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Performance of Fennel (*Foeniculum vulgare* Mill.) as Influenced by Saline Water Irrigation and Organic Input Management in Semi-arid Conditions

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Abstract

Irrigation water is one of the scarcest but critical resources for agricultural production and most of the arid and semi-arid regions are usually underlain by aquifers of poor quality. A field experiment was conducted for four years during *rabi* season to assess the impact of saline water irrigation and organic input management options for sustaining productivity of high value spice crop fennel (var. Hisar Swarup HF-33). Saline water of low (EC_{iw}, 2 dS m^{-1}) and high (EC_{iw} 8.6 dS m^{-1}) salinity were used for irrigation. These types of waters are commonly encountered in arid and semi-arid regions. Eight inorganic and organic input options were used to verify the hypothesis whether the adverse effect of saline water irrigations can be mitigated through organic inputs. Surprisingly the average seed yield of fennel with low and high saline water use was almost at par (1.56 ± 0.02 t ha^{-1}) showing its suitability for saline irrigation. Average seed yield of fennel under inorganic and organic input treatments ranged from 1.4 to 1.7 t ha^{-1}. The trend in yield over the years reveals that application of organic inputs in various combinations can play an important role in sustaining the yield through improvement in fertility of salt-affected soils especially when irrigated with poor quality waters. Amongst all the combinations, farmyard manure + vermi-compost (50:50 ratios for equivalent N) produced economically remunerative and sustainable yield over the years with a net income of about Rs 124 thousand per ha.

Key words: Farm yard manure, Fennel, Neem manure, Organic inputs, Saline water, Seed yield, Vermi-compost, *Foeniculum vulgare*

Introduction

India is a leading producer of spices and condiments; and the seed spices have unique position being the commodity of economic importance. In India, seed spice fennel (*Foeniculum vulgare* Mill.) is grown in Gujarat, Rajasthan, Madhya Pradesh, Haryana and Uttar Pradesh covering an area of about 100 thousand ha with production of 143 thousand tones in the year 2012-13 (Indian Horticulture Database, 2013). Since the crop is widely grown in arid and semi-arid regions where soil and water often contain high concentration of salts, farmers resort to irrigate it with saline groundwater (Ashraf and Akhtar, 2004; Qasim *et al.*, 2003). Though the farmers use saline water for irrigation but no systematic information is available on irrigation water salinity tolerance limits of this crop particularly when organic and inorganic inputs are used. In addition to this, there is growing concern about the adverse impacts of pesticides and chemical fertilizers on the environment, quality of food and safety of human and animal populations. As the people are becoming more quality conscious, the demand for organically grown spices is increasing in the global market. Although the benefits of organic fertilizers are widely documented (Enwall *et al.*, 2005; Lal, 2004; Fliessbach *et al.*, 2009; Pimental *et al.*, 2005), but simultaneously it has also emerged that application of organic inputs may be at the cost of yield-loss over short periods (Mader *et al.*, 2002). However, Mbagwu (1992) advocated that use of organic fertilizers can be as effective as chemical fertilizers over longer periods of time. At present; there is limited information available on cultivation of seed spices using saline water; and role of organic fertilizers in mitigating the adverse effects of saline water. Therefore, the present study was planned with the objectives (i) to assess the effect of saline water irrigations on the yield of fennel and (ii) to investigate the mitigation of adverse impacts of saline water through appropriate combinations of organic inputs under irrigation using low and high saline water for sustainable production of the crop.

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Materials and Methods

A field experiment was initiated during *kharif* season of 2008 with sesame-fennel crop rotation, fennel being cultivated during the *rabi* season at Bir Forest Farm, Hisar (29° 10' N latitude and 75° 44'E longitude at an altitude

of 220 m above mean sea level). The study site is categorized as semi-arid with an average annual rainfall of about 450 mm. The total average annual rainfall received during four years (2008-09 to 2011-12) varied from 399.2 mm to 918.8 mm, of which 75% was received during July to September. Only 10 to 15% of the total annual rainfall was received during the *rabi* seasons (Table 1). The pan evaporation ranged from 1.2-10.3 mm day^{-1} during November 2008 to May 2012. The low temperatures in the area during December and January adversely affected the growth of the fennel but crop growth resumed afterwards with the rise in temperature. The soil of the experimental site is highly calcareous (Ustic Haplocambids) sandy loam with EC_e 0.80 – 0.86 dS m^{-1}, pH_s 8.2 – 8.5 and organic carbon 0.26%. The water quality of two tube wells available at the farm was analyzed at different intervals following standard methods (Jackson, 1973) to keep track of the temporal changes in the water quality. The average EC_{iw} of two tube wells was 1.9 dS m^{-1} and 8.6 dS m^{-1} and designated as low saline and high saline water, respectively. Periodic EC_{iw}, pH, RSC and SAR of low saline water were 2.0 dS m^{-1}, 8.4, 4.8 meq l^{-1} and 12.9 m mol l^{-1}; and of high saline water these values were 8.6 dS m^{-1} , 7.7, nil and 18.5 mmol l^{-1}, respectively (Fig. 1).

The crop was sown in first week of November every year and harvested in last week of April to 3rd week of May of the next respective years in 3-4 plucking. Irrigations were applied commonly to all the treatments but depending upon the climatic conditions, numbers of irrigations varied from 5 – 7 during the four years of study. The fennel variety Hisar Swarup (HF-33) was cultivated for all the four seasons. The treatments composed of irrigations with two water qualities of water in main plots. In sub plots, 8 different treatments comprised of inorganic fertilizer in the recommended dose (60 kg N ha^{-1} and 30 kg P_2O_5 ha^{-1}); inorganic fertilizer and organic manures in combination; and 6 combinations of organic inputs, viz., farmyard manure, vermin-compost and non-edible Neem manure as shown in the following treatments:

T_1 : 100% inorganic fertilizer which includes 60 kg N ha^{-1} through urea and 30 kg P_2O_5 ha^{-1} through single super phosphate;

T_2 : 50% N through urea and P through SSP (inorganic) + 50% using organic inputs, for initial three years. This treatment was fully converted to organic inputs in the 4th year applied through FYM+VC+NM @ 8 t, 1.74 t and 1.60 t ha^{-1}, respectively;

T_3 : 50% of N equivalent each using farmyard manure @ 6 t ha^{-1} + vermi-compost @ 1.3 t ha^{-1};

T_4 : 50% of N equivalent each using farmyard manure @ 6 t ha^{-1} + non-edible Neem manure @ 1.2 t/ha;

T_5 : 33.3% of N equivalent each using farmyard manure @ 4 t + vermi-compost @ 0.87 t + non-edible Neem manure @ 0.8 t ha^{-1};

T_6 : 100% N equivalent (200% of treatments 3) each using farmyard manure @ 12 t + vermin-compost @ 2.6 t ha^{-1};

T_7 : 100% N equivalent (200% of treatments 4) each using farmyard manure @ 12 t + non-edible Neem manure @ 2.4 t ha^{-1};

T_8 : 66.6% N equivalent (200% of treatments 5) each using farmyard manure @ 8 t + vermi-compost @ 1.74 t + non-edible Neem manure @ 1.60 t ha^{-1}.

Table 1. Rainfall, evaporation and temperature during crop growth period (Nov. 2008-May 2012)

Climatic parameters	Years	Months						
		Nov.	Dec.	Jan.	Feb.	March	April	May
Rainfall (mm)	2008-09	3.2	0.8	10.3	6.1	4.1	24.9	38.2
	2009-10	0.0	0.0	11.5	7.6	2.5	0.0	1.9
	2010-11	0.0	43.6	0.0	34.8	12.5	35.2	84.9
	2011-12	0.0	0.0	14.4	0.0	0.0	33.3	29.8
Evaporation (mm/day)	2008-09	2.3	1.5	1.4	2.1	3.7	7.4	9.3
	2009-10	2.1	1.6	0.9	2.3	4.2	8.1	10.3
	2010-11	2.2	1.4	1.2	1.9	3.0	5.5	9.1
	2011-12	2.6	1.4	1.4	2.2	3.8	5.6	8.7
Temperature (^{0}C) (maximum)	2008-09	28.9	23.5	20.1	24.1	29.4	35.8	40.8
	2009-10	27.1	23.1	17.3	25.8	34.9	41.1	42.9
	2010-11	27.7	21.3	16.9	22.7	28.6	34.4	40.1
	2011-12	29.4	22.9	18.4	21.0	28.5	34.2	39.9
Temperature (^{0}C)(minimum)	2008-09	10.6	6.8	5.8	7.3	11.8	17.3	23.7
	2009-10	9.9	4.9	5.9	7.4	16.7	20.4	24.4
	2010-11	11.5	4.6	4.2	8.1	11.4	16.7	23.9
	2011-12	11.0	5.2	4.8	5.3	10.3	18.0	22.3

The treatments were replicated three times. The crop was sown at row to row spacing of 50 cm in 2 m x 3 m plots. The chemical fertilizers; full dose of phosphorous was applied as basal while nitrogen was applied in two splits, half as basal and half at 30 days after sowing. All the organic inputs were applied before sowing the crop and mixed well into the soil. Observations on plant height, number of umbels per plant, number of umbellets per umbel and seed weight per umbel were recorded on randomly selected and tagged 5 plants per plot. Plucked umbels were kept in shade for drying and seed yield (kg per plot) was recorded after threshing of dried umbels. Soil samples (0-30 cm depth) were collected at the time of harvesting every year and analyzed for EC_e, pH_s, organic carbon, available nitrogen and phosphorous content after each season. Statistical analysis was performed for judging the significance of difference among different treatments at 0.95 level of probability with the help of a statistical package (OPSTAT online). An account of the expenses made under each treatment was maintained for detailed economic analysis.

Results and Discussion

Effects of use of saline water irrigation and organic fertilizer inputs on growth and yield attributes of the fennel crop are discussed in the following sections.

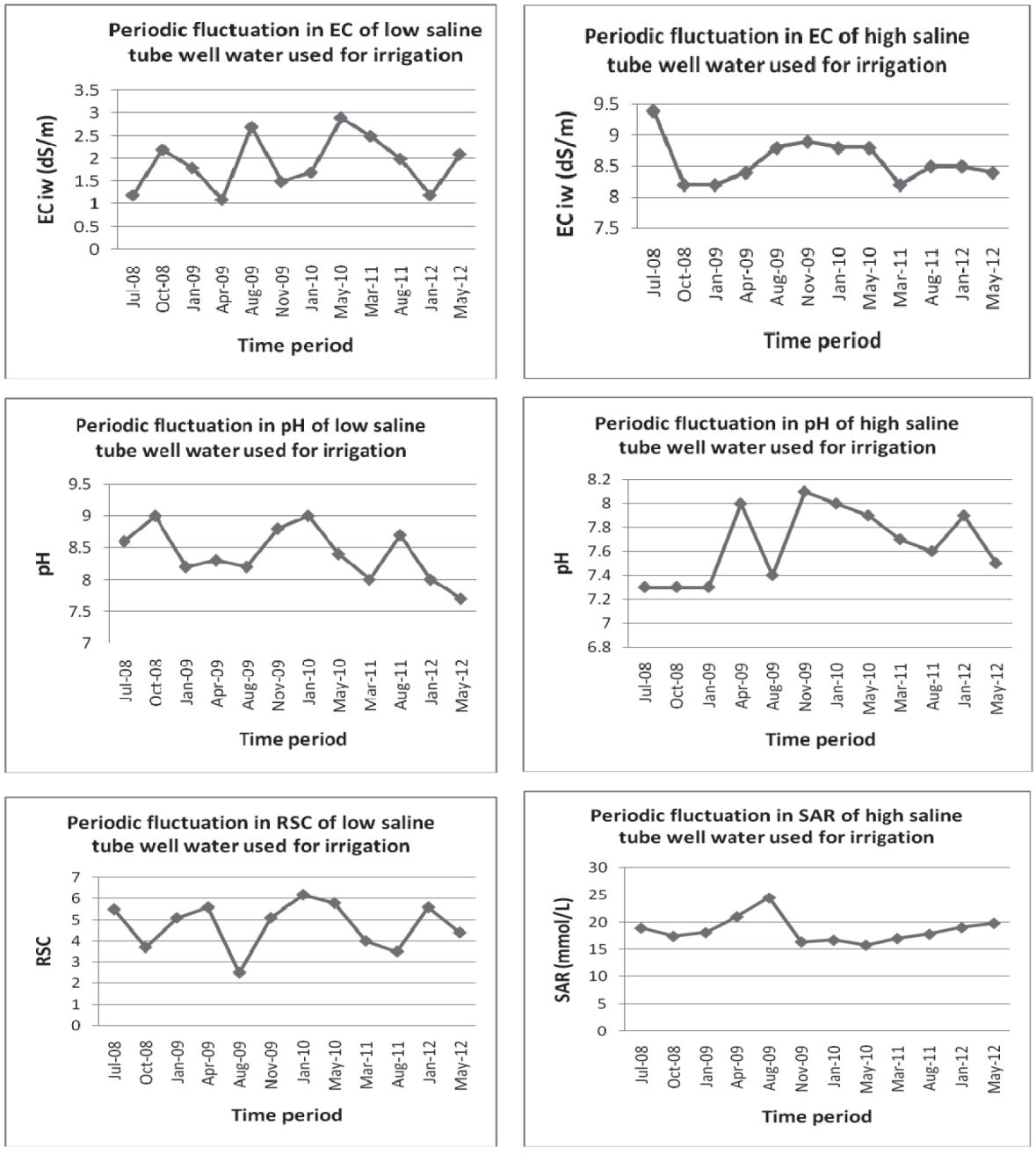

Fig. 1. Periodic water quality measurement of tube well used for irrigation (2008-2012)

Effect of saline water irrigation on growth parameters

Perusal of data on plant height showed that the average plant height (136.4 cm) was highest under low saline irrigation although it was not significantly different to high saline water during 2008-09 and 2010-11 (Table 2). The data show that fennel was able to tolerate high salinity to a great extent without much reduction in plant height. Number of umbels per plant ranged from 20.1 to 28.2 with an average of 23.2 with low saline and 22.7 with high saline water. No significant difference in number of umbels/plant was observed, however, the highest number (30.1) of umbels/plant were recorded during first year under high saline water irrigation. Number of umbellets/umbel decreased from 21 to 19.2 during first three years although maximum (28.3) were recorded during fourth year under low saline water irrigation. Number of umbellets/umbels increased from 18 in first year to 27 in the fourth year under high saline water irrigation. It could be attributed to improved physical condition of soil under various organic inputs over the years. Significant difference in number of umbellets was observed during first and third years with higher average number of umbellets (22.4) recorded in low saline water irrigation (Table 2). Similar results have been reported by Mangal *et al.* (1986) and Abou El-Magd *et al.* (2008).

Effect of saline water irrigation on yield and yield attributes

Seed weight per umbel varied from 1.16-4.04 g and 1.27-3.81 g with low and high saline water, respectively with an average of 2.30 and 2.25 g, respectively (Table 3). Contrary to the expectation of large differences, only the small differences were recorded between two salinities of irrigation water. This might be due to several reasons, possibly higher RSC in low saline water and mitigation of the adverse effect of saline water irrigation by application of different organic inputs. Seed weight of 100 seeds did not differ significantly during the initial three years while significant differences were observed only in fourth year. Averaged data showed that maximum 100 seed weight was recorded under high saline water, may be due to presence of RSC in low saline irrigation water which might have adversely affected the development of seeds as compared to high saline water. Similarly, seed yield of fennel showed decreasing trend initially which got reversed during third and fourth years. Averaged seed yield showed that the higher yield of 1.57 t ha^{-1} was obtained under low saline water which was not much different than 1.56 t ha^{-1} with high saline water irrigation (Table 3). The reasons for such minor differences have been discussed previously in this section. Similar results were obtained by Mangal *et al.* (1986) and Abou El-Magd *et al.* (2008).

Effect of organic manures on growth parameters

Application of organic inputs had significant effect on plant height of fennel during all the years. Application of inorganic fertilizers resulted in significantly lower plant heights of 114.3, 100 and 137.5 cm during first, second and fourth year, respectively. Among the treatments, application of farmyard manure, vermi-compost and neem manure (*Neem shakti*) in different combinations (T_3-T_8) resulted in increased plant height as compared to inorganic fertilizer alone (T_1) or combination of inorganic fertilizer + organic manures (T_2). Results also showed that effect of organic manures was quite discernible during the fourth year probably because of the fact that few years are required to improve and rejuvenate the soil fertility. Average plant height was 122.4 cm with application of inorganic fertilizer alone while higher values were obtained in all other treatments. The year-to-year variations in plant height might be due to climate variability, rainfall, impact of saline water irrigation and role of organic manures in mitigating its adverse effects. The role of organic manures in mitigating the adverse effect resulted in overall good plant growth. Average number of umbels/plant under organic manures application ranged from 21.1 to 24.1. There was no significant difference in umbels per plant under different organic manures as compared to inorganic fertilizer alone or their combination (T_2). The maximum number of umbels per plant ranging from 24.3 to 33.3 were recorded during first year and there was general decline in later years. Number of umbellets/umbel has significant variation only in the first year while remaining non-significant in the following years. Maximum umbellets were recorded during fourth year with average number of umbellets per umbel ranging from 19.8 to 23.5 (Table 2). Similar findings in plant height and yield of capsicum spice crop were also reported by Gopinath *et al*. (2008); Jaipaul *et al*. (2011).

Effect of organic input application on yield and yield attributes

Perusal of the data presented in Table 3 showed that seed weight per umbel and seed yield with different organic input management options varied significantly during first year. Average seed weight per umbel ranged from 2.0 g with inorganic treatment to 2.6 g with organic manure treatment T_8. Highest seed weight per umbel was recorded during fourth year which ranged from 3.40 to 4.40 g. Data on 100 seed weight showed that it differed non-significantly during all the years averaging 0.74 to 0.77 g under different treatments.

In first year, the lowest seed yield (1.17 t ha^{-1}) of fennel was obtained with the application of inorganic + organic input combination in the ratio of 50:50 while highest 1.63 t $ha^{-1}$was obtained under treatment T_8 which was at par with the seed yield (1.44 t ha^{-1}) obtained in treatment T_3. The results of lower yield in treatment T_2 (50% inorganic+50% organic) are in line with the results available in literature on several crops, since the availability of nutrients applied through organic inputs needs time to

Table 2. Growth and growth parameters of fennel under saline water and organic input application during 2008-09 to 2011-12

Treatments	Plant height (cm)					Umbels/plant					Umbellets/umbel				
	08-09	09-10	10-11	11-12	Av.	08-09	09-10	10-11	11-12	Av.	08-09	09-10	10-11	11-12	Av.
Salinity of irrigation water															
Low saline	131.2	121.0	143.3	149.9	136.4	28.2	21.7	20.1	22.9	23.2	21.0	20.9	19.2	28.3	22.4
High saline	120.5	98.5	140.3	143.3	125.7	30.1	18.6	21.6	20.3	22.7	18.0	18.5	20.4	27.0	21.0
LSD (p=0.05)	NS	22.2	NS	5.1	-	NS	NS	NS	NS	-	1.8	NS	0.8	NS	-
Organic input options															
T_1	114.3	100.1	137.7	137.5	122.4	28.5	21.1	21.5	21.5	23.2	19.8	18.0	18.2	25.0	20.3
T_2	115.6	100.6	134.3	147.5	124.5	24.3	16.8	20.8	22.5	21.1	17.3	18.5	20.0	23.5	19.8
T_3	120.5	110.4	139.7	141.6	128.1	27.3	19.6	23.8	22.8	23.4	20.0	18.2	18.8	28.3	21.3
T_4	124.7	106.2	140.5	146.3	129.4	28.0	19.7	22.2	21.3	22.8	17.8	18.2	21.0	27.0	21.0
T_5	133.0	105.0	139.7	143.2	130.2	29.8	19.8	19.7	20.5	22.5	20.3	20.5	20.0	28.7	22.4
T_6	132.8	113.9	138.9	146.7	133.1	32.8	22.5	20.8	20.3	24.1	20.2	21.6	20.2	31.8	23.5
T_7	131.8	119.0	152.1	157.1	140.0	29.0	20.0	18.7	21.7	22.4	20.2	21.0	20.5	27.2	22.2
T_8	134.0	122.7	151.3	153.0	140.3	33.3	21.7	19.2	22.0	24.1	20.7	21.5	20.0	29.5	22.9
LSD (p=0.05)	10.9	14.4	11.1	9.2	-	NS	NS	NS	NS	-	2.0	NS	NS	NS	-

(T_1:100% Inorganic fertilizer T_2: Inorganic + organic inputs (50:50)-fully organic after 3 years, T_3: Farmyard manure+ Vermi-compost (50:50), T_4: Farmyard manure + Non-edible Neem manure (50:50), T_5: Farmyard manure + Vermi-compost + Non-edible Neem manure (33.3:33.3:33.3), T_6: Farmyard manure + Vermi-compost (100: 100), T_7: Farmyard+Non-edible Neem manure (100:100), T_8: Farmyard manure+Vermi-compost+Non-edible Neem manure (66.6:66.6:66.6).

Table 3. Seed yield and yield parameters of fennel under saline water and organic input application during 2008-09 to 2011-12

Treatments	Seed weight/umbel (g)					100 seed weight (g)					Seed yield (t/ha)				
	08-09	09-10	10-11	11-12	Av.	08-09	09-10	10-11	11-12	Av.	08-09	09-10	10-11	11-12	Av.
Salinity of irrigation water															
Low saline	2.46	1.54	1.16	4.04	2.30	0.90	0.55	0.72	0.79	0.74	1.50	1.26	1.50	2.03	1.57
High saline	2.26	1.64	1.27	3.81	2.25	0.90	0.63	0.77	0.76	0.77	1.40	0.85	1.87	2.13	1.56
LSD (p=0.05)	0.07	NS	NS	0.14	-	NS	NS	NS	0.01	-	NS	0.41	0.06	NS	-
Organic input options															
T_1	2.20	1.31	1.10	3.40	2.00	0.90	0.54	0.75	0.79	0.75	1.37	0.97	1.53	1.78	1.41
T_2	1.95	1.45	1.27	3.37	2.01	0.89	0.56	0.71	0.79	0.74	1.17	1.01	1.55	2.16	1.47
T_3	2.32	1.59	0.94	3.92	2.19	0.87	0.62	0.74	0.78	0.75	1.44	1.20	1.65	2.10	1.60
T_4	2.20	1.53	1.32	4.02	2.27	0.88	0.64	0.78	0.76	0.77	1.34	1.11	1.61	2.17	1.56
T_5	2.23	1.58	1.25	4.11	2.29	0.85	0.60	0.75	0.77	0.74	1.55	1.17	1.63	2.01	1.59
T_6	2.55	1.84	1.25	4.09	2.43	0.90	0.57	0.74	0.75	0.74	1.44	0.88	1.97	1.97	1.57
T_7	2.47	1.69	1.29	4.06	2.38	0.93	0.57	0.74	0.78	0.76	1.60	1.05	1.56	2.17	1.60
T_8	2.95	1.74	1.29	4.40	2.60	0.97	0.60	0.75	0.77	0.77	1.63	1.03	1.98	2.21	1.71
LSD (p=0.05)	0.41	NS	NS	NS	-	NS	NS	NS	NS	-	0.03	NS	NS	NS	-

Depictions for treatments are as in Table 2.

build-up for its availability to the plants. As expected under field conditions, there are year to year variations in crop yield varying from 0.88 to 2.21t ha^{-1}. These can be attributed to initial soil conditions as salinity build-up take time within the season or over the years, variations in quality of irrigation water and rainfall and its distribution during the crop growth period.

Averaged seed yield of fennel (ranged from 1.47 to 1.71 t ha^{-1}) in various treatments, the highest being in treatment T8 with 200% application on N basis. Most economical combination over the four years period however, was T_3, where farmyard manure + vermin-compost was used in 50:50 ratio on N basis with an average seed yield of 1.60 t ha^{-1}. It could fetch a net income of Rs. 123980 per ha. According to Edwards (1998), vermin-compost contains most of the plant nutrients such as; nitrate, phosphates, exchangeable calcium, soluble potassium, and microelements. Thus, application of vermin-compost helps in improving plant growth and development and is responsible for increased qualitative and quantitative yield of many crops (Atiyeh *et al.*, 2002; Roy *et al.*, 2010). A cursory look at the results of four years revealed that saline water up to 8.5 dS m^{-1} can be used for irrigation of fennel with application of organic manures. Later helps in mitigating the adverse effect of saline water application and sustaining the productivity of high value crop as compared to application of inorganic fertilizers alone. It can be attributed to improved soil physical state especially in low saline RSC water and sustained release of macro and micro nutrients. Similar results were also reported by several workers (Bahadur *et al.*, 2006; Gopinath *et al.*, 2008; Bahadur *et al.*, 2009; Jaipaul *et al.*, 2011; Upadhyay *et al.*, 2012). Results obtained by Phogat *et al.* (2010) also show that synergy of chemical amendments and organic inputs sustained vegetable production irrigated with high RSC waters. The results presented in this paper are of great importance in managing saline water in arid and semi-arid regions for cultivation of seed spices in general and fennel in particular.

Conclusion

Groundwater of poor quality is a general character of arid and semi-arid ecology where fennel crop is cultivated. Results of four years study reveal that cultivation of high value seed spices in general and fennel in particular is possible using saline water up to EC 8.5 dS m^{-1} without much yield reduction. The long-term adverse effect of saline water if any can be mitigated by application of organic inputs (farmyard manure, vermin-compost and neem manure. The organic inputs in various combinations help in improving the soil physico-chemical properties that mitigates the adverse effect of saline water including RSC, which is known to cause adverse effects on soil physical properties. Considering the cost and quality of organic inputs, a combination of 6 t ha^{-1} farmyard manure and 1.3 t ha^{-1} vermi-compost seems to be a good combination to achieve the sustainable production of fennel crop in saline environment and fetching net income of Rs 124 thousand per ha.

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