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Research Paper

Halophilic microbial formulations for improving crop productivity and soil health under saline *Vertisols* of Gujarat

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ABSTRACT

A study was carried out during winter (*rabi*) seasons of 2018 and 2019 at research farm of ICAR-Central Soil Salinity Research Institute, Regional Research Station, Bharuch, Gujarat to find out the effect of various halophilic microbial formulations in combination of organic manure and chemical fertilizers on winter (*rabi*) wheat (*Triticum aestivum* L.) productivity under saline *Vertisols*. Experiment was conducted in a randomized block design (RBD) comprised of 5 treatments, viz. T_1, Un-inoculated + Vermicompost @2.5 t/ha + 100% RDF (recommended dose of fertilizers); T_2, Un-inoculated + Vermicompost @2.5 t/ha + 75% RDF; T_3, Vermicompost @2.5 t/ha + 75% RDF + Halo-*Azo* inoculation; T_4, Vermicompost @2.5 t/ha + 75% RDF + Halo-PSB inoculation; and T_5, Vermicompost @2.5 t/ha + 75% RDF + Mix of Halo-*Azo* and Halo-PSB inoculation, replicated thrice. Results showed that application of different halophilic microbial formulations like Halo-*Azo (Azotobacter* sp. and *Bacillus* sp.) and Halo-PSB (consortia of *Eneterobacter* and *Brevibacterium* sp.) with vermicompost @2.5 t/ha + 75% RDF (recommended dose of fertilizers), provided at par yield with full dose (120 : 60 : 00; N : P : K kg/ha) of fertilizers, thus able to reduce 25% chemical fertilizer dose. Halo-*Azo* formulation performed better for improving crop yield as compared to Halo-PSB formulation. Combined application of Halo-*Azo* and Halo-PSB with vermicompost @2.5 t/ha and 75% RDF performed the best and provided significantly higher grain yield (2.75 t/ha) as compared to other treatments. Single and combined application of Halo-*Azo* and Halo-PSB with vermicompost @2.5 t/ha and 75% RDF also improved soil health parameters and significant results, i.e. declined EC (2.46 dS/m) and *p*H (7.33), improved organic carbon (0.69%) and nutrient availability (available N: 299.8 kg/ha and P: 28.7 kg/ha) were obtained. Results showed that integration of halophilic microbial formulations with organics and chemical fertilizers was able to improve wheat yield up to 15% than conventional farming under saline *Vertisols* of Gujarat.

Key words: Crop productivity, Halo-*Azo*, Halo-PSB, Saline *Vertisols*, Soil health

Vertisols are a group of heavy-textured soils with some distinct characteristic which occur extensively in the tropics, subtropics and warm temperate zones. These soils hamper agricultural crop production due to their typical physico-chemical properties i.e. waterlogging due to poor hydraulic conductivity and cracking behaviour (Jewitt e*t al.,* 1979; Virmani *et al.*, 1982). Saline *Vertisols* covers an area of approximately 1.1 million hectares in India, of which 0.12 million hectares are estimated to occur in Gujarat (Prasad *et al*., 2017). Salinity stress inhibit growth and development of plant by changing biochemical and physiological processes such as leaf and root growth, water uptake, stomatal conductance and photosynthesis (Patil, 2013; Panhwar *et al.*, 2019; Ismayilov *et al.,* 2021). Salinity stress also causes several nutritional disorders in plant by limiting nutrient availability in soil and essential nutrient uptake by crop plants which ultimately results in yield losses (Sun *et al.*, 2020). To cope-up with low productivity, use of all possible sources of plant nutrients in an integrated manner is receiving attention in intensive agriculture and positive results are reported in various studies (Pandey *et al.*, 2009, Mubarak and Singh, 2011). The yield of agricultural crops can be increased by about 25% and the use of chemical fertilizers can be reduced by about 25–50% N and 25% P through biofertilizer application (Kachroo and Razdan, 2006; Khan and Chattopadhyay, 2009; Saber *et al.,* 2012). However, basic biofertilizers perform less effectively in saline soils and their activity decreases in these soils (Rajput *et al.,* 2018). The rhizosphere of halophytic plants serve as a rich source of salinity stress tolerant bacteria and application of these bacteria in other field crops

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can positively affect the growth and yield of plants under salinity stress (Jha and Saraf, 2015).

ICAR-Central Soil Salinity Research Institute (CSSRI), Regional Research Station, Lucknow, Uttar Pradesh developed various liquid bioformulations Halo-*Azo*, Halo-PSB and Halo-Zn having salt tolerant (halophilic) bacterial strains of N-fixers, P solubilizes and Zinc solubilizing bacteria (ZSB), isolated from native saline soils and tested at multi-locations in saline as well as normal soils. These bioformulations with salt-tolerant varieties further improves crop production in saline areas efficiently (Arora *et al*., 2021). Therefore, keeping these points in view, an experiment was planned to evaluate the halophilic microbial formulations for improving wheat (*Triticum aestivum* L.) crop productivity on saline *Vertisols*.

MATERIALS AND METHODS

An experiment was conducted during winter (*rabi*) seasons of 2018 and 2019 at research farm of ICAR-Central Soil Salinity Research Institute, Regional Research Station, Bharuch (21°-51' N and 72°-53' to 72°-54' E with an elevation of 17.18 m above mean sea-level), Gujarat. The climate of experimental area is semi-arid with hot and dry pre-monsoon summer (May to June) followed by monsoon rains (June to September) receiving 735 mm of average annual rainfall with south-west monsoon currents. The soil of the experimental field was saline *Vertisols* with surface and subsurface salinity ranging from 2.96 to 3.12 dS/m (EC_2), *p*H-7.70 and low in organic carbon (0.49%) and available N (219.5 kg/ha), medium in available P_2O_5 (18.03 kg/ha) and high in K (570.49 kg/ha). Clay content of the soil ranged from 48–64% resulting in poor hydraulic conductivity due to which soils prone to waterlogging conditions and upward moment of salt present in lower layers observed while drying. Adverse effects of salinity become more pronounced even with low concentration of salts present in upper layers in this type of soils due to restricted leaching.

Experiment was conducted in a randomized block design (RBD) comprised of 5 treatments imposed on wheat crop i.e., T_1, Un-inoculated + Vermicompost (VC) @2.5 t/ha + 100% RDF (recommended dose of fertilizers); T_2, Un-inoculated + Vermicompost @2.5 t/ha + 75% RDF; T_3, Vermicompost @2.5 t/ha + 75% RDF + Halo-*Azo* inoculation; T_4, Vermicompost @2.5 t/ha + 75% RDF + Halo-PSB inoculation; and T_5, Vermicompost @2.5 t/ha + 75% RDF + Mix of Halo-*Azo* and Halo-PSB inoculation, replicated thrice. Key characteristic of formulations used in this study are given below:

Halo-Azo: It contains highly efficient salt tolerant N-fixing bacteria *(Azotobacter* sp. and *Bacillus* sp.) that can be used in normal as well as saline soils, supplements the nitrogen requirement of crops and also promotes plant growth. It is more suited for soils with *p*H 7.5 to 9.8. It can be used for rice, wheat, mustard, millets and vegetables. It can add 15–20 kg N/ha to the soil and helps in increasing crop yield by 10–15%. The liquid formulation has a shelf-life of over 1 year and can be stored at room temperature (Arora *et al.*, 2021).

Halo-PSB: It contains highly efficient salt tolerant strains of Phosphate solubilizing bacteria (PSB) (consortia of *Eneterobacter* and *Brevibacterium* sp.) that can be used in normal as well as saline soils. It ensures better root development and nutrient uptake and thereby vigorous crop growth. Liquid formulation of Halo-PSB can be used for rice, wheat, mustard, maize and vegetables crops. It suitable for soils with *p*H 7.5 to 9.7. Inoculation of P solubilizer helps to add 15 to 20 kg P_2O_5/ha. The liquid formulation has a shelf-life of over 1 year and can be stored at room temperature (Arora *et al.*, 2021).

Salt tolerant wheat variety (KRL-210) was taken for experimentation and crop was sown in the month of November during both the years. The recommended dose of fertilizer 120:60:00; N:P:K kg/ha was given to the crop as per treatments with full P and 50% N as basal and the remaining N in two splits. The liquid formulations of Halo-*Azo* and Halo-PSB, cultured, prepared and developed by ICAR-Central Soil Salinity Research Institute (CSSRI), Regional Research Station, Lucknow, Uttar Pradesh were procured and wheat seeds were treated with bioformulation solutions (100 ml/acre seed) according to different treatment combinations before sowing. For control without bacterial treatment, the seeds were soaked in sterile distilled water (100 ml/acre seed). Various growth and yield parameters were recorded to study the effects of microbial formulation on crop performance on saline *Vertisols*. Soil samples were also collected before start of the experiment and after harvesting during both the years. Data on growth and yield parameter of wheat were subjected to analysis of variance (ANOVA) as per the procedure described by Cochran and Cox.

RESULTS AND DISCUSSION

Growth parameters

The different microbial formulations showed positive effect on various wheat crop growth parameters. Statistically significant increases were observed with application of combination of Halo-*Azo* and Halo-PSB inoculation + VC @2.5 t/ha + 75% RDF (T_5). Significantly higher plant height at harvest (72.55 cm), fresh weight [4.50 g and 6.30 g at 60 and 90 days after sowing (DAS)] and dry weight (1.07 and 2.64 g at 60 and 90 DAS) were observed under treatment T_5 followed by treatment T_3 (T_2 + Halo-*Azo* inoculation) and T_1 (uninoculated + VC @2.5 t/ha + 100%

Table 1. Effect of different microbial formulations treatments on wheat growth and yield parameters (Pooled data of 2 years)

Treatment	Plant height (cm)	Total fresh weight/plant (g)			Total dry weight/plant (g)			Tillers/ plant	Test weight (g)	Grain yield (t/ha)	Straw yield (t/ha)
		30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS				
T_1	68.65	3.34	3.69	4.73	0.59	0.87	2.15	8.12	40.70	2.39	7.93
T_2	63.05	3.17	3.10	3.53	0.51	0.54	1.67	7.80	38.95	2.19	7.68
T_3	69.85	3.44	3.97	5.69	0.60	0.76	2.36	8.53	41.70	2.60	9.15
T_4	65.05	3.28	3.58	4.24	0.52	0.87	1.91	8.20	39.55	2.32	8.05
T_5	72.55	3.66	4.50	6.30	0.60	1.07	2.64	9.05	43.45	2.75	9.39
SEm±	1.91	0.39	0.24	0.51	0.05	0.09	0.17	0.53	1.22	0.11	0.35
CD (P=0.05)	5.80	NS	0.74	1.53	NS	0.27	0.53	NS	NS	0.33	1.18

Treatment details are given under Materials and Methods. DAS, Days after sowing.

RDF) (Table 1). Significant improvement might be seen due to enhancement in different growth promoting mechanisms i.e. better nutrient availability in soil and nutrient uptake, and increased root growth and proliferation. Rajput *et al.*, (2013) also reported 37% increase in overall plant growth under salt stress by inoculation of salt-tolerant, PSB strain. Similar results were reported by Singh *et al.*, (2010) and Rajput *et al.,* (2018).

Yield and yield parameters

Various yield parameters of wheat were also studied to evaluate the performance of microbial formulations and results showed that number of tillers/plant and test weight were not affected significantly with various treatments (Table 2). However numerically higher values were observed with treatment T_5 (VC @2.5 t/ha + 75% RDF + Mix of Halo-*Azo* and Halo-PSB inoculation). Combined application of halophilic microbial formulation with vermicompost and 75% RDF treatment provided significantly highest grain yield (2.75 t/ha) and straw yield (9.39 t/ha) as compared to other treatments. This seed yield was 15% more from application of uninoculated + vermicompost @2.5 t/ha + 100% RDF; and 26% more from uninoculated + vermicompost @2.5 t/ha + 75% RDF. These results reflect that by inoculation of various microbial formulations with vermicompost, a better growth and crop yield can be obtained with reduced doses of fertilizers (75% RDF). Improvement in yield might be owing to halophilic plant growth promoting rhizobacteria (PGPR) formulations which increase conversion of the unavailable forms of nutrients to plant-available form ultimately improve growth and yield at extraneous nutrient supply also. Similar results were also reported by Rajput *et al.*, (2013), Rajput *et al.,* (2018) and Sahay *et al.,* (2018).

Soil properties

After two years of experiment with combination of chemical fertilizer, vermicompost and different microbial formulations, it was found that soil pH_2 and EC_2 were decreased from initial values under different treatments. However, these results were non-significant. Highest decline was observed in pH_2 in T_5 treatment 7.33 (0–15 cm) and 7.48 (15–30 cm) as compared to initial values 7.70 and 8.0, respectively during both the years. Decline in soil salinity was observed under T_5, which reflected in EC_2 of different layers of soil i.e. 2.46 dS/m (0–15 cm) and 2.19 dS/m (15–30 cm) as compared to initial values 2.96 dS/m and 3.12 dS/m, respectively. Non-significant results for all

Table 2. Effect of different microbial formulations treatments on fertility status of soil (after 2 years)

Treatment	Soil depth 0–15 cm						Soil depth 15–30 cm					
	pH_2	EC_2 (dS/m)	SOC (%)	Available nutrient (kg/ha)			pH_2	EC_2 (dS/m)	SOC (%)	Available nutrient (kg/ha)		
				N	P_2O_5	K				N	P_2O_5	K
T_1	7.49	2.56	0.452	243.5	22.0	475.0	7.64	2.44	0.318	205.3	18.3	466.8
T_2	7.47	2.65	0.478	236.9	20.3	472.3	7.62	2.46	0.328	219.6	16.1	435.5
T_3	7.38	2.48	0.614	275.3	25.4	516.6	7.53	2.38	0.361	233.8	20.3	508.4
T_4	7.53	2.55	0.542	262.5	24.3	477.1	7.68	2.44	0.347	230.8	19.9	468.9
T_5	7.33	2.46	0.689	299.8	28.7	531.7	7.48	2.19	0.408	237.3	23.6	523.5
Initial	7.70	2.96	0.49	219.5	18.03	570.49	8.00	3.12	0.45	166.2	14.6	544.05
SEm±	0.29	0.37	0.05	11.6	0.84	33.0	0.29	0.35	0.04	11.5	4.05	33.5
CD (P=0.05)	NS	NS	0.15	35.33	2.55	NS	NS	NS	NS	NS	NS	NS

Treatment details are given under Materials and Methods. EC, Electrical conductivity; SOC, Soil organic carbon.

parameters were observed for soil depth 15–30 cm. Soil organic carbon (SOC), available nitrogen and phosphorus significantly affected by the treatments in surface layer (0–15 cm) and the highest improvement in these parameters from initial (OC, 0.49%; available N, 219.5 kg/ha; and P, 28.7 kg/ha) and as compared to other treatments was observed with treatment T_5 (OC, 0.69%; available N, 299.8 kg/ha; and P, 28.7 kg/ha). Additionally, a number of research revealed that halophilic microbes were found very effective in salt affected soils for improving crop productivity and soil properties (Sahay and Patra, 2013; Kumar *et al.,* 2014; Sahay *et al*., 2018; Arora *et al.*, 2021).

Based on the two years study, it can be concluded that different halophilic microbial formulations with vermicompost helps to reduce chemical fertilizer doses up to 25% and provided 15% higher yield compared to the full dose of fertilizers and vermicompost without inoculation. Combined application of Halo-*Azo* and Halo-PSB with vermicompost performed the best for increasing crop productivity and their single and combined application also helped in reduction of soil salinity, improvement of soil chemical properties and nutrient availability.

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