Journal of Spices and Aromatic Crops
Vol. 16 (2) : 93–98 (2007)

Indian Society for Spices

Effect of non-symbiotic microbial inoculants on growth, yield and quality of fennel (*Foeniculum vulgare* Mill.) grown in sodic soil

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Received 25 May 2007; Revised 18 August 2007; Accepted 12 September 2007

Abstract

The response of non-symbiotic microbial inoculants on growth, yield and quality of fennel (*Foeniculum vulgare*) grown in partially reclaimed sodic soils was studied at Lucknow (Uttar Pradesh). The results revealed that inoculation of phosphate solubilizing bacteria or in combination with *Azotobacter chroococcum* was superior resulting in 14%–15% increase in seed yield. Application of fertilizers (80 kg ha^{-1} N + 25 kg ha^{-1} P) with inoculants had an additive effect on plant growth. An increase in availability of soil P (41%–44%) and essential oil content (10%–14%) was also noticed.

Keywords: fennel, *Foeniculum vulgare*, , non-symbiotic microbial inoculants, sodic soil.

Introduction

Several investigations have been made on agronomical aspects to increase the yield of fennel (*Foeniculum vulgare* Mill.) on normal and sodic soils (Avatar & Mahey 1994; Garg *et al*. 2000a; Rai *et al*. 2002). In general, sodic soils are low in N and P status; however, little is known about the response of biofertilizers particularly non-symbiotic inoculants on the yield and quality of fennel grown in such soils.

Hence, a preliminary study was conducted with the objective to know the response of *Azotobacter chroococcum* and phosphate solubilizing bacteria (*Pseudomonas* sp.) on plant growth, yield and seed quality of fennel grown in partially reclaimed sodic soils.

Materials and methods

The field trial was conducted on sodic soils of Banthra Research Station, National Botanical Research Institute, Lucknow ($26^0$40′–$26^0$45′ N, $80^0$45′–$80^0$53′ E) during 2003–04. The soil is partially reclaimed through biological means (Khoshoo 1987). In general, soil pH varies from 8.6–10.0 with low to medium status of organic carbon (0.574%). The soil belongs to fine loamy mixed hyperthermic family of *Typic Natrutalfs* (Garg *et al*. 2000b). The experiment was laid out in a randomized block design with three replications. A basal dose of FYM @ 20 t ha^{-1} was given during land preparation. There were eight treatment combinations namely, T_1-Control; T_2-B_oF_o, only fertilizer @ 80 kg N ha^{-1} and 25 kg P ha^{-1}; T_3-*Azotobacter chroococcum* (AZB) inoculation; T_4-AZB inoculation + 80

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kg N ha^{-1} and 25 kg P ha^{-1}; T_5-Phosphate solubilizing bacteria (PSB) inoculation; T_6-PSB + 80 kg N ha^{-1} and 25 kg P ha^{-1}; T_7-Combined inoculation of AZB + PSB, T_8-AZB + PSB + 80 kg N ha^{-1} and 25 P ha^{-1}.

Efficient strains of *A. chroococcum* (AZB) and *Pseudomonas* sp. (PSB) isolated from alkali soil were used for inoculation in the study (Johri *et al*. 1999). Slurry of carrier-based culture was made with 10% gum Arabica prepared in water to serve as sticker. The seeds of fennel cultivar HF-107 were inoculated by mixing with slurry and were dried in shade for about 2 h. The seeds were sown in plots of 3 m^2 size during the 2nd week of November 2003. Normal cultural practices were followed and the crop was harvested at maturity. Observations were recorded on plant height, number of branches, umbel $plant^{-1}$, umbellets $umbel^{-1}$, test-weight 1000 $seed^{-1}$ and total seed yield $plot^{-1}$ at harvest. The data were subjected to statistical analysis (Panse & Sukhatme 1961).

Essential oil was extracted by hydro distillation in Cleavenger's apparatus and oil yield was calculated by multiplying the seed yield by its oil content.

To assess the microbial population, 24 samples of rhizosphere soil were collected from the control treatment having application of fertilizer alone, and biofertilizers alone or in combination during flowering stage of fennel. AZB population count was determined by using Jensen's medium as described by Black (1965). Population of PSB was determined using root-free soil surrounding the roots of fennel. The total bacterial counts were determined by dilution plate technique using Pikovskaya medium (Pikovskaya 1948).

To know the relationship of biofertilizers with soil fertility, representative surface soil samples from each treatment were drawn before sowing and after harvest of crop. Soil samples were analysed for pH, EC, organic carbon, total N, available P and K, cation exchange capacity (CEC) and exchangeable sodium percentage (ESP) following standard procedures (Jackson 1967).

Results and discussion

Application of fertilizers (N and P) alone (T_2) increased growth and yield parameters over control (Table 1). Fennel seed inoculated with AZB and PSB alone or in combination increased plant height, number of branches $plant^{-1}$, number of umbels $plant^{-1}$, number of umbellets $umbel^{-1}$ and seed yield over control, but the data were not statistically significant. The application of bioinoculants in comparison to inorganic fertilizer showed significant difference in test weight 1000 $seed^{-1}$ when compared to control. Inoculation with AZB alone (T_3) resulted in increase of 1.9% in plant height, 2.5% in number of umbellets $umbel^{-1}$, 13% seed test weight and 2.4% in seed yield. Number of branches $plant^{-1}$ and number of umbels $plant^{-1}$ did not show any response to AZB. Inoculation of PSB (T_5) alone reflected an increase of 11% in plant height, 2.2% in number of branches $plant^{-1}$, 17% seed test weight and 8.9% in seed yield. Rest of the parameters did not show any response to PSB. However, application of combined biofertilizers indicated an increase of 14.8% in plant height, 3.05% in number of branches $plant^{-1}$, 100% increase in number of umbels $plant^{-1}$, 14.3% increase in number of umbellets $umbel^{-1}$, 18% seed test weight and an enhancement of 14.8% in seed yield (Table 1). The increase in growth and yield may be attributed to better utilization of inorganic N, greater biological N fixation, higher synthesis of plant growth hormones and enhanced availability of P in the presence of biofertilizers. Further, increased uptake of N and P nutrients, although not studied here, play an important role in the development of meristematic tissues at growing points for promoting growth and also aid in formation of seeds and fruits in plants. Increase in seed yield due to inoculation by AZB and PSB has been observed in other crops like soybean, tomato and chilli (Chhonker & Tarafdar 1984; Hamedunnisa & Begum 1998; Sajan *et al*. 2002)

In general, inoculation of microorganisms enhanced their population in soil during crop

Table 1. Effect of *Azotobacter chroococcum* and phosphate solubilizing bacteria on growth and seed yield of fennel grown in sodic soil

Treatment	Plant height (cm)	Branches plant^{-1}	Umbels plant^{-1}	Umbellets umbel^{-1}	Test weight 1000 seed^{-1} (g)	Seed yield plot^{-1} (g)
Biofertilizer						
B_0	55.78	7.22	8.72	13.22	4.4540	140.0
B_1	56.89	7.22	7.44	13.55	5.0354	143.3
B_2	62.00	7.38	7.39	13.27	5.2327	152.5
B_3	64.05	7.44	17.5	15.11	5.2530	160.8
SEm±	2.99	0.43	7.07	1.11	0.1520	37.7
C D (P=0.05)	6.42	0.93	15.17	2.39	0.3260	92.3
Fertilizer						
F_0	55.64	7.25	8.22	13.19	4.9784	145.4
F_1	61.72	7.63	12.30	14.38	5.0091	182.9
SEm±	2.11	0.3	5.00	0.78	0.1074	22.87
CD (P=0.05)	4.54	0.66	10.73	1.69	0.2305	52.75
Interaction						
B x F						
SEm±	4.23	0.61	10	1.57	0.2149	49.70
C D (P=0.05)	9.08	1.32	21.45	3.38	0.46115	118.65

B_0=Control; B_1=*Azotobacter chroococcum* (AZB); B_2=Phosphate solubilizing bacteria (PSB); B_3=AZB + PSB; F_0=No fertilizer; F_1=Fertilizer 80 kg ha^{-1} N, 25 kg ha^{-1} P

growth at flowering stage. The population of AZB varied from 1.45 x 10^2–1.84 x 10^3 with a mean of 7.19 x 10^2 g^{-1} soil and that of PSB ranged from 1.20 x 10^2–1.16 x 10^3 with an average of 4.84 x 10^2 g^{-1} soil under control. Inoculation of AZB alone resulted in an increase of its population ranging from 1.80–1.90 x 10^6 with a mean of 1.83 x 10^6 g^{-1} soil. The population of PSB counts varied from 1.99 x 10^4–1.84 x 10^6 with a mean of 7.45 x 10^6 g^{-1} soil. There was a little variation in the population of PSB but population of AZB was enhanced on application of N and P fertilizers. In case of combined inoculation, mean counts of AZB population escalated further to 1.43 x 10^7 g^{-1} soil and of PSB to 6.76 x 10^7 g^{-1} soil (Table 2). The highest population of PSB occurred due to combined application of bioinoculants with and without application of fertilizers (N and P) showing beneficial effect which may be due to the synergistic interaction of these two biofertilizers. Application of fertilizers to the soil probably improves the microbial activity because of the availability of more readily obtainable nutrients. In soil, microbes are in dynamic

Table 2. Mean microbial population in surface soil after application of *Azotobacter chroococcum* and phosphate solubilizing bacteria to fennel crop grown in sodic soil

Treatment	AZB	PSB
B_0F_0	7.19 x10^2	4.84 x 10^2
B_0F_1	7.08 x 10^2	5.87 x 10^2
B_1F_0	1.83 x 10^6	-
B_1F_1	2.01 x 10^6	-
B_2F_0	-	7.45 x 10^6
B_2F_1	-	7.69 x 10^6
B_3F_0	1.43 x 10^7	6.67 x 10^7
B_3F_1	2.01 x 10^7	7. 23 x 10^7

B_0=Control; B_1=*Azotobacter chroococcum* (AZB); B_2=Phosphate solubilizing bacteria (PSB); B_3=AZB + PSB; F_0=No fertilizer; F_1=Fertilizer 80 kg ha^{-1} N, 25 kg ha^{-1} P

Table 3. Chemical properties of soil (experimental plot) before sowing of fennel crop

Treatment	pH (1:2)	EC (dSm^{-1})	Org. C (%)	Av. K (kg ha^{-1})	Av. P (kg ha^{-1})	Total N (%)	CEC cmol kg^{-1})	ESP
B_0F_0	8.83	0.74	0.77	304.5	15.40	0.077	13.90	28.00
	±0.12	±1.16	±0.26	±24.6	±10.00	±0.026	±0.29	±0.55
B_oF_1	8.63	0.81	0.80	301.0	18.10	0.075	14.05	28.00
	±0.21	±0.28	±0.31	±17.3	±4.60	±0.031	±0.25	±0.87
B_1F_0	8.91	1.03	0.66	282.7	15.04	0.065	14.53	27.00
	±0.34	±0.38	±0.10	±13.4	±2.26	±0.010	±0.37	±0.12
B_1F_1	8.72	0.85	0.62	319.2	20.32	0.062	14.57	26.00
	±0.11	±0.23	±0.11	±29.3	±2.74	±0.011	±0.49	±0.54
B_2F_0	8.85	0.63	0.80	297.7	20.14	0.080	14.33	27.00
	±0.12	±0.09	±0.23	±17.4	±10.26	±0.020	±0.39	±1.60
B_2F_1	8.65	0.89	0.80	320.0	19.86	0.080	14.20	28.00
	±0.12	±0.02	±0.21	±22.1	±3.88	±0.020	±0.49	±0.92
B_3F_0	8.77	0.58	0.74	288.3	21.25	0.073	15.23	29.00
	±0.06	±0.03	±0.09	±17.7	±3.78	±0.009	±0.21	±0.82
B_3F_1	8.77	0.79	0.77	266.9	20.87	0.076	15.23	29.00
	±0.26	±0.20	±0.26	±15.0	±4.54	±0.026	±0.21	±0.82

B_0=Control; B_1=*Azotobacter chroococcum* (AZB); B_2=Phosphate solubilizing bacteria (PSB); B_3=AZB + PSB; F_0= No fertilizer; F_1=Fertilizer 80 kg ha^{-1} N, 25 kg ha^{-1} P; EC=Elecrtical conductivity; CEC=Cation exchange capacity; ESP=Exchangeable sodium percentage

Table 4. Effect of *Azotobacter chroococcum* and phosphate solubilizing bacteria applied alone and in combination with N and P fertilizers on soil chemical properties after harvest of fennel

Treatment	pH (1:2)	EC (dSm^{-1})	Org. C (%)	Av. K (kg ha^{-1})	Av. P (kg ha^{-1})	Total N (%)	CEC (cmol kg^{-1})	ESP
B_0F_0	8.58	0.56	0.78	327.30	26.70	0.078	13.50	27.00
	±0.26	±0.12	±0.09	±19.20	±1.80	±0.012	±0.33	±0.49
B_0F_1	8.56	0.50	0.75	311.60	28.70	0.074	14.24	27.00
	±0.30	±0.13	±0.12	±24.50	±6.40	±0.014	±0.31	±0.32
B_1F_0	8.75	0.60	0.81	270.20	24.89	0.086	15.14	27.00
	±0.10	±0.04	±0.09	±18.50	±3.78	±0.005	±0.10	±0.56
B_1F_1	8.85	0.52	0.83	393.47	28.40	0.083	14.70	25.00
	±0.06	±0.10	±0.06	±44.80	±2.04	±0.007	±0.34	±0.13
B_2F_0	8.88	0.49	0.78	412.40	28.44	0.078	13.85	26.00
	±0.04	±0.04	±0.09	±38.15	±4.89	±0.012	±0.15	±1.82
B_2F_1	8.63	0.61	0.76	442.17	32.83	0.070	14.74	26.00
	±0.23	±0.09	±0.15	±46.63	±6.93	±0.018	±0.32	±1.47
B_3F_0	8.67	0.51	0.86	332.07	30.57	0.086	15.53	26.00
	±0.16	±0.15	±0.08	±70.98	±2.33	±0.010	±0.34	±0.48
B_3F_1	8.71	0.48	0.75	313.83	31.32	0.075	15.42	27.00
	±0.18	±0.08	±0.16	±61.57	±3.55	±0.019	±0.42	±0.46

B_0=Control; B_1=*Azotobacter chroococcum* (AZB); B_2=Phosphate solubilizing bacteria (PSB); B_3=AZB + PSB; F_0= No fertilizer; F_1=Fertilizer 80 kg ha^{-1} N, 25 kg ha^{-1} P; EC=Elecrtical conductivity; CEC=Cation exchange capacity; ESP=Exchangeable sodium percentage

equilibrium and they compete with the plants and autotrophic bacteria are stimulated by the addition of fertilizers. The other possible reason may be attributed to better plant growth and direct contribution of inoculants in improving the fertility conditions of soil due to bacterial activity (Martinez *et al.* 1993).

The relationships of AZB and PSB alone or

Table 5. Influence of *Azotobacter chroococcum* and phosphate solubilizing bacteria on volatile oil yield in fennel seed grown in sodic soil

Treatment	Volatile oil (%)	Oil yield (l ha^{-1})
Biofertilizer		
B_o	1.925 ± 0.05	8.98
B_1	2.115 ± 0.06	10.10
B_2	2.075 ± 0.07	10.54
B_3	2.075 ± 0.04	11.12
Fertilizer		
F_0	2.045 ± 0.03	9.90
F_1	2.050 ± 0.05	12.49

B_0=Control; B_1=*Azotobacter chroococcum* (AZB); B_2=Phosphate solubilizing bacteria (PSB); B_3=AZB + PSB; F_0= No fertilizer; F_1=Fertilizer 80 kg ha^{-1} N, 25 kg ha^{-1} P

in combination with and without inoculation before sowing and after harvest of crop on soil properties indicated a remarkable increase in availability of phosphorus (28.44 kg ha^{-1}) during crop growth due to application of PSB alone and in combination with AZB and PSB (30.57 kg ha^{-1}) as compared to control (20.14 kg ha^{-1} P and 21.25 kg ha^{-1} P, respectively) before sowing of crop (Tables 3 & 4). Hence, there was about 41.2% increase in availability of P on inoculation with PSB alone but it was 43.8% with combined application of bio fertilizers during crop growth than before sowing. Apparently inoculation of PSB enhanced availability of P in soil probably by solubilizing unavailable form of Ca-bound soil phosphorus through excreting organic acids (Halvorson & Kornberg 1990; Yadav & Dadarwal 1997)

Application of biofertilizers did not indicate any marked response on volatile oil concentration of fennel seed (Table 5). There was about 8%–11% increase in oil content when the seeds were inoculated with AZB and PSB. Oil yield was greater in PSB alone or in combination with AZB treatment (>2.00%) which is slightly higher than the value of 1.95% reported on sodic soils (Garg *et al*. 2004). Therefore, it seemed that volatile oil increased marginally due to PSB leading to improvement in seed quality.

The study indicated that inoculation of PSB when applied alone or in combination with AZB along with fertilizers (N and P) increased seed yield and oil content of fennel.

Acknowledgement

The financial support offered by Council of Science and Technology, Uttar Pradesh, Lucknow, is gratefully acknowledged.

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