient management influenced growth, yield and economics of fennel (*Foeniculum vulgare*) under semi arid conditions

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ABSTRACT

A field experiment was conducted during the winter seasons of 2007–08 to 2009–10 at Jobner, Rajasthan, to investigate the effect of integrated nutrient management on growth, productivity, quality and economics of fennel (*Foeniculum vulgare* Mill.). Integrated application of 50% recommended dose of nitrogen (RDN) through vermicompost (VC) + 50% RDN through fertilizers showed higher values of all the growth and yield attributes, viz. plant height, branches/plant, umbels/plant, umbellates/umbel, seeds/umbellate and 1,000-seed weight to the magnitude of 14.0, 22.0, 45.5, 24.9, 25.4 and 20.6% over the absolute control, respectively, closely followed by 100% RDN through fertilizers. Among the different nutrient-management practices, significantly highest mean seed (1.82 t/ha), stover (3.78 t/ha) and biological (5.60 t/ha) yields, gross (₹127,400/ha) and net monetary returns (₹101,883/ha), essential oil content (2.17%), oil yield (39.49 kg/ha) and available soil nitrogen balance (144.7 kg/ha) were recorded with 50% RDN through VC + 50% RDN through fertilizers realizing 54.4, 51.8, 52.6, 54.4, 59.9, 17.3, 81.1 and 12.9% increase over absolute control, respectively. Similarly, it also recorded 3.99 benefit: cost ratio which was superior to the control (3.39) and remained at par with other treatments, but significantly lower to 100% RDN through fertilizers (4.72). Therefore, it is recommended to apply 50% RDN through VC + 50% RDN through fertilizers and reduced chemical fertilizers to 50%.

Key words **:** Farmyard manure, Fennel, Neem-cake, Poultry manure, Vermicompost

India has been recognized as a land of spices and at present it is the world's largest producer, consumer and exporter of seed spices. In India, spices and seed spices occupies an area of 3.07 and 1.39 million ha, with production of 5.74 and 1.23 million tonnes, respectively. Rajasthan occupies an area of 730 and 709 thousand ha, with production of 871 and 856 thousand tonnes of spices and seed spices respectively (Directorate of Agriculture, Rajasthan, 2013). Aromatic plants are traditionally employed for seasoning and prolongation of shelf-life of food. Among the aromatic plants, we consider the fennel, in which its seeds have several uses (culinary, pharmaceutical, etc). Fennel is also highly recommended for diabetes, bronchitis and chronic coughs, treatment of kidney stones, and is considered to have diuretic, stomachic and galactogogue properties. Fennel is mainly cultivated in Gujarat, Rajasthan and Uttar Pradesh. Rajasthan and Gujarat contribute more than 80% of the total seed spices production in the country. Therefore, this region also called as seed spices bowl of the country. India is the largest producer of fennel with an area of about 100,000 ha and annual production of 143,000 tonnes having the productivity of 1,430 kg/ha. In Rajasthan, it occupies an area of 14,790 ha and production of 14,970 tonnes with average productivity of 1,012 kg/ha. Hence the average productivity of the fennel crop is low as compared to other parts of the country.

Of late, there has been increasing recognition of the importance of organics, as the global consumers are showing inclination towards health cautiousness with their day-to-day diet. Organic food as is self-explanatory needs large quantity of organic manures to supply nutrients in soil but on the contrary, there is a serious decline in organic matter in Indian soils particularly in tropical regions under the influence of arid and semi-arid climate. Recently, there has been increasing importance of organic sources of plant nutrients due to growing ecological concern and depleting inherent soil fertility leading to multiple deficiencies of essential plant nutrients. The results of long-term fertilizer experiments have emphasized that sustainability can only be maintained by integration of fertilizers and organic sources of nutrients (Chettri and Bandhopadhya, 2005).

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Addition of organic manures like farmyard manure, vermicompost, neem-cake, poultry manure, etc. not only supplies most of the essential plant nutrients, but also improves the soil structure by providing binding substance to soil aggregates leading to increase in cation-exchange capacity and water-holding capacity of the soil. Hence the replacement of external inputs, viz. chemical fertilizer by farm-derived organic inputs normally leads to a reduction in variable input costs under organic management. Therefore the present investigation was undertaken to evaluate different organic inputs, nutrient sources and to compare the chemical and integrated treatments in fennel under semi-arid region.

MATERIALS AND METHODS

A field investigation was carried out during the winter seasons of 2007–08 to 2009–10 at S.K.N. College of Agriculture, Jobner (26°05' N, 75°20' E, 427 m above mean sea-level), Jaipur, (Rajasthan). The soil was loamy sand, low in organic carbon (0.21%), available N (144.1 kg/ha), available P (6.9 kg/ha) and medium in available K (142.9 kg/ha) with alkaline (pH 8.3) in reaction, having 1.5 Mg/m^3 bulk density, 2.65 Mg/m^3 particle density, 12.97% field capacity and 4.85% permanent wilting point at the beginning of the experiment. The experiment was laid out in randomized block design with 3 replications. The experiment comprised 14 treatments for application of recommended dose of nitrogen (RDN) to fennel through different sources, viz. control, 100% RDN though fertilizers (90 kg N + 19.6 kg P + 0 kg K/ha), 100% RDN through farmyard manure (FYM), 100% RDN through poultry manure (PM), 100% RDN through vermicompost (VC), 100% RDN through neem-cake (NC), 50% RDN through FYM + 50% RDN through fertilizers, 50% RDN through PM + 50% RDN through fertilizers, 50% RDN through VC + 50% RDN through fertilizers, 50% RDN through NC + 50% RDN through fertilizers, 75% RDN through FYM + 25% RDN through fertilizers, 75% RDN through PM + 25% RDN through fertilizers, 75% RDN through VC + 25% RDN through fertilizers and 75% RDN through NC + 25% RDN through fertilizers. Full dose of N and P as per treatments were applied manually through diammonium phosphate and urea at the time of sowing. Nitrogen content was estimated in organic sources on dry-weight basis and their quantities required for a specific amount of N as per treatment were calculated. The well decomposed FYM, PM, VC and NC with mean composition (N 0.42, 2.80, 1.54 and 4.80%, P 0.24, 2.22, 1.24 and 1.07% and K 0.51, 1.42, 0.84 and 1.28% respectively) were applied 2 weeks before sowing and incorporated in soil as per treatments. 'RF 101' fennel variety was sown at 50 cm × 20 cm using 10 kg seed/ha in the last week of October during all the years. All improved package of practices were followed to raise the crop under irrigated conditions. Data on growth and yield attributes were taken from 5 tagged plants. Biological and economic yields were taken from net plot. Stover yield was obtained by subtracting seed yield from the total biological yield. To ascertain the economic feasibility of different treatments, economics of treatments was worked out on the basis of prevailing market prices of inputs and outputs and expressed in terms of net profit/ha, so that most remunerative treatment could be recommended. The essential oil was estimated by using Clevenger's apparatus (AOAC, 1988). The composite soil sample was analyzed after harvesting of the crop to find out the change in organic carbon and available nitrogen. Regular analysis of variance was performed for each trait for all the 3 seasons and the combined (pooled) analysis over seasons after testing error variance homogeneity was carried out according to the procedure outlined by Gomez and Gomez (1984), using the MSTATC version 2.1 (Michigan State University, USA) statistical package design. Significant differences between the treatments were compared with the critical difference at ± 5% probability by LSD.

RESULTS AND DISCUSSION

Growth and yield attributes

Nutrient management through organic sources and fertilizers alone or in combination significantly improved growth attributes, viz. plant height and branches/plant except 100% RDN through NC and yield attributes, viz. umbels/plant, umbellates/umbel, seeds/umbellate and 1,000-seed weight over the absolute control (Table 1). The application of 100% RDN through fertilizers showed an increase of 12.6, 14.0, 46.3, 21.5, 22.6 and 18.7% in plant height, branches/plant, umbels/plant, umbellates/umbel, seeds/umbellate and 1,000-seed weight over the absolute control respectively. An application of recommended dose of N and P through fertilizers enhanced the availability of nutrients, which resulted in increased photosynthetic activity and translocation of photosynthates from source to sink and this might be the cause of higher growth and yield attributes. Godara *et al.* (2014) also recorded higher growth and yield attributes when RDF was applied through fertilizers in fennel followed by integrated nutrient management.

The plant height, branches/plant, umbels/plant, umbellates/umbel, seeds/umbellate and 1,000-seed weight were significantly increased by 6.3, 10.0, 18.7, 9.0, 15.7 and 16.0% with 100% RDN through FYM; 10.3, 10.0, 29.3, 12.4, 15.3 and 17.4% with 100% RDN through PM; 9.1, 16.0, 37.4, 16.4, 19.9 and 18.7% with 100% RDN through VC; and 5.3, 4.0, 30.1, 14.7, 17.1 and 14.9% with

100% RDN through NC over the control respectively. Moreover, organics, besides supplying macro-and micronutrients, have also solubilizing effect on native soil nutrients due to the action of organic acids produced during decomposition and resulted in higher growth attributes. Application of manures increased the supply of easily assimilated major as well as micronutrients to plants besides mobilizing unavailable nutrients into available form. Our findings support the results of Tolanur (2009) and Singh (2011).

Application of 50% RDN through VC + 50% RDN through fertilizers showed higher values of all the growth and yield attributes, viz. plant height, branches/plant, umbels/plant, umbellates/umbel, seeds/umbellate and 1,000-seed weight to the magnitude of 14.0, 22.0, 45.5, 24.9, 25.4 and 20.6% over absolute control, respectively, closely followed by 100% RDN through fertilizers. The combination of organic and fertilizer source of nutrients ensured ready availability of nutrients for initial requirement through fertilizers and slow pace as long-term availability through organic source throughout the crop-growth period. The combined effect of organic and fertilizer sources played a very important role owing to their synergistic effect. The increased and balanced supply of nutrients to plants promotes flowering and fruiting and supply of food material and its subsequent partitioning in the sink. The results corroborate the findings of Panwar and Munda (2007). Contrary to our findings, Patel *et al.* (2013) recorded the maximum yield of cumin when RDF applied through fertilizers as compared to organic manures and integrated nutrient management.

Seed, stover and biological yields

On the basis of 3 years pooled analysis, it was found that the yields were significantly improved by the application of organic manures or fertilizers alone or in combination with manures, viz. FYM, PM, VC and NC, over the absolute control (Table 1). The 100% RDN through fertilizers significantly increased seed, stover and biological yields to the tune of 49.7, 56.1 and 54.2% over absolute control respectively. The increased nutrient supply contributed to improvement of plant growth and development leading to higher yield as reported from fenugreek by Asaf *et al.* (2009).

The seed, stover and biological yields of fennel were also significantly improved registering 32.1, 29.8 and 30.5% with 100% RDN through FYM; 36.5, 35.9 and 36.1% with 100% RDN through PM; 44.6, 37.2 and 39.6% with 100% RDN through VC; and 27.0, 27.3 and 27.2% with 100% RDN through NC over the control respectively. The organic sources supply not only the major nutrients but also minor nutrients which play crucial role

Table 1. Effect of integrated nutrient management on growth and yield of fennel (pooled data of 3 years)

Treatment	Plant height (cm)	Branches/ plant	Umbels/ plant	Umbellates/ umbel	Seeds/ umbellate	1,000-seed weight(g)	Seed yield (t/ha)	Stover yield (t/ha)	Biological yield (t/ha)
Control	109.2	5.0	12.3	17.7	287	5.57	1.18	2.49	3.67
100% RDN through fertilizers	123.0	5.7	18.0	21.5	352	6.61	1.76	3.89	5.66
100% RDN through FYM	116.1	5.5	14.6	19.3	332	6.46	1.56	3.23	4.79
100% RDN through PM	120.4	5.5	15.9	19.9	331	6.54	1.61	3.38	4.99
100% RDN through VC	119.1	5.8	16.9	20.6	344	6.61	1.71	3.42	5.12
100% RDN through NC	115.0	5.2	16.0	20.3	336	6.40	1.50	3.17	4.67
50% RDN through FYM +50% RDN through fertilizers	118.5	5.7	16.5	20.8	349	6.58	1.68	3.70	5.39
50% RDN through PM + 50% RDN through fertilizers	119.1	5.7	17.4	21.6	346	6.65	1.71	3.56	5.27
50% RDN through VC + 50% RDN through fertilizers	124.5	6.1	17.9	22.1	360	6.72	1.82	3.78	5.60
50% RDN through NC + 50% RDN through fertilizers	117.9	5.5	16.5	20.2	345	6.53	1.70	3.55	5.25
75% RDN through FYM + 25% RDN through fertilizers	117.7	5.6	16.4	21.0	344	6.55	1.67	3.52	5.19
75% RDN through PM + 25% RDN through fertilizers	119.6	5.8	17.3	21.1	352	6.51	1.66	3.58	5.17
75% RDN through VC + 25% RDN through fertilizers	121.9	5.4	17.9	21.2	355	6.61	1.73	3.68	5.48
75% RDN through NC + 25% RDN through fertilizers	117.0	5.5	15.7	20.3	340	6.40	1.58	3.47	5.05
SEm ±	2.0	0.1	0.4	0.4	7	0.11	0.05	0.12	0.15
CD (P=0.05)	5.8	0.3	1.2	1.3	20	0.32	0.14	0.33	0.44

RDN, Recommended dose of nitrogen; FYM, farmyard manure; PM, poultry manure; VC, vermicompost; NC, neem-cake

in enzymatic reactions in rhizosphere of the plant and thus helped the plant to grow vigorously and to produce more yields. Vermicompost is also beneficial in improving the soil environment which in turn encourages proliferous root growth, resulting in better absorption of moisture, nutrients and thus producing higher biomass. The significant differences in dry matter and seed yield may be attributed to the higher levels of nutrients, besides growth-stimulating substances (enzymes, antibiotics and growth hormones) available in vermicompost. Neem-cake is known as high-value manure having low C:N ratio that also possesses good pesticide and insecticidal properties. The growth promoting effect of FYM as a source of plant nutrients and humus improved the soil physio-chemical condition by increasing its capacity to absorb and store water, improving aeration and favouring beneficial microbial activity in groundnut (Choudhary *et al.,* 2011).

Among the different nutrient management, the highest mean seed yield was obtained with conjunctive use of 50% RDN through VC + 50% RDN through fertilizers, which was comparable with 100% RDN through fertilizers, 75% RDN through VC + 25% RDN through fertilizers, 50% RDN through PM + 50% RDN through fertilizers, 100% RDN through VC, 50% RDN through NC + 50% RDN through fertilizers and 50% RDN through FYM + 50% RDN through fertilizers. However, seed yield recorded with 50% RDN through VC + 50% RDN through fertilizers was significantly higher by 54.4, 21.6, 16.9, 15.3, 13.1, 9.9 and 8.9% over the control, 100% RDN through NC, 100% RDN through FYM, 75% RDN through NC + 25% RDN through fertilizers, 100% RDN through PM, 75% RDN through PM + 25% RDN through fertilizers and 75% RDN through FYM + 25% RDN through fertilizers, respectively. The integrated use of 50% RDN through VC + 50% RDN through fertilizers also recorded 51.8 and 52.6% significantly higher stover and biological yields over absolute control, respectively, and was comparable with 100% RDN through fertilizers as well as combined application of organic and inorganic sources of nutrients in varying proportions. The increased yield might also be owing to better nutritional status of the soil which might have stimulated the rate of various plant physiological processes which led to increased growth and yield-attributing characteristics and their cumulative effect resulted in enhanced seed, stover and biological yields of fennel. The results on yield thus confirmed the trend observed earlier in the yield-attributing characters and upheld the need of supplementing the RDN through fertilizers with organic and emphasized the utter need for organic manuring along with chemical fertilizers. Singh (2011) recorded the maximum biomass, seed and oil yield in coriander with the application of 7.5 t vermicompost + 25% recommended dose of NPK fertilizers. Contrarily, Godara *et al.* (2014) reported the maximum seed yield of fennel with RDN (100%) applied through fertilizers closely followed by 50% RDN through fertilizers + 50% RDN through vermicompost but 50% RDN through fertilizers + 50% RDN through vermicompost showed the highest biological yield closely followed by 100% RDN through fertilizers.

Economics

Nutrient management had significant influence on the economics of fennel (Table 2). The application of 100% RDN through fertilizers obtained ₹41,020 and 38,228/ha more gross and net returns and 1.33 benefit: cost ratio, which were significantly higher by 49.7, 59.9 and 39.2% compared with the absolute control. Application 100% RDN through FYM, PM, VC and NC also fetched significantly higher gross returns by ₹26,460, 30,100, 36,820 and 22,260/ha, registering 32.1, 36.5, 44.6 and 27.0% increase; and net returns by ₹20,960, 23,806, 26,178 and 8,025/ha, registering 32.9, 37.4, 41.1 and 12.6% increase over the control respectively. The benefit: cost ratio was higher with 100% RDN through FYM and PM, but it declined by use of 100% RDN through VC and NC as compared to the absolute control.

Further, amongst the integrated treatments, 50% RDN through VC + 50% RDN through fertilizers recorded the highest gross and net monetary returns which were at par with 100% RDN through fertilizers but significantly superior to the control, 100% RDN through organic manures and all combinations of organic manures and fertilizers (Table 2). This treatment obtained higher gross and net returns ₹44,870 and 38,153/ha, being 54.4 and 59.9% over absolute control. Similarly, it also recorded more benefit: cost ratio than the control, remaining at par with the other treatments, but significantly lower as compared to 100% RDN through fertilizers. The lower net returns and benefit: cost ratios were obtained with sole NC or its integration with fertilizers that might have resulted from higher cost of NC. The lower quantity of fertilizers is required to fulfil the 100% RDN which resulted in lesser investment which ultimately gave the highest benefit: cost ratio or higher returns per rupee investment over organic manures but organic manures offer benefits of enhancement of soil physical, chemical and biological properties over long term instead of meeting a part of nutrients need of the crop to sustain high yield. Singh *et al.* (2013) found that 50% RDN through FYM + 50% through urea, 80% RDN through vermicompost + 20% through urea and 25% RDN through FYM + 75% through urea, being at par with each other, fetched significantly higher net returns and benefit: cost ratio from pearlmillet. However, 100% RDN

Table 2. Effect of integrated nutrient management on economics, essential oil and soil fertility after harvesting of fennel (pooled data of 3 years)

Treatment	Gross returns (× 10³₹/ha)	Net returns (× 10³₹/ha)	Benefit: cost ratio	Essential oil(%)	Oil yield (kg/ha)	Organic carbon (%)	Available N(kg/ha)
Control	82.5	63.7	3.39	1.85	21.8	0.20	128.1
100% RDN through fertilizers	123.5	101.8	4.72	2.11	37.2	0.24	132.2
100% RDN through FYM	109.0	84.7	3.49	2.04	31.8	0.35	136.4
100% RDN through PM	112.6	87.5	3.49	1.98	31.9	0.31	137.5
100% RDN through VC	119.4	89.9	3.05	2.13	36.3	0.27	143.3
100% RDN through NC	104.8	71.8	2.17	2.03	30.4	0.25	139.1
50% RDN through FYM + 50% RDN through fertilizers	117.8	94.9	4.13	2.07	34.9	0.30	137.8
50% RDN through PM + 50% RDN through fertilizers	119.5	96.1	4.11	2.02	34.6	0.26	138.9
50% RDN through VC + 50% RDN through fertilizers	127.4	101.9	3.99	2.17	39.5	0.26	144.7
50% RDN through NC + 50% RDN through fertilizers	119.2	92.0	3.37	2.03	34.5	0.25	139.2
75% RDN through FYM + 25% RDN through fertilizers	113.5	89.9	3.81	1.99	33.3	0.29	136.9
75% RDN through PM + 25% RDN through fertilizers	115.9	91.7	3.79	2.08	34.4	0.27	140.3
75% RDN through VC + 25% RDN through fertilizers	121.2	93.8	3.41	2.15	37.2	0.26	144.2
75% RDN through NC + 25% RDN through fertilizers	110.5	80.4	2.66	2.02	32.0	0.27	141.3
SEm±	2.0	2.0	0.16	0.04	0.61	0.01	1.4
CD (P=0.05)	6.1	5.5	0.45	0.12	1.7	0.03	3.9

RDN, Recommended dose of nitrogen; FYM, farmyard manure; PM, poultry manure; VC, vermicompost; NC, neem-cake

applied through fertilizers exhibited highest net returns and benefit: cost ratio, closely followed by 50% RDN through fertilizers + 50% RDN through vermicompost as recorded by Godara *et al.* (2014) in fennel cultivation.

Essential oil content and oil yield

Nutrient application either through organic manures or chemical fertilizes as well as their integrated use significantly improved essential oil content in seed and oil yield of fennel as compared to the control (Table 2). The 100% RDN through fertilizers significantly increased essential oil content and oil yield to the tune of 14.1 and 70.7% over the absolute control. Essential oil content in seed was also significantly improved with 100% RDN through FYM, PM, VC and NC, recording an increase of 10.3, 7.0, 15.1 and 9.7% over the control respectively. Maximum essential oil content and oil yield were observed with 50% RDN through VC + 50% RDN through fertilizers which was at par with 100% RDN through fertilizers, 100% RDN through VC, 75% RDN through PM or VC + 25% RDN through fertilizers and 50% RDN through FYM + 50% RDN through fertilizers, but significantly superior to rest of the treatments. It registered 17.3 and 81.1% increase over the absolute control. The superiority of integrated nutrient management can also be attributed to their effect on better seed development. However, it was reported that essential oil content was not influenced by organic and inorganic fertilizers in coriander (Singh *et al.*, 2013) and cumin (Patel *et al.,* 2013).

Soil-fertility status

After harvesting of fennel, the organic carbon (OC) and available N in soil markedly improved due to 100% RDN through fertilizers as well as organic manures and all combinations of organic manures and fertilizers over the control. Further, addition of nutrients either only through organic manures or in combination with fertilizers in different proportions increased the OC and available N in soil over 100% RDN only through fertilizers. Application of 50% RDN through organic + 50% RDN through fertilizers, 75% RDN through organic + 25% RDN through fertilizers and 100% RDN through organic, i.e. FYM, PM, VC and NC, enhanced progressively OC content of the soil over the initial content. Contrary to this, available N increased progressively from 100% RDN through organic sources alone towards integrated use of organic and fertilizers sources. The significantly highest values of OC was recorded with 100% RDN through FYM, whereas 50% RDN through VC + 50% RDN through fertilizers indicated the highest available N balance. Organic manure has got some solubilizing effect on some mineral compounds present in soil and brings about the conversion of a num-

ber of chemical elements in available form. The beneficial effect of organic manures on organic carbon content could be attributed to the presence of higher residue and litter and enhanced microbial activity. Parihar and Rana (2010) also recorded improvement in soil fertility after crop harvesting owing to integrated nutrient management. Singh *et al.* (2013) reported highest OC and available soil N in pearlmillet cultivation with 100% RDN through FYM followed by 80% RDN through vermicompost + 20% through urea and integrated use of RDN through FYM + urea in different proportions.

The use of organic manure in combination with fertilizers helps in balancing soil fertility, environment and reduce the cost of inputs as reported by several workers. It was concluded that 50% RDN through VC + 50% RDN through fertilizers may be applied for realizing higher productivity, quality of produce and net monetary returns from fennel along with improvement in soil health.

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