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ENHANCING VEGETABLE COWPEA GROWTH AND YIELD IN SEMI-ARID REGIONS: EFFECT OF LIQUID MICROBIAL CONSORTIA AND VARIABLE NITROGEN DOSES UNDER SALINE AND CANAL WATER IRRIGATION

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ABSTRACT

A 2-year experiment was undertaken to assess the impact of irrigation water quality, nitrogen doses, and microbial inoculants on soil nutrient availability, plant growth parameters, and green pod yield of cowpea in the semi-arid region of Punjab, India. Irrespective of other factors, nitrogen levels significantly influenced available N, P, and Fe in both years and across years when pooled, while Mn content was notably affected only when data were combined across years. Elevated soil pH, EC, K, and micronutrients (Fe, Cu, Zn, and Mn) were observed in saline water irrigated plots in both years and across pooled data, whereas available N and P were high in canal water irrigated plots. Microbial inoculants reduced soil pH and EC while enhancing soil nutrient availability. Canal water irrigation, regardless of other variables, increased plant height by 13.9%, 16.4%, and 15.1%, pods per plant by 6.0%, 5.9%, and 2.7%, pod length by 6.1%, 4.3%, and 5.2%, and green pod yield by 114.4%, 118.0%, and 116.3% in 2019, 2020, and pooled years. Decreasing nitrogen levels also reduced pods per plant by 6.9%, 6.8%, and 6.7%, pod length by 10.6%, 11.8%, and 11.2%, and green pod yield by 8.6%, 7.2%, and 7.8% in 2019, 2020, and pooled years, regardless of other factors. Likewise, liquid bio-fertilizers, either alone or in combination, significantly affected pods per plant by 16.6%, 18.6%, and 17.5%, pod length by 26.4%, 28.1%, and 27.3%, and green pod yield by 12%, 32.82%, and 14.2% in 2019, 2020, and pooled years, irrespective of other factors.

Keywords: Green pod yield, Microbial inoculants, Nitrogen levels, Saline water, Soil nutrients

Cowpea (*Vigna unguiculata* L. Walp), popularly known as *lobia*, holds significance as a versatile legume crop cultivated for its green pods (vegetable), grains, forage, and as a source of green manure. Legume crops contribute a substantial amount of nitrogen (up to 30 kg ha^{-1}) to the soil. Despite cowpea being a legume crop with the ability to fix atmospheric nitrogen, it still shows a positive response to the basal application of nitrogenous fertilizers. Nevertheless, an elevated nitrogen dosage could lead to a reduction in both the number and growth of nodules, consequently decreasing the nitrogen-fixation capability (Singh and Nair, 1995). In order to mitigate environmental pollution due to excessive use of mineral fertilizers, bio-fertilizers could be considered an important candidate for sustainable agriculture. Currently there is a significant demand for inoculating legume seeds with bacterial culture containing effective strains carrier-based bio-fertilizers, aiming to enhance crop yield and soil fertility. Numerous reviews have highlighted that the inoculation of seeds with nitrogen-fixing and phosphate-solubilizing biofertilizers (PSB) notably boosted plant growth, root development, nodulation, and consequently, the pod yield of cowpea (Bohra *et al.,* 1990; Stamford *et al.,* 2013). Carrier-based bio-fertilizers are sensitive to temperature fluctuations, whereas temperature tolerance represents an advantage of liquid bio-fertilizers (Kumaresan and Reetha, 2011). In South-Western Punjab, cowpea is predominantly sown in spring-summer season (February - March). The crop demands light and frequent irrigation throughout the summer months due to high evaporative demand. However, irregular supply of canal water and brackish nature of tube well water poses serious hurdles for obtaining optimum crop yield. In South-Western region of Punjab encompassing districts such as Bathinda, Fazilka, Muktsar and Mansa, there is an abundance of inland saline groundwater with salinity levels ranging from 3 to 15 ppm. As a result, agricultural output is low in these regions as compared to the rest of Punjab, due to poor soil fertility and insufficient irrigation network systems. If saline water is used for irrigation, it could effectively double the amount of available water for agriculture, helping to reduce water stress in many areas. Nevertheless, the accumulation of salts in the soil could alter its characteristics for crop cultivation, affecting the distribution of exchangeable cations, soil reaction, physical attributes, as well as the impacts of osmotic and specific ion toxicity. The salt-tolerant microbes have potential to improve crop productivity

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in arid and semiarid regions (Niu *et al.,* 2018). Many workers (Sharma *et al.,* 2016; Sarkar *et al.,* 2018) have reported that *Pseudomonas*, *Bacillus*, *Enterobacter*, *Agrobacterium*, *Streptomyces,* *Klebsiella*, and *Ochromobacter* improved the productivity of different crops under saline conditions. There is significant potential to enhance cowpea pod yield by boosting nutrient availability and enhancing plant growth through the integration of bio-fertilizers into agronomic practices, particularly in saline soil environments. However, choosing the right microbial species is essential for attaining the intended outcomes. With these considerations in mind, the current study was designed to evaluate the impact of two liquid microbial consortia, both individually and in combination with varying nitrogen doses, on cowpea growth, green pod yield, and soil nutrient availability under different irrigation conditions of saline and canal water.

MATERIALS AND METHODS

Field experiment

The field experiment was conducted during summer seasons of 2019 and 2020 at Jodhpur Romana Farm of Punjab Agricultural University-Regional Research Station, Bathinda (30° 09'36" N latitude, 74° 55'28" E longitude and at an altitude of 211 m above mean sea level). The experimental soil was loamy sand in texture with 80.1% sand, 12.2% silt and 7.7% clay. Examination of the initial properties of the experimental soil indicated that nutrient availability was slightly higher in plots irrigated with canal water compared to those irrigated with saline (tube well) water. However, the soil pH and electrical conductivity were slightly higher in the latter (Table 1).

The canal water was good (EC iw- <2 dS m^{-1}; SAR iw- <10 m mol L^{-1}; RSC- <2.5 meq L^{-1}) for irrigation, however, the tube well water has high SAR and was saline (EC iw- >4 dS m^{-1}; SAR iw- >10 m mol L^{-1}; RSC- <2.5 meq L^{-1}) (Table 2). The experiment was laid out in split-split plot design with 16 treatment combinations replicated thrice. Irrigation water quality, nitrogen doses and microbial inoculants were allotted to main-plots, sub-plots and sub-sub plots, respectively.

There were two types of irrigation water quality (Table 2), two levels of nitrogen doses – recommended dose of nitrogen (RDN) (50 kg ha^{-1}) and 75% RDN, and four treatments in sub-sub plots – control, liquid microbial inoculant of *Burkholderia seminalis,* liquid microbial inoculant of *Bradyrhizobium* sp. and liquid microbial inoculant of *B. seminalis* + *Bradyrhizobium* sp. The cowpea variety 'Selection 263' released by the Punjab Agricultural University, Ludhiana, for vegetable purpose was sown at the seed rate of 20 kg ha^{-1} as per treatment schedule at an inter-row spacing of 45 cm and intra-row spacing of 15 cm. In all treatments, 40 kg of P_2O_5 ha^{-1} and 25 kg of K_2O ha^{-1} were supplied at sowing through single superphosphate and muriate of potash, respectively. However, 100% N (50 kg ha^{-1}) and 75% N (37.5 kg ha^{-1}) was supplied by urea in a single dose two weeks after sowing. Seed treatment was done with liquid microbial inoculants of *B. seminalis* and *Bradyrhizobium* sp. as per treatments @ 250 ml ha^{-1}. Inoculated seeds were air dried in shade and sown within 2 hours. Recommended cultural and plant protection measures were followed to control weeds, insect-pests and diseases (Anonymous, 2020).

Table 1. Initial characteristics of the experimental soil at 0-15 cm depth

Characteristic	Canal water irrigated soil			Tube well (Saline) water irrigated soil		
	2019	2020	Mean	2019	2020	Mean
pH (1: 2)	8.42	8.43	8.43	8.87	8.84	8.86
$EC_{1:2}$ (dS m^{-1})	0.22	0.24	0.23	0.61	0.58	0.60
OC (%)	0.33	0.32	0.33	0.32	0.31	0.32
Available N (kg ha^{-1})	235.0	232.0	233.50	210.0	204.0	207.0
Available P (kg ha^{-1})	10.60	10.40	10.50	8.86	8.82	8.84
Available K (kg ha^{-1})	207.0	205.0	206.0	186.0	182.0	184.0
Iron (mg kg^{-1})	5.80	5.76	5.78	5.30	5.26	5.28
Copper (mg kg^{-1})	1.68	1.64	1.66	1.33	1.32	1.33
Zinc (mg kg^{-1})	2.32	2.28	2.30	2.05	2.04	2.05
Manganese (mg kg^{-1})	6.77	6.64	6.71	6.12	6.06	6.09
Soil texture	Loamy sand					
Sand (%)	80.1					
Silt (%)	12.2					
Clay (%)	7.7					

Table 2. Irrigation water quality (IWQ) parameters used for irrigation of cowpea

Particulars	Values					
	Canal water			Saline (Tubewell) water		
	2019	2020	Mean	2019	2020	Mean
EC (dS m^{-1})	0.35	0.38	0.37	4.34	4.35	4.35
Na^{+} (meq L^{-1})	1.36	1.32	1.34	34.10	34.15	34.13
Ca^{+2}+ Mg^{+2} (meq L^{-1})	1.88	1.85	1.87	6.95	6.84	6.90
Cl^{-1} (meq L^{-1})	0.80	0.82	0.81	11.20	10.80	11.00
CO_3^{-2} (meq L^{-1})	nil	Nil	Nil	nil	nil	nil
HCO_3^{-} (meq L^{-1})	1.80	1.76	1.78	6.34	6.31	6.33
RSC (meq L^{-1})	nil	Nil	Nil	nil	nil	nil
SAR ($mmol_c$ $L^{-1})^{0.5}$	1.40	1.37	1.39	18.29	18.47	18.38

Soil sampling and analysis

The soil samples were collected, dried under shade, passed through 2-mm sieve and stored at room temperature for analyzing. The chemical properties of soil such as soil reaction (pH), electrical conductivity (EC), organic carbon (OC), available N, P and K were determined by standard methods as described by Jackson (1973). Available micronutrients (Fe, Cu, Zn and Mn) in soil samples were determined using the procedure of Lindsay and Norvell (1978).

Plant growth parameters and green pod yield

The plant height (cm) was recorded at 30 days after sowing on ten randomly selected plants leaving two border rows from each plot. Plant height was recorded by using a scale held vertically from base of the plant to the tip of the leaf. The green pod plant^{-1} and pod length were measured at the time of green pod picking. The green and tender pods were harvested at regular intervals from each plot and weighed with an electronic balance. Green pod yield (kg plot^{-1}) was calculated by adding the weight of green pods from all pickings and was later on converted to t ha^{-1}.

Statistical analysis

The experimental data on various aspects were subjected to analysis of variance (ANOVA) procedure laid out for split-split plot design (Rangaswamy, 2014) and tested for significance by Fisher's Least Significant Difference (LSD) test at 5% level of significance ($P \leq 0.05$).

RESULTS AND DISCUSSION

Soil nutrient availability

The levels of nitrogen exerted significant effects ($P \leq 0.05$) on available N, P and Fe in both the years and for data pooled over years. However, the manganese content was significantly influenced when the data were pooled over years. Further, non-significant effects on soil reaction (pH), electrical conductivity (EC), organic carbon (OC), available potassium (K), available (Cu) and zinc (Zn) content at 0-15 cm depth were observed after crop harvest, irrespective of irrigation water quality and microbial inoculants. Similarly, plots that received 100% N had recorded higher values of nutrients than those incorporated with 75% N. Significant increase in soil N, P and Fe content could be due to application of recommended fertilizers for the crop. The contribution of legume crops to increased soil N content can be derived from unused ("spared") soil mineral N and rhizodeposits of N remaining after crop growth, or N mineralized from above-ground organic residues and the nodulated roots following crop harvest (Jensen *et al.,* 2010). Furthermore, it is a well-known fact that the legume crops can accumulate N both from soil as well as from atmosphere. Yahaya (2019) reported that cowpea is able to fix up to 337 kg N ha^{-1}. According to Nuruzzaman *et al.* (2005) the carboxylate-exuding legumes, exude particularly large amounts of organic acids into the rhizosphere. Under such conditions, these exudates can help mobilise P and Fe from soil-P pools, which are unavailable to plants. The high P and Fe content are likely due to its large root system rather than enhanced P and Fe uptake through a specialized mechanism. Thus, its positive effect on increased soil P and Fe concentration after harvesting is more closely related to the mineralization of P and Fe rich plant residues to residual effects of the root exudates on soil chemistry.

Irrespective of the levels of nitrogen and microbial inoculants, the irrigation water quality resulted in significant effects on soil pH, EC, available N, P, K and micronutrients (Fe, Cu, Zn and Mn) after crop harvest (Table 3). Significantly higher soil pH, EC, K and micronutrients (Fe, Cu, Zn and Mn) were observed under tube well (saline) water irrigated plots in both the years and for data pooled over years. However, soil available N and P content were higher in canal water irrigated plots. Higher soil pH of tube well irrigated soils may be due to higher accumulation of cations (Ca^{+2} and Mg^{+2}) present in tube well water compared to canal water. Furthermore, high level of CO_3^{-2} and HCO_3^- ions combined with Ca^{+2} and Mg^{+2} may have precipitated as calcium carbonate ($CaCO_3$) or magnesium carbonate ($MgCO_3$) which in turn caused an alkalizing effect and increased the soil pH. Slightly higher soil pH of ground water irrigated soils of Bathinda district compared to canal water irrigated soil has earlier been reported by Yadav (2020). Tube well water irrigated soils showed higher EC which may be due to higher amount of soluble salts present in ground water. The result was supported by the findings of Kim *et al.* (2016), Tan and Thanh (2021) and Yadav (2021), who reported that when the salt concentration in water increased by 4 to 25%, the salinity of the soil also increased. Similarly, higher K and micronutrients (Fe, Cu, Zn and Mn) were reported in tube well water irrigated soils, as higher K^+ and micronutrient (Fe, Cu, Zn and Mn) ions were added to soils through ground water. The ground waters of Bathinda district have substantial amount of dissolved K (Yadav, 2021; Yadav and Thaman, 2021) and irrigation with such waters results into higher amounts of available K in these soils. The soil N content was decreased with tube well (saline) water irrigation which might be due to more denitrification losses under saline conditions. However, low soil P in tube well saline water irrigated plots may be due to low P solubility under saline condition. low nutrient ion activity of macronutrients (N, P, K, Ca, Mg) and micronutrients (Fe, Mn, Zn, Cu) due to extreme ratios of Na^+/Ca^{2+}, Na^+/K^+, Ca^{2+}/Mg^{2+}, and Cl^-/NO_3^- in the soil solution was reported by Bidalia *et al.* (2019). Specifically, the P availability was reduced due to the ionic strength effect, a high sorption capacity to soil particles and a low solubility of minerals in saline soil (Grattan and Grieve, 1998).

Regardless of the N level and the quality of irrigation water, the application of liquid bio-fertilizers did not produce significant effects (P≤0.05) on various soil properties, including pH, electrical conductivity (EC), organic carbon (OC), available nitrogen (N), phosphorus (P), and micronutrients (Fe, Cu, Zn, and Mn) over the course of both years and when data were pooled. This lack of significant impact may be attributed to the endosymbiotic nature of the bacterial inoculants, which likely preferentially colonized host tissues and inhabited root nodules. This conclusion aligns with the findings of Ramya *et al.* (2021), who similarly observed non-significant effects on soil OC and the availability of N, P, and K when using liquid microbial inoculants compared to a control group. However, it's noteworthy that in our study, the application of liquid bio-fertilizers did result in significant effects on soil available potassium (K) across both years and when data were pooled, as well as on soil available manganese (when data were pooled over the years). This could possibly be attributed to the potassium-solubilizing efficiency of the inoculants. Numerous studies have identified various rhizospheric microorganisms capable of solubilizing potassium, including *B. mucilaginosus*, *Arthrobacter* sp., *Burkholderia*, *A. ferrooxidans*, *Paenibacillus mucilaginosus*, and *Paenibacillus glucanolyticus* (Sheng and He, 2006; Liu *et al.*, 2012; Sangeeth *et al.*, 2012; Zarjani *et al.*, 2013).

Overall the microbial inoculants tended to lower soil pH and electrical conductivity (EC), while simultaneously enhancing the soil nutrient availability. Particularly, the application of dual inoculants (M1+M2) yielded superior outcomes compared to their individual application. The interaction effects (microbial inoculants x N levels and microbial inoculants x irrigation water quality) were non-significant for soil macro- (N, P, K) and micro-nutrients' (Fe, Cu, Zn and Mn) availability, but pooled data over the years showed significant differences for soil available K. Similarly, interaction between irrigation

Table 3. Effect of irrigation water quality on soil nutrients availability after crop harvest

Year	Irrigation water quality	pH (1:2)	$EC_{1:2}$ (dS/m)	OC (%)	N (kg/ha)	P (kg/ha)	K (kg/ha)	Fe (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Mn (mg/kg)
2019	CW	8.46	0.26	0.34	208.83	11.31	190.96	4.68	1.28	1.96	5.92
	TW	8.99	0.61	0.34	187.38	9.80	200.96	5.03	1.64	2.28	6.55
	LSD (p≤0.05)	0.04	0.009	NS	1.58	0.08	0.62	0.16	0.02	0.013	0.32
2020	CW	8.48	0.34	0.34	221.50	11.80	195.29	4.60	1.26	1.93	5.84
	TW	9.02	0.34	0.34	196.71	10.14	217.96	4.89	1.61	2.25	6.44
	LSD (p≤0.05)	0.04	NS	NS	1.58	0.07	1.58	0.14	0.03	0.014	0.06
Pooled	CW	8.47	0.26	0.34	215.17	11.55	193.13	4.65	1.27	1.95	5.88
	TW	9.00	0.61	0.34	192.04	9.97	213.96	4.96	1.62	2.27	6.49
	LSD (p≤0.05)	0.02	0.004	NS	0.71	0.03	0.50	0.07	0.01	0.005	0.02

Table 4. Interaction effects of irrigation water quality (IWQ) × nitrogen levels (NL) on availability of N, P and K in soil after crop harvest

Year	IWQ	N (kg ha^{-1})		P (kg ha^{-1})		K (kg ha^{-1})	
		100% N	75% N	100% N	75% N	100% N	75% N
2019	CW	209.5	208.2	11.4	11.2	190.9	191.0
	TW	188.8	186.0	10.4	9.2	210.1	209.8
	LSD (p≤0.05)	0.35		0.13		NS	
2020	CW	222.2	220.8	11.9	11.7	195.0	195.1
	TW	198.3	195.4	10.8	9.5	218.3	218.1
	LSD (p≤0.05)	0.28		0.16		NS	
Pooled	CW	215.85	214.50	11.65	11.45	192.95	193.05
	TW	193.55	190.70	10.60	9.35	214.20	213.95
	LSD (p≤0.05)	0.24		0.87		NS	

water quality x N levels showed non-significant effects on soil available K and micro-nutrients (Fe, Cu, Zn and Mn) availability, but, showed significant effects on N and P availability in soil (Table 4).

Irrespective of the irrigation water quality and microbial inoculants, the N levels resulted in non-significant effect on plant height and green pod yield. However, the plant height and green pod yield were decreased by 2.2 and 7.8% under saline (tube well) water irrigation as compared to that under canal water. The imposition of salinity stress through the application of saline water leads to a reduction in plant growth and yield. This decline is attributed to alterations in various physiological responses, including water uptake levels, photosynthetic efficiency, and carbon utilization and allocation (Kotagiri and Kolluru, 2017).

Plant growth parameters and green pod yield

Irrespective of the levels of nitrogen and microbial inoculants, the irrigation water quality resulted in significant effects on plant height, pods $plant^{-1}$, pod length and green pod yield (Table 5). Significantly higher plant height, pods $plant^{-1}$, pod length and green pod yield were observed with canal water irrigated plots in both the years and for data pooled over years. The canal water increased the plant height by 13.9%, 16.4% and 15.1%, pods $plant^{-1}$ by 6.0%, 5.9% and 2.7%, pod length by 6.1%, 4.3% and 5.2%, and green pod yield by 114.4%, 118.0 % and 116.3% in 2019, 2020 and pooled, respectively compared to tube well water. The lower plant growth parameters (plant height, pods $plant^{-1}$, pod length) as well as green pod yield in tube well water may be due to its saline nature. The salinity increases the concentration of Na^+ and Cl^- ions and decreases the concentration of N^+, PO_4^{-3}, K^+, Mg^{+2} and Ca^{+2} ions in the leaves (Khalid and Cai, 2011). The growth of plants and yield is affected by reduction in the uptake of water and nutrients and accumulation of toxic sodium and chloride ions (Gehan, 2015).

The saline nature of water causes many adverse effects on plant growth due to low osmotic potential of soil solution (osmotic stress), specific ion effects (salt stress), nutritional imbalances, or a combination of these factors (Ashraf, 2004). All these factors cause

Table 5. Effects of irrigation water quality on growth parameters and green pod yield of cowpea

Year	IWQ	Plant height (30 DAS)	Pods $plant^{-1}$	Pod length (cm)	Green pod yield (t ha^{-1})
2019	CW	20.28	13.79	18.66	9.52
	TW	17.81	13.01	17.59	4.44
	LSD (p≤0.05)	1.04	0.49	0.58	1.87
2020	CW	19.75	12.79	18.02	9.31
	TW	16.97	12.08	17.27	4.27
	LSD (p≤0.05)	1.39	0.47	0.49	2.33
Pooled	CW	20.01	13.29	18.34	9.41
	TW	17.39	12.94	17.43	4.35
	LSD (p≤0.05)	0.56	0.42	0.52	2.10

Table 6. Effect of nitrogen doses on growth parameters and green pod yield of cowpea

Year	RDN level	Plant height (30 DAS)	Pods plant^{-1}	Pod length (cm)	Green pod yield (t ha^{-1})
2019	100%	19.25	13.88	19.14	7.29
	75%	18.83	12.92	17.11	6.66
	LSD (p≤0.05)	NS	0.65	0.98	0.48
2020	100%	18.57	12.88	18.75	7.04
	75%	18.15	12.01	16.53	6.53
	LSD (p≤0.05)	NS	0.62	0.31	0.45
Pooled	100%	18.91	13.36	18.95	7.16
	75%	18.49	12.46	16.82	6.60
	LSD (p≤0.05)	NS	0.59	0.54	0.42

adverse effects on plant growth and development at physiological and biochemical levels (Munns and James, 2003). The results reported here are in good agreement with those reported by Dadson *et al.* (2005) and Murillo-Amador *et al.* (2006), who observed significant reduction in seed germination, plant height and shoot dry weight with increasing salinity-induced stress in cowpea cultivars.

The nitrogen levels demonstrated significant effects (P≤0.05) on pods per plant, pod length, and green pod yield, while showing non-significant effects on plant height at the initial stage (30 DAS). Regardless of microbial inoculants and irrigation water quality, decreasing nitrogen levels resulted in reductions of 6.9%, 6.8%, and 6.7% in pods per plant, 10.6%, 11.8%, and 11.2% in pod length, and 8.6%, 7.2%, and 7.8% in green pod yield in the years 2019, 2020, and when data were pooled, respectively (Table 6).

This outcome could be attributed to the early and abundant availability of nitrogen, which creates a more favourable nutritional environment in the root zone, promoting growth and development. As nitrogen is one of the major essential plant nutrients required for growth, therefore, higher N might have increased cell number and cell size leading to better growth in terms of height, pods plant^{-1}, pod length and green pod yield. Nitrogen accelerate photosynthetic rate and thereby increase the supply of carbohydrate to plant and increased the plant growth and yield. The findings of this investigation corroborate the findings of Patel *et al.* (2004), Sharma and Dayal (2005) and Choudhary and Yadav (2011).

Table 7. Effect of inoculums on growth parameters and green pod yield of cowpea

Year	Inoculums	Plant height (30 DAS)	Pods plant^{-1}	Pod length (cm)	Green pod yield (t ha^{-1})
2019	C	18.87	11.91	15.13	6.40
	M1	19.18	14.58	20.48	7.24
	M2	19.58	13.67	18.66	7.15
	M1 + M2	18.53	13.42	18.22	7.12
	LSD (p≤0.05)	NS	1.26	0.75	0.49
2020	C	18.19	10.91	14.57	6.05
	M1	18.50	13.58	20.39	7.10
	M2	18.89	12.75	18.08	7.01
	M1 + M2	17.86	12.50	17.53	9.99
	LSD (p≤0.05)	NS	1.17	0.70	0.75
Pooled	C	18.53	11.42	14.85	6.22
	M1	18.84	14.08	20.44	7.17
	M2	19.24	13.21	18.38	7.08
	M1 + M2	18.20	12.96	17.88	7.06
	LSD (p≤0.05)	NS	0.95	0.43	0.55

C-uninoculated; M1=*B. seminalis*; M2=*Bradyrhizobium* sp.

Similarly, regardless of N level and irrigation water quality, the liquid bio-fertilizers, either alone or in combination, also demonstrated significant effects (P≤0.05) on pods per plant by 16.6%, 18.6%, and 17.5%, pod length by 26.4%, 28.1%, and 27.3%, and green pod yield by 12.0%, 32.8%, and 14.2% in 2019, 2020, and pooled data (Table 7) when compared with the control's average values. The data further indicate that the impact of microbial inoculants on growth parameters and green pod yield was comparable. Notably, a significant increase in pods per plant, pod length, and green pod yield was observed due to seed inoculation with *B. seminalis* and *Bradyrhizobium* sp. as well as their combined inoculation compared to the uninoculated control.

The inoculation of seeds likely elevated the presence of an effective and robust strain in the rhizosphere, leading to increased fixation of atmospheric nitrogen in the soil for plant utilization. This, in turn, resulted in enhanced growth and significantly higher numbers of pods per plant, longer pods, increased seed count per pod, and ultimately, greater green pod yields compared to non-inoculated conditions. Comparable results were also documented by Chattopadhyay and Dutta (2003), Yadav and Malik (2005), and Karnan et al. (2013) in cowpea.

Plots irrigated with saline (tube well) water exhibited significantly higher soil pH, EC, K, and micronutrient levels (Fe, Cu, Zn, and Mn), whereas plots irrigated with canal water showed higher availability of N and P. The application of microbial inoculants led to a decrease in soil pH and EC, while increasing soil nutrient availability. Plant height, pods per plant, pod length, and green pod yield were significantly higher with canal water irrigation in both years and across pooled data. Nitrogen levels had significant effects on pods per plant, pod length, and green pod yield, while showing non-significant effects on plant height at the initial stage (30 DAS) and decreasing with lower N levels.

Furthermore, liquid bio-fertilizers, alone or in dual inoculants, significantly influenced plant growth and green pod yield compared to the uninoculated control, although they were comparable to each other. Consequently, the present study concludes that microbial inoculation enhances cowpea yield by mitigating the adverse effects of saline water irrigation and improving nutrient availability.

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Authors' contribution

Conceptualization of research work and designing of experiments (BKY, NG, GP, AK); Execution of field/lab experiments and data collection (BKY, NG, GP, AK); Analysis of data and interpretation (BKY, NG, GP); Preparation of manuscript (BKY, NG, GP, AK).

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