

Effect of integrated use of nutrients on soil properties and productivity of pearl millet–wheat cropping system irrigated with saline water in northwestern India

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The burgeoning shortage of freshwater resources coerced Indian farmers to use poor-quality water for crop production in order to meet the growing and diversified food demands. Such conditions are likely to become more alarming in the future. Therefore, the present study was undertaken to identify the ideal crop combinations and agronomic practices which might give good yield under stressed conditions. An on-field experiment was conducted for two years to determine the suitable combinations of organic manure (farmyard manure @ 10 t/ha, vermicompost @ 2.5 t/ha and biogas slurry @ 2.5 t/ha), chemical fertilizers (75%, 100% and 125% recommended dose of fertilizer (RDF)) and microbial inoculants (*Azotobacter chroococcum* and Biomix) for enhancing productivity of the pearl millet–wheat cropping system irrigated with saline water. A significant improvement in the yield of pearl millet and wheat crops was obtained by integrated application of nutrients compared with untreated control and RDF treatments. Furthermore, a decrease in soil EC and pH, and an increase in organic carbon were noticed. A marked improvement in the availability of nitrogen, phosphorus, potassium, calcium and magnesium status in the soil and reduction in sodium content resulted as an outcome. The T₁₀ combination (RDF + VC + Biomix) was found to be the most suitable for profitable production of pearl millet and wheat crops under saline conditions of northwestern India.

Keywords: Crop production, integrated nutrient management, pearl millet, saline water, wheat

SALT-AFFECTED soils are distributed in 950 m ha area globally, with 6.74 m ha in India¹. Presently, agriculture uses using 89% of the country's good-quality water resources. Surveys in India showed that 32–84% of the presently running wells have poor quality of groundwater in different states². Due to water scarcity and uncertainty of rainfall, farmers often have to irrigate crop with poor quality of water. With further depleting water resources,

this situation is likely to become more alarming in the future. To address the emerging problem of salinity, global food security and declining freshwater resources, it is imperative to find ways for better utilization of salt-affected soils and water for crop production. Pearl millet being better adapted to abiotic stress than other cereals, is well-suited for cultivation under saline conditions. Additionally, it is a rich and cheap source of energy, protein, iron, zinc, fibres, etc. The widespread cultivation and moderate tolerance to salinity enable wheat cultivation under different agro-climatic conditions. It is also a major source of energy, protein and fibre to the vegetarian population. Therefore, pearl millet–wheat is a nutritionally packed eco-friendly cropping system. Imbalance in the use of fertilizers is one of the deterrents for crop production. Integrating all sources of nutrients is effective in improving plant growth through their beneficial effect on physical, chemical and biological properties of saline soils³. Hence integration of fertilizers, organic sources of nutrients and biofertilizers may help in increasing the system productivity under saline conditions. Therefore, the present study was undertaken keeping in view of three major aspects, i.e. use of saline water for crop production, judging the effectiveness of organic manures and performance of pearl millet and wheat under saline conditions.

Materials and methods

The experiment was conducted at the Research Farm, Department of Soil Science, Chaudhary Charan Singh Haryana Agricultural University (CCS HAU), Hisar, India, situated at 29°10'N lat., 75°46'E long. and an elevation of 215.2 m amsl. Figure 1 shows the mean weekly meteorological data during the cropping seasons.

The composite soil samples (0–15 cm depth) collected before start and after completion of the experiment, were analysed according to methods suggested in Table 1 (refs 4–10).

The experiment was laid out in randomized block design (RBD) with three replications of 12 treatments, viz. T₁: control (no fertilizers), T₂: 75% RDF (recommended

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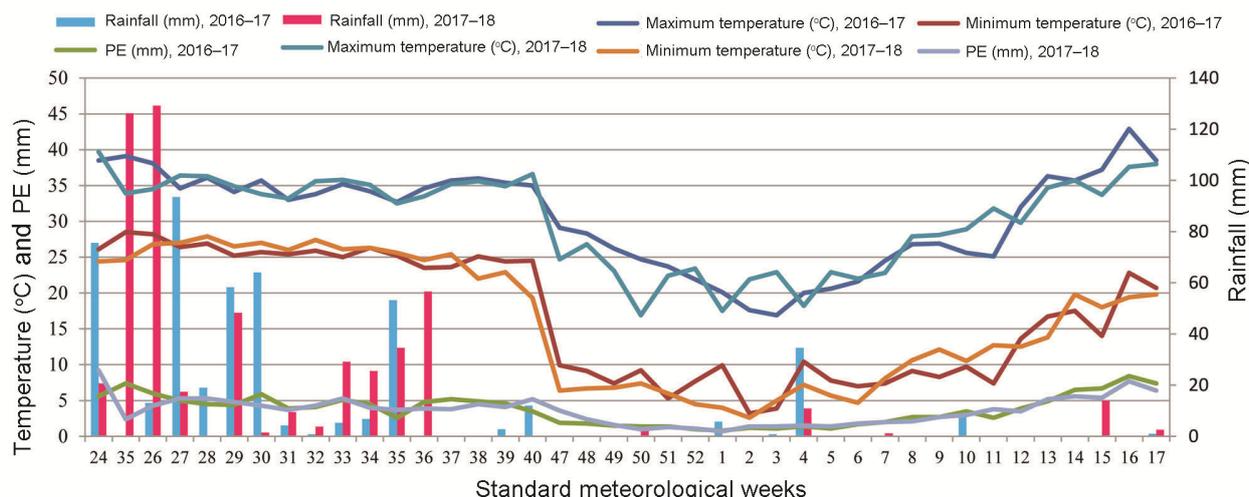


Figure 1. Mean weekly meteorological data during crop-growing seasons 2016–17 and 2017–18.

Table 1. Initial soil and water characteristics

Components	Initial (2016–17)	Method used	
Mechanical analysis (%)			
Sand	59.7	International pipette method ⁴	
Silt	22.4		
Clay	17.9		
Chemical analysis			
pH (1 : 2)	8.28	Glass electrode pH meter ⁵	
EC (dS/m, 1 : 2 at 25°C)	0.84	Conductivity bridge meter ⁶	
SOC (%)	0.28	Walkley and Black ⁷	
Available N (kg/ha)	169.2	Subbiah and Asija ⁸	
Available P (kg/ha)	16.6	Olsen’s method ⁹	
Available K (kg/ha)	348.8	Flame photometric method ⁶	
Available S (mg/kg)	9.65	Chesnin and Yien ¹⁰	
Water soluble ions (meq/l)			
Ca ²⁺	2.25	The standard methods given in the USDA Handbook 60 (ref. 6) were followed.	
Mg ²⁺	6.56		
Na ⁺	18.2		
K ⁺	0.34		
CO ₃ ²⁻	1.12		
HCO ₃ ⁻	8.32		
Cl ⁻	10.79		
SO ₄ ²⁻	6.24		
Irrigation water quality			
EC _{iw} (dS/m)	7.5–8.0		
pH _(iw)	7.8		
SAR _{iw} (mmol/l) ^{1/2}	17.34		
RSC (meq/l)	Nil		

EC, Electrical conductivity; SOC, Soil organic carbon; SAR, Sodium adsorption ratio; RSC, Residual sodium carbonate; INM, Integrated nutrient management.

dose of fertilizer), T₃: RDF, T₄: 125% RDF, T₅: 75% RDF + farm yard manure (FYM) + Biomix, T₆: RDF + FYM + Biomix, T₇: 75% RDF + biogas slurry (BGS) + ST-3, T₈: RDF + BGS + ST-3, T₉: 75% RDF + vermicompost (VC) + Biomix, T₁₀: RDF + VC + Biomix, T₁₁: 75% RDF + VC + ST-3 and T₁₂: RDF + VC + ST-3. FYM, VC and BGS were applied @ 10, 2.5 and 2.5 t/ha respectively. RDF was 156.25 kg N/ha and 62.5 kg P₂O₅/ha for pearl millet, and 150 kg N/ha and 60 kg

P₂O₅/ha for wheat. The soil was initially high for available potash; therefore K was not applied. ST-3 is a salinity-tolerant single strain (Mac-27) of *Azotobacter chroococcum*, while Biomix is a triple strain of *Azotobacter* (Mac-27) with 25% content, *Azospirillum* (J 11-12) with 25% content and PSB (p-36) with 50% content.

Sowing of pearl millet (cv. HHB223) was done in the first week of July during both *kharif* seasons at 45 cm row spacing using 5 kg seed/ha. Wheat (cv. WH1105)

Table 2. Effect of different INM treatments on yield (t/ha) and harvest index (%) of pearl millet

Treatment	Grain yield			Stover yield			Biological yield			Harvest index		
	2016	2017	Pooled	2016	2017	Pooled	2016	2017	Pooled	2016	2017	Pooled
T ₁ : Control	1.65	1.77	1.71	4.90	5.26	5.08	6.55	7.03	6.79	25.2	25.1	25.2
T ₂ : 75% RDF	2.53	2.73	2.63	7.29	7.91	7.60	9.82	10.64	10.23	25.8	25.6	25.7
T ₃ : RDF	3.01	3.23	3.12	8.37	8.91	8.64	11.38	12.14	11.76	26.4	26.6	26.5
T ₄ : 125% RDF	3.28	3.47	3.38	8.78	9.43	9.11	12.06	12.91	12.49	27.2	26.9	27.1
T ₅ : 75% RDF + FYM + Biomix	2.90	3.17	3.03	8.28	8.80	8.54	11.18	11.98	11.58	25.9	26.5	26.2
T ₆ : RDF + FYM + Biomix	3.27	3.58	3.42	8.78	9.48	9.13	12.05	13.06	12.55	27.1	27.4	27.3
T ₇ : 75% RDF + BGS + ST-3	2.94	3.23	3.08	8.15	8.77	8.46	11.09	11.99	11.54	26.5	26.9	26.7
T ₈ : RDF + BGS + ST-3	3.29	3.59	3.44	8.84	9.49	9.16	12.13	13.08	12.60	27.1	27.5	27.3
T ₉ : 75% RDF + VC + Biomix	3.05	3.31	3.18	8.36	8.82	8.59	11.41	12.13	11.77	26.7	27.3	27.0
T ₁₀ : RDF + VC + Biomix	3.40	3.68	3.54	9.00	9.63	9.32	12.40	13.32	12.86	27.4	27.7	27.5
T ₁₁ : 75% RDF + VC + ST-3	2.96	3.25	3.10	8.15	8.71	8.43	11.10	11.96	11.53	26.6	27.2	26.9
T ₁₂ : RDF + VC + ST-3	3.33	3.59	3.46	8.92	9.54	9.23	12.25	13.13	12.69	27.2	27.4	27.3
SEm ±	0.12	0.11	0.11	0.22	0.19	0.19	0.22	0.22	0.25	0.83	0.79	0.82
CD at 5%	0.34	0.34	0.31	0.64	0.55	0.56	0.64	0.63	0.74	NS	NS	NS

was sown in the last week of November during both *rabi* seasons at 20 cm row spacing using 125 kg seed/ha. All the package and practices of both the crops were followed according to the recommendations of CCS HAU. Seeds were treated with Biomix and ST-3 according to the respective treatments. Two post-sowing irrigations in pearl millet and one pre-sowing with four post-sowing irrigations of saline water (EC: 7.5–8.0 dS/m) were applied to the wheat crop. The data were statistically analysed by standard method¹¹ at 5% level of significance using one-factor RBD in OPSTAT software (http://14.139.232.166/op_stat/index.asp).

Results and discussion

Pearl millet

Grain, stover and biological yield and harvest index. The pooled grain yield for pearl millet under different treatments was in range 1.71–3.54 t/ha during both years (Table 2). The minimum grain yield was obtained in control and maximum in treatment T₁₀ followed by T₁₂, T₈ and T₆ which remained statistically at par with each other. The treatments T₁₀, T₁₂, T₈ and T₆ out-yielded RDF by 13.5%, 11.0%, 10.3% and 9.2% respectively. A similar pattern of results was observed for stover and biological yield. The maximum stover (9.32 t/ha) and biological yield (12.86 t/ha) were recorded in treatment T₁₀, which was statistically at par with treatments T₁₂, T₈, T₆ and T₄. The average percentage increase in stover yield over RDF using treatments T₁₀, T₁₂, T₈ and T₆ was 7.9%, 6.8%, 6.0% and 5.8% respectively. All the treatments remained statistically at par with each other for harvest index. The improvement in yields may rely on better physiological growth of plants and more availability of nutrients through organic manure. Their application also increased the water-holding capacity of the soil, which might have helped to counteract osmotic stress under saline condi-

tions^{12,13}. Apart from providing essential nutrients^{14,15}, organic manure also influences soil structure and water movement by improving leaching of soluble salts out of the rhizosphere, either by enhancing soil porosity or root vigour¹⁶.

The data showed that 7–9% higher grain, stover and biological yields were recorded in the second season, which might be due to more conducive environment resulting from higher pre-sowing (180 mm) and post-sowing (81 mm) rainfall, more number of rainy days and less evapotranspiration than the first season. This indicates a direct correlation between rainfall and leaching of the soluble salts along with associated yield advantages¹⁷. When compared to BGS and FYM, VC resulted in higher yields of pearl millet and wheat. This was possibly due to the differences in their elemental composition, applied quantity, nutrient release pattern and C/N ratio. As a result VC recorded higher yield improvement than FYM, even if the rate of application of the latter was four times higher.

Wheat

Grain, stover and biological yield and harvest index. Among different treatments, grain yield in wheat varied between 2.15 and 5.12 t/ha during *rabi* 2016–17 and 1.89–4.83 t/ha during *rabi* 2017–18 respectively (Table 3). Maximum values of grain yield were attained by T₁₀ during both the years, which were statistically at par with T₁₂, T₈, T₆, T₄ and T₉ during 2016–17 while they remained at par with treatments T₄, T₆, T₇, T₈, T₉, T₁₁ and T₁₂ during 2017–18. Treatments T₁₀, T₁₂, T₈ and T₆ out-yielded RDF by 12.1%, 11.6%, 9.4% and 8.1% respectively. Similarly, maximum straw (7.32 t/ha) and biological (12.2 t/ha) yields were also recorded by T₁₀. Researchers have shown that application of 50% additional N through inorganic fertilizers over and above RDF does not significantly improve the yield of crops at higher salinity

Table 3. Effect of various INM treatments on yield (t/ha) and harvest index (%) of wheat

Treatment	Grain yield			Straw yield			Biological yield			Harvest index		
	2016–17	2017–18	Pooled	2016–17	2017–18	Pooled	2016–17	2017–18	Pooled	2016–17	2017–18	Pooled
T ₁ : Control	2.15	1.89	2.03	3.81	3.44	3.63	5.96	5.34	5.65	36.15	35.50	35.82
T ₂ : 75% RDF	4.06	3.75	3.91	6.26	5.80	6.03	10.31	9.56	9.94	39.33	39.28	39.31
T ₃ : RDF	4.59	4.29	4.44	6.82	6.31	6.57	11.41	10.60	11.01	40.22	40.44	40.33
T ₄ : 125% RDF	4.82	4.52	4.67	7.04	6.52	6.78	11.85	11.04	11.45	40.62	40.93	40.78
T ₅ : 75% RDF + FYM + Biomix	4.59	4.33	4.46	6.60	6.23	6.41	11.20	10.56	10.88	41.03	41.04	41.03
T ₆ : RDF + FYM + Biomix	4.95	4.65	4.80	6.93	6.63	6.78	11.89	11.28	11.58	41.67	41.23	41.45
T ₇ : 75% RDF + BGS + ST-3	4.66	4.47	4.57	6.71	6.33	6.52	11.37	10.80	11.08	40.99	41.40	41.19
T ₈ : RDF + BGS + ST-3	5.01	4.71	4.86	7.10	6.71	6.91	12.11	11.42	11.76	41.34	41.25	41.30
T ₉ : 75% RDF + VC + Biomix	4.77	4.60	4.69	6.97	6.66	6.82	11.74	11.27	11.50	40.66	40.86	40.76
T ₁₀ : RDF + VC + Biomix	5.12	4.83	4.98	7.32	7.03	7.17	12.44	11.86	12.15	41.18	40.75	40.96
T ₁₁ : 75% RDF + VC + ST-3	4.69	4.53	4.61	6.72	6.53	6.62	11.40	11.06	11.23	41.10	40.97	41.03
T ₁₂ : RDF + VC + ST-3	5.10	4.80	4.95	7.14	6.74	6.94	12.24	11.54	11.89	41.70	41.60	41.65
SEm ±	0.13	0.16	0.14	0.11	0.20	0.16	0.29	0.31	0.30	0.91	0.88	0.86
CD at 5%	0.38	0.47	0.35	0.31	0.58	0.47	0.84	0.92	0.86	NS	NS	NS

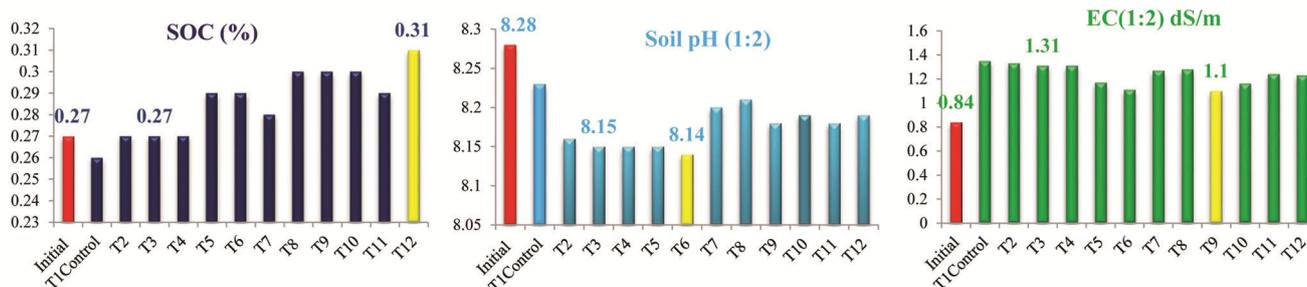


Figure 2. Effect of various integrated nutrient management treatments on EC, pH and OC of experimental soil. Yellow bar: Maximum improvement; red bar: Initial soil status.

levels^{17–19}. These results are in good agreement with the present findings, as the application of 125% RDF did not bring any significant improvement in the yields over RDF. This may be explained on the basis of higher volatilization losses of N in saline conditions. Therefore, a better strategy will be to substitute a part of inorganic fertilizer requirements through organics. Organic manure reduces NH₃ volatilization losses, as NH₄⁺ ion gets adsorbed on the organic matter surface which results into reduction in aqueous NH₄⁺ concentration in soil solution²⁰. Here organic manure temporarily immobilizes the ammoniacal N and subsequently releases it to the crops during the later growing season.

Unlike pearl millet, the grain, straw and biological yields of wheat had reduced during the second season compared to the first season. This may be on account of salt accumulation in the soil profile due to saline water irrigation. Seasonal climatic variations, including less amount of rainfall (49.7 mm in the first season and 32.5 mm in the second season) and higher evaporative losses might be other possible factors.

Soil analysis

Soil EC (dS/m), pH and O (%). Saline water irrigation increased the salinity level of the soil (Figure 2). The maximum and minimum salinity build-up was observed in control (1.35 dS/m) and T₉ (1.10 dS/m) respectively. The soil pH decreased slightly than the initial value (8.28), which reveals that integrated nutrient management (INM) helped in attaining neutral pH compared with no fertilization. FYM, VC and BGS application led to high soil organic carbon (SOC) compared to inorganic and control. RDF with ST-3 and VC had the highest SOC (0.31%), whereas no fertilization had the lowest SOC (0.26%). Specifically, soil incorporated with VC showed maximum SOC (0.31%), followed by BGS (0.30%) and FYM (0.28%). These variations in soil electrical conductivity (EC) and pH depend on initial characteristics of organic manure and the site-specific factors (initial pH, EC, rainfall, etc.) of the experimental field. The BGS applied in the experiment had maximum initial EC and pH followed by VC and FYM. Accordingly, they

Table 4. Effect of different INM treatments on available nutrients (N, P, K in kg/ha and S in mg/kg)

Treatment	Available N	Available P	Available K	Available S
T ₁ : Control	148.3	11.3	290.41	7.94
T ₂ : 75% RDF	157.4	13.35	312.23	8.88
T ₃ : RDF	163.3	14.66	320.31	9.56
T ₄ : 125% RDF	164.6	16.81	347.2	10.12
T ₅ : 75% RDF + FYM + Biomix	172.3	19.11	356.35	10.67
T ₆ : RDF + FYM + Biomix	174.8	19.49	360.25	11.12
T ₇ : 75% RDF + BGS + ST-3	172.7	16.94	345.4	10.84
T ₈ : RDF + BGS + ST-3	177.0	17.26	351.42	11.13
T ₉ : 75% RDF + VC + Biomix	176.2	17.74	341.84	10.81
T ₁₀ : RDF + VC + Biomix	182.0	18.08	352.43	11.46
T ₁₁ : 75% RDF + VC + ST-3	173.4	16.82	340.44	10.92
T ₁₂ : RDF + VC + ST-3	177.8	17.48	350.43	11.33
SEm ±	1.8	1.09	3.06	0.39
CD at 5%	5.33	3.21	9.04	0.912
Initial soil status	169.2	16.6	348.8	9.65

Table 5. Effect of various INM treatments on water-soluble cations (meq/l) of experimental soil after two years

Treatment	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺
T ₁ : Control	2.27	6.64	22.6	0.35
T ₂ : 75% RDF	2.33	6.66	21.5	0.43
T ₃ : RDF	2.32	6.65	20.7	0.49
T ₄ : 125% RDF	2.31	6.63	20.6	0.55
T ₅ : 75% RDF + FYM + Biomix	3.87	7.77	17.6	0.66
T ₆ : RDF + FYM + Biomix	3.88	7.81	17.9	0.68
T ₇ : 75% RDF + BGS + ST-3	4.51	7.95	19.5	0.52
T ₈ : RDF + BGS + ST-3	4.64	7.90	19.9	0.53
T ₉ : 75% RDF + VC + Biomix	5.11	8.12	18.3	0.68
T ₁₀ : RDF + VC + Biomix	5.02	8.07	18.7	0.69
T ₁₁ : 75% RDF + VC + ST-3	5.13	8.10	18.4	0.61
T ₁₂ : RDF + VC + ST-3	5.12	8.03	18.6	0.63
SEm ±	0.52	0.38	0.78	0.06
CD at 5%	1.54	1.11	2.32	0.18
Initial soil status	2.34	6.63	18.3	0.36

displayed the same line of action on salt build-up and pH stabilization¹⁶. The remarkable reduction in salinity by organic manure is owing to its role in improving soil porosity, aeration and leaching of soluble salts^{19,21}. Additionally, it is also a source of Ca²⁺ and Mg²⁺, which act as bases because they exist as oxides, hydroxides and carbonates when applied to the soil. This increases the concentration of Ca²⁺ in the soil solution, leading to increase in Na⁺-Ca²⁺ exchange at the soil exchange sites, permitting greater leaching of exchanged Na⁺ in percolating water and subsequent reduction in soil salinity¹¹.

Available N, P, K and S (kg/ha). The lowest available N was observed in control (148.3 kg/ha), while maximum was noticed in the T₁₀ (182.0), indicating significant improvement over all other treatments, except T₁₂ (177.84 kg/ha) (Table 4). It is pertinent to mention that ammonia volatilization from applied nitrogenous fertilizers increased with increase in salinity level, which can be checked by organic manure. Therefore, combined use of

organic manure and fertilizers is recommended. Mineralization of organic N from various organic sources is a function of nutrient quantity and C/N ratio of the manure used. In the present experiment, FYM, VC and BGS were used as organic sources and their effect on soil properties was positively correlated with total N content and negatively with C/N ratio of the manure applied^{21,22}.

The lowest available P was obtained in control (11.30 kg/ha) and maximum was observed in T₆ (19.49 kg/ha). It recorded 8.19 and 4.83 kg/ha higher available P over control and RDF respectively. P availability in salt-affected soil is a complex phenomenon. It may decrease, increase or remain unchanged depending upon the nature and degree of salinity, soil pH (optimum is 5.5–7.0) and organic matter content. When soils have pH >7.0, P availability decreases and as salt-affected soils have high pH and low organic carbon, P availability is a major limiting factor. Therefore, INM is beneficial for P management. The availability of K was lowest in control (290.41 kg/ha) and maximum in T₆ (360.25 kg/ha). It recorded 69.84 and 39.94 kg/ha higher available K over control and RDF treatments respectively. Higher K availability in the plots with integrated application of nutrients may be due to initial high content of K in the applied manure. RDF with VC and Biomix had the highest soil available S (114.6 kg/ha), whereas control had the lowest (79.4 kg/ha). These improvements may be attributed to enhanced rate of mineralization with the application of organic manure and additional supply of nutrients, i.e. N, P, K, Ca and Mg^{11,23,24}.

Water soluble cations Ca²⁺, Mg²⁺, K⁺ and Na⁺. Significant improvement was seen in the concentration of soluble cations (Table 5). The maximum Ca²⁺ concentration was observed in T₇ followed by T₈ > T₁₁ > T₁₂ > T₆ > T₅ > T₁₀ > T₉. Likewise, a significant improvement in soluble Mg²⁺ content was observed in T₁₁ followed by T₇ > T₁₂ > T₈ > T₆ > T₇ > T₁₀ > T₉. For Na⁺ a reverse

trend was observed, as Na⁺ is one of the dominating cations in the salt-affected soils and is also responsible for structural instability. So, it is essential to reduce its concentration to an optimum level. Organic manure resulted in reduction of Na⁺ ion and the treatment efficiency was observed in the pattern T₉ > T₁₀ > T₁₁ > T₇ > T₈ > T₁₂ > T₆ > T₅. Maximum Na⁺ concentration was found in T₁ and minimum in T₉. Soluble K⁺ content also varied significantly and was found maximum in T₁₂ followed by T₁₁ = T₁₀ > T₉ > T₈ > T₇ > T₆, while the minimum was observed in control. Together, the present findings confirm the use of organic manure in salt-affected areas on account of its high organic matter content which has many beneficial effects, i.e. slow release of nutrients, soil structure improvement and soil protection against erosion¹².

Conclusion

Use of FYM, VC and BGS along with chemical fertilizers (75% RDF and RDF) and seed treatment with *A. chroococcum* (ST-3) or with Biomix were found effective in improving the yield of pearl millet and wheat crops irrigated with saline water. The N, P, K, S, Ca and Mg status of soil was improved, pH was stabilized, EC was reduced and SOC had increased compared to control. Overall, these findings suggest that INM is likely to be helpful for managing soil salinity and improving productivity of pearl millet and wheat crop under saline conditions.

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