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RESEARCH ARTICLE

Integrated nutrient management as a strategy for higher production of pearl millet and wheat under saline water irrigation on sandy loam soils of Haryana

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Abstract

The poor quality irrigation water is a major cause of the development of soil salinity and reduced agricultural production inthe arid and semi-arid areas. Although pearl millet and wheat are moderately salinity-tolerant crops, their productivity is affected by salinity to a large extent. A field experiment was conducted to evaluate the effect of integrated nutrient management on yield and yield attributes of pearl millet and wheat under saline water irrigation during 2022-23 and 2023-24. The experiment consisted of twelve treatments, viz. T_1 [(75 % recommended dose of fertilizers (RDF)], T_2 (100 % RDF), T_3 [75 % RDF + ST-3 (*Azotobacter chroococcum*)], T_4 (100 % RDF + ST-3), T_5 [75 % RDF + 2.5 t ha^{-1} biogas slurry (BGS) + ST-3], T_6 (100 % RDF + 2.5 t ha^{-1} BGS + ST-3), T_7 [75 % RDF + 2.5 t ha^{-1} vermicompost (VC) + ST-3], T_8 (100 % RDF + 2.5 t ha^{-1} VC + ST-3), T_9 [75 % RDF + 10 t ha^{-1} farm yard manure (FYM) + biomix], T_{10} (100 % RDF + 10 t ha^{-1} FYM + biomix), T_{11} (75 % RDF + 2.5 t ha^{-1} VC + biomix) and T_{12} (100 % RDF + 2.5 t ha^{-1} VC + biomix). Results revealed that the number of effective tillers per meter row length, earhead/spike length and the plant height increased with integrated nutrient management and maximum values of these parameters were observed under T_{10}. However, these parameters decreased under the sole application of inorganic fertilisers under saline water irrigation in bothpearl millet and wheat crops. The highest grain and stover yield, viz. 27.43 and 78.19 q ha^{-1} of pearl millet; grain and straw yield of wheat, viz. 38.66 and 55.18 q ha^{-1} was also reported under treatment T_{10}.

Keywords: biogas slurry; FYM; INM; salinity; vermicompost

Introduction

Soil salinity is considered the most significant cause of land degradation after soil erosion and its effects have been documented for nearly 10000 years, contributing to the decline of agricultural societies. The problem continues to intensify, with about 2000 hectares (ha) of productive agricultural land becoming unproductive each day due to salinisation. Many crops suffer a yield reduction of about 10-25 % under elevated salinity (1). Electrical conductivity (EC) is an essential indicator of soil salinity is expressed in deciSiemens per meter (dS m^{-1}) under the SI system.

Pearl millet-wheat is the most prominent cropping system in irrigated tracts of arid and semi-arid regions of India, contributing a considerable amount to grain production. Pearl millet (*Pennisetum glaucum*, 2n = 2x=14) is the fourth most widely cultivated food crop after rice, wheat and maize in India. It belongs to the Poaceae family and has a panicle inflorescence with a caryopsis fruit type. It occupies an area of 6.93 million ha with an average production of 8.61 million tonnes (Mt) and productivity of 12.43 q ha^{-1} (2). In India, wheat (*Triticum aestivum* L., 2n = 6x = 42) occupies 29.58 million ha with an average production of 99.70 Mt and productivity of 33.71 q ha^{-1} (3). It is a hexaploid crop, belonging to the Poaceae family and has a spike inflorescence composed of many smaller spikelets. The fruit type of wheat is also a cryopsis. As people are struggling for natural resources and against climate change to meet the growing food demand (4), it is essential to reduce the crop losses occurring due to soil degradation.

The inevitable use of saline water resulted in increased concentration of salts, especially sodium ions, which have a dispersing effect on soil aggregates that deteriorates the soil structure, which interferes with better crop production and overall soil health. Irrigation-induced soil salinity is a major concern for agricultural sustainability and economic growth of a nation in arid and semi-arid regions where good-quality irrigation water is not available for crop production. It affects the soil fertility status and plant growth (5). High levels of soil salinity adversely affect 69 % of the total wheat production (6). The high concentration of salts raises the osmotic pressure of the soil solution, creating conditions similar to drought stress. Even when soil moisture appears adequate, plants may wilt because their roots cannot absorb water with a high osmotic potential. As transpiration continues, the water lost from the shoots cannot be replaced, leading to physiological drought and eventual wilting (7). The elevated levels of salts can inhibit the seed germination and seedling growth due to the combined effect of osmotic potential and specific ion toxicity. Also, the imbalanced use of fertilisers along with the cultivation of two cereals on the same piece of land year after year leads to soil health deterioration. Saline water, if skilfully used, leads to the production of a variety of crops.

Restoring soil quality is the biggest challenge under the current scenario. The sole application of inorganic fertilisers is not sufficient to maintain the sustainability of soil health and productivity. Under such conditions, the organic amendments work as soil conditioners that have the capability to improve soil structure, water holding capacity, soil aggregation and microbial activities. Although pearl millet and wheat are moderately salinity-tolerant crops, their productivity is affected by salinity to a large extent. To sustain soil health and fertility for the long term, it is better to adopt age-old practice of adding organic manure. Farmyard manure and vermicompost play a crucial role in the improvement of soil fertility and productivity through their positive effects on soil physico-chemical and biological properties and in balanced plant nutrition (8). Integrated nutrient management (INM) is one of the most important tools for improving resource use efficiency and achieving higher productivity at lower input costs. Studies have reported that adopting INM pearl millet remarkably enhanced yield attributes (9). Combining different nutrient sources enhanced plant growth and productivity. Inorganic fertilisers increase the immediate availability of nitrogen to plants, while organic manures like vermicompost improve soil structure, hydraulic conductivity and availability of N, P and K. These improvements support better vegetative growth, improve photosynthetic capacity and promote efficient partitioning of assimilates towards developing sinks, resulting in higher yield traits in pearl millet and wheat (10). The inclusion of biofertilizers further enhances nitrogen availability and stimulates root growth, which collectively contribute to improved yield components (11). To combat the problem of irrigation-induced salinity and to get higher production, the present study was conducted to know the effect of INM on yield and yield attributes of pearl millet and wheat under saline water irrigation on sandy loam soils of Haryana.

Materials and Methods

Site description

The present investigation was carried out at Soil Research Farms of Chaudhary Charan Singh (CCS) Haryana Agriculture University, Hisar (Haryana), during Kharif and Rabi seasons of 2022-23 and 2023-24. The site is characterised by a semi-arid climate with maximum temperature ranges between 43 to 48 °C during summer in May and June, while temperatures below the freezing point accompanied by frost occur during December and January. The mean annual rainfall of the area is about 450 mm. The texture of the soil at the experimental site was sandy loam.

Treatment details

The experiment consisted of twelve treatments i.e. T_1 (75 % recommended dose of fertilizers (RDF)), T_2 (100 % RDF), T_3 [75 % RDF + ST-3 (*Azotobacter chroococcum*)], T_4 (100 % RDF + ST-3), T_5 [75 % RDF + 2.5 t ha^{-1} biogas slurry (BGS) + ST-3], T_6 (100 % RDF + 2.5 t ha^{-1} BGS + ST-3), T_7 [75 % RDF + 2.5 t ha^{-1} vermicompost (VC) + ST-3], T_8 (100 % RDF + 2.5 t ha^{-1} VC + ST-3), T_9 [75 % RDF + 10 t ha^{-1} farm yard manure (FYM) + biomix (*Azotobacter* + *Azospirillum* + phosphate solubilizing bacteria (PSB))], T_{10} (100 % RDF + 10 t ha^{-1} FYM + biomix), T_{11} (75 % RDF + 2.5 t ha^{-1} VC + biomix) and T_{12} (100 % RDF + 2.5 t ha^{-1} VC + biomix) and was laid out in factorial randomized block design (RBD) with three replications. The FYM, VC and BGS were used as organic sources and urea, single super phosphate and murate of potash were used as chemical fertilisers. The chemical composition of organic manures used in the experiment has been presented in Table 1 and organic manures were applied during both Kharif and Rabi seasons. Pearl millet variety HHB 299 and wheat variety HD 3086 were used for the experiment. Saline water having an EC of 7.5 - 8.0 dS m^{-1} was used for irrigation. The soluble cations and anions (13) in irrigation water were: Na^+(54.49 meq L^{-1}), K^+(0.32 meq L^{-1}), Ca^{2+}(8.63 meq L^{-1}), Mg^{2+}(15.28 meq L^{-1}), HCO_3^- (1.83 meq L^{-1}), Cl^- (61.03 meq L^{-1}) and SO_4^{2-} (17.12 meq L^{-1}).

Agronomic and soil parameters

Length of earhead/spike of three randomly selected pearl millet/ wheat plants was measured with the help of a scale meter and then averaged and expressed in centimetres (cm). Number of effective tillers were recorded by counting number of effective tillers number per meter row length (mrl) from five rows in each plot at the harvest stage, then averaged and expressed in terms of number of effective tillers/ meter row length. Five plants from each experimental plot were selected randomly. Plant height (cm) from base of the plant to the top of the growing shoot of pearl millet and wheat was recorded at the harvest stage, with the help of a meter scale and then the average was taken and expressed in cm. Test weight was measured by taking 1000 grains (randomly) threshed from each plot of pearl millet and wheat crop and then their weight was measured in

Table 1. Chemical composition of organic manures used in the investigation

Chemical properties	FYM	VC	BGS	Method	References
pH	7.41	7.40	7.53	pH meter	(12)
EC (dS m^{-1})	1.27	1.30	1.42	Conductivity meter	(13)
Total nitrogen (%)	0.75	1.59	1.63	Nesslers' reagent	(14)
Total phosphorus (%)	0.61	0.57	1.02	Vanadomolybdate phosphoric acid yellow colour method	(15)
Total potassium (%)	1.12	1.09	1.46	Flame photometer	(15)
Iron (mg kg^{-1})	2.50	2.10	2.30		
Manganese (mg kg^{-1})	286	271	277	DTPA extractable method	
Zinc (mg kg^{-1})	224	216	219		(16)
Copper (mg kg^{-1})	25.0	26.1	25.2		

FYM= farm yard manure; VC= vermicompost; BGS= biogas slurry; EC= electrical conductivity grams (g). The produce of each net plot was threshed separately and grains thus obtained were winnowed, cleaned and weighed. The yield was recorded in kg plot^{-1} and then this yield was converted into q ha^{-1}. The dry weight of straw was calculated by subtracting the grain yield from the total biological yield of the crop. Finally, stover/straw yield per plot was converted into q ha^{-1}. The chemical analysis of soil properties of the experimental site was performed using established protocols as given in Table 2.

Statistical analysis

Statistical significance was tested at the 5 % probability level using the *F*-test. The difference between treatments was calculated using the critical difference (CD) worked out by OPSTAT software developed by the Department of Statistics, CCS Haryana Agricultural University (21).

Results

Effective tillers per meter row length

The results revealed that effective tillers per meter row length increased significantly with integrated application of fertilisers under saline water irrigation during both years of the cropping season, viz. 2022-23 and 2023-24 (Table 3). The mean highest number of effective tillers per meter row length was observed under treatment T_{10}, i.e., 14.12 and 75.23 under pearl millet and wheat, respectively, followed by treatment T_{12} (13.62 and 74.68). The mean lowest number of effective tillers per meter row length was found under sole application of inorganic fertiliser, i.e. 75 % RDF (T_1), i.e., 8.03 and 51.29 for pearl millet and wheat, respectively. The treatment T_{10} was at par with T_{12} and T_9. The treatments T_3, T_5, T_7, T_9 and T_{11} recorded 3.5, 51.1, 61.0, 51.1 and 51.5 % higher numbers of effective tillers (per meter row length) in pearl millet; 4.4, 16.3, 24.3, 26.3 and 25.3 % in wheat, as compared to treatment T_1, respectively.

Earhead/spike length of pearl millet and wheat

The data, as presented in Table 4, revealed that the highest earhead length (27.17 cm) of pearl millet and spike length (9.27 cm) of wheat were found with treatment T_{10} (100 % RDF + FYM + biomix) under saline water irrigation and it increased after two years of experimental study with saline water irrigation. The treatment T_{10} was at par with T_{12}. The lowest earhead length (20.47 cm) and spike length (7.60 cm) of pearl millet and wheat, respectively, were observed under treatment T_1 (75 % RDF). Under the treatment T_1, 3.7 and 3.8 % lower earhead and spike lengths were obtained, respectively, as compared to T_3. The treatment T_{12} was at par with T_{11}.

Table 2. Initial soil properties of the experimental site

Soil property	Value	Analytical method	References
pH	8.10	Glass electrode pH meter	(12)
Available K (kg ha^{-1})	290	Ammonium acetate extractable K method	(12)
EC (dS m^{-1}, 25 °C)	0.87	Conductivity meter	(13)
Texture	Sandy loam	International pipette method	(17)
Organic carbon (%)	0.45	Wet digestion method	(18)
Available N (Kg ha^{-1})	122	Alkaline potassium permanganate method	(19)
Available P (Kg ha^{-1})	16.3	Sodium bicarbonate extractable P method	(20)

Table 3. Effect of INM on the number of effective tillers per meter row length of pearl millet and wheat under saline water irrigation

		Pearl millet			Wheat		
Code	Treatments	2022-23	2023-24	Mean	2022-23	2023-24	Mean
T_1	75 % RDF	8.05 ± 0.03	8.01 ± 0.01	8.03	51.36 ± 0.71	51.21 ± 0.69	51.29
T_2	100 % RDF	8.75 ± 0.01	8.67 ± 0.03	8.71	53.59 ± 0.82	53.64 ± 0.55	53.62
T_3	75 % RDF + ST-3	8.27 ± 0.02	8.35 ± 0.03	8.31	53.17 ± 0.35	53.91 ± 0.70	53.54
T_4	100 % RDF + ST-3	9.35 ± 0.01	9.49 ± 0.01	9.42	57.36 ± 0.51	58.00 ± 0.47	57.68
T_5	75 % RDF + BGS + ST-3	12.10 ± 0.01	12.16 ± 0.01	12.13	59.11 ± 0.37	60.15 ± 0.41	59.63
T_6	100 % RDF + BGS + ST-3	12.85 ± 0.03	13.10 ± 0.05	12.98	65.28 ± 0.72	66.47 ± 0.75	65.88
T_7	75 % RDF + VC + ST-3	12.90 ± 0.01	12.95 ± 0.02	12.93	63.12 ± 0.68	64.35 ± 0.56	63.74
T_8	100 % RDF + VC + ST-3	13.00 ± 0.01	13.05 ± 0.01	13.03	70.06 ± 0.18	71.23 ± 0.51	70.65
T_9	75 % RDF + FYM + biomix	12.67 ± 0.01	12.71 ± 0.02	12.70	63.82 ± 0.54	65.74 ± 0.79	64.78
T_{10}	100 % RDF + FYM + biomix	14.06 ± 0.05	14.17 ± 0.05	14.12	74.26 ± 0.83	76.19 ± 0.83	75.23
T_{11}	75 % RDF + VC + biomix	12.60 ± 0.03	12.85 ± 0.03	12.73	63.71 ± 0.56	64.87 ± 0.72	64.29
T_{12}	100 % RDF + VC + biomix	13.60 ± 0.05	13.63 ± 0.03	13.62	73.32 ± 0.88	76.03 ± 0.84	74.68
C.D. (p=0.05)		0.21	0.13	0.16	0.61	1.02	1.25

RDF= recommended dose of fertilisers; ST-3= *Azotobacter chroococcum*; BGS= biogas slurry; VC= vermicompost; FYM= farm yard manure; INM= integrated nutrients management

Table 4. Effect of INM on earhead length (cm) of pearl millet and spike length (cm) of wheat under saline water irrigation

		Pearl millet			Wheat		
Code	Treatments	2022-23	2023-24	Mean	2022-23	2023-24	Mean
T_1	75 % RDF	20.56 ± 0.25	20.37 ± 0.31	20.47	7.78 ± 0.05	7.22 ± 0.02	7.60
T_2	100 % RDF	21.63 ± 0.21	21.84 ± 0.27	21.74	8.29 ± 0.02	7.93 ± 0.05	8.11
T_3	75 % RDF + ST-3	21.02 ± 0.27	21.43 ± 0.22	21.23	7.97 ± 0.03	8.02 ± 0.09	7.89
T_4	100 % RDF + ST-3	22.44 ± 0.24	21.87 ± 0.25	22.16	8.32 ± 0.04	8.47 ± 0.06	8.40
T_5	75 % RDF + BGS + ST-3	22.78 ± 0.19	23.60 ± 0.21	23.19	8.53 ± 0.05	8.71 ± 0.05	8.62
T_6	100 % RDF + BGS + ST-3	24.34 ± 0.26	25.22 ± 0.17	24.78	8.69 ± 0.08	9.13 ± 0.03	8.91
T_7	75 % RDF + VC + ST-3	22.88 ± 0.23	24.00 ± 0.19	23.44	8.47 ± 0.03	8.65 ± 0.02	8.56
T_8	100 % RDF + VC + ST-3	24.42 ± 0.27	25.36 ± 0.26	24.89	8.72 ± 0.02	9.21 ± 0.01	8.97
T_9	75 % RDF + FYM + biomix	23.87 ± 0.21	25.24 ± 0.24	24.67	8.59 ± 0.01	9.02 ± 0.05	8.81
T_{10}	100 % RDF + FYM + biomix	26.81 ± 0.25	27.73 ± 0.28	27.17	8.97 ± 0.05	9.57 ± 0.06	9.27
T_{11}	75 % RDF + VC + biomix	23.42 ± 0.31	24.11 ± 0.25	24.12	8.48 ± 0.08	8.73 ± 0.07	8.61
T_{12}	100 % RDF + VC + biomix	26.70 ± 0.22	27.31 ± 0.22	26.83	8.79 ± 0.07	9.35 ± 0.05	9.07
C.D. (p=0.05)		0.74	0.91	0.87	0.61	0.47	0.56

RDF= recommended dose of fertilisers; ST-3= *Azotobacter chroococcum*; BGS= biogas slurry; VC= vermicompost; FYM= farm yard manure; INM= integrated nutrients management

Plant height

The results about plant height of pearl millet and wheat revealed that plant height was significantly improved with INM under saline water irrigation after two years of experimental study (Table 5). Significantly, the highest plant height was recorded with T_{10}, i.e., 190.02 and 100.90 cm in pearl millet and wheat, respectively. The treatment T_{10} recorded 15.6 and 10.0 % higher plant height as compared to treatment T_1 in pearl millet and wheat, respectively. The seed inoculation with biofertilizer (as in treatments T_3 and T_4) improved the plant height as compared to the sole application of inorganic fertiliser (T_1 and T_2) in both pearl millet and wheat crops. The treatment T_1 obtained 0.1, 9.3, 10.8, 14.1 and 11.3 % lower plant height in pearl millet and 1.5, 3.9, 5.6, 6.9 and 7.0 % in wheat as compared to T_3, T_5, T_7, T_9 and T_{11}, respectively.

Test weight

The results related to test weight (g) of pearl millet and wheat showed that the test weight of both crops varied non-significantly among various treatments under saline water irrigation (Table 6). However, the mean highest value of test weight was recorded with treatment T_{10}, i.e. 8.35 g for pearl millet and 41.2 g for wheat under saline water irrigation. The lowest test weight of pearl millet (8.03 g) and wheat (38.4 g) was observed with treatment T_1. The increasing salinity level decreased the test weight of both the crops under saline water irrigation with the sole application of inorganic fertilisers.

Grain and stover/straw yield of pearl millet and wheat

The results about grain and stover/straw yield of pearl millet and wheat revealed that the yield was significantly improved with integrated application of fertilisers in various treatments after two years of study (Table 7 & 8). The maximum grain and stover yield of pearl millet was obtained under treatment T_{10}, i.e., 27.43 q ha^{-1} and 78.19 q ha^{-1} of pearl millet, which was at par with treatment T_{12} and T_8. The grain yield of pearl millet was observed to be 29.9 % higher under T_{10} as compared to T_1. The grain yield of pearl millet was observed 5.4, 2.4 and 0.5 % higher and stover yield was observed 11.3, 5.3 and 3.1 % higher under treatment T_{10} as compared to T_6, T_8 and T_{12}. The treatments T_1, T_2 and T_3 varied non-significantly from each other. The grain yield of pearl millet was recorded 16.5 % lower under treatment T_1 as compared to treatment T_4.

The grain and stover/straw yield were reduced with increasing salinity level under sole application of inorganic fertilisers, i.e. treatment T_1 and T_2. Similarly, the highest grain and straw yield of wheat was obtained under treatment T_{10} (38.66 q ha^{-1} and 55.18 q ha^{-1}), which was at par with treatment T_{12}. The grain and straw yield of wheat was recorded as 20.0 and 8.4 % higher under treatment T_{10} as compared to T_2, respectively. The treatments T_3, T_5, T_7, T_9 and T_{11} also recorded higher grain and straw yield as compared to T_1. The treatment T_{10} recorded 3.3, 2.6 and 0.9 % higher grain yield and 10.7, 8.8 and 6.4 % higher straw yield of wheat as compared to T_6, T_8 and T_{12}, respectively. The grain yield of wheat under T_{10} was 3.6 % higher than under T_9. The grain and straw yield of wheat was observed to be 1.7 and 2.3 % higher under treatment T_{12} as compared to T_8. The treatments T_1, T_2, T_3 and T_4 varied non-

Table 5. Effect of INM on plant height (cm) of pearl millet and wheat under saline water irrigation

		Pearl millet			Wheat		
Code	Treatments	2022-23	2023-24	Mean	2022-23	2023-24	Mean
T_1	75 % RDF	165.80 ± 15.13	162.94 ± 10.96	164.37	92.52 ± 5.76	90.86 ± 8.23	91.69
T_2	100 % RDF	168.43 ± 12.18	167.59 ± 14.87	168.01	96.15 ± 3.45	93.48 ± 7.81	94.82
T_3	75 % RDF + ST-3	165.87 ± 15.76	163.31 ± 19.81	164.59	93.26 ± 7.61	92.77 ± 3.29	93.02
T_4	100 % RDF + ST-3	170.91 ± 18.31	173.12 ± 14.23	172.02	94.14 ± 8.92	93.78 ± 5.62	93.96
T_5	75 % RDF + BGS + ST-3	178.82 ± 16.24	180.60 ± 11.67	179.71	96.49 ± 11.34	94.12 ± 6.31	95.31
T_6	100 % RDF + BGS + ST-3	183.84 ± 10.23	184.12 ± 15.76	183.98	98.23 ± 4.71	98.67 ± 7.67	98.45
T_7	75 % RDF + VC + ST-3	180.90 ± 19.54	183.20 ± 15.75	182.05	96.61 ± 13.45	97.11 ± 8.93	96.86
T_8	100 % RDF + VC + ST-3	185.90 ± 25.62	187.54 ± 19.09	186.72	98.75 ± 5.94	100.08 ± 9.06	99.42
T_9	75 % RDF + FYM + biomix	187.40 ± 18.27	187.65 ± 12.27	187.53	97.54 ± 7.09	98.48 ± 5.73	98.01
T_{10}	100 % RDF + FYM + biomix	189.80 ± 8.76	190.23 ± 11.66	190.02	99.68 ± 6.16	102.12 ± 7.02	100.90
T_{11}	75 % RDF + VC + biomix	185.60 ± 15.10	180.18 ± 18.45	182.89	97.08 ± 7.42	99.07 ± 2.85	98.08
T_{12}	100 % RDF + VC + biomix	187.25 ± 11.34	189.00 ± 6.56	188.13	99.12 ± 18.92	100.15 ± 14.31	99.64
C.D. (p=0.05)		5.36	4.89	3.80	2.19	4.23	2.60

RDF= recommended dose of fertilisers; ST-3= *Azotobacter chroococcum*; BGS= biogas slurry; VC= vermicompost; FYM= farm yard manure; INM= integrated nutrients management

Table 6. Effect of INM on test weight (g) of pearl millet and wheat under saline water irrigation

		Pearl millet			Wheat		
Code	Treatments	2022-23	2023-24	Mean	2022-23	2023-24	Mean
T_1	75 % RDF	8.02 ± 0.03	8.03 ± 0.01	8.03	39.40 ± 0.14	37.41 ± 0.11	38.41
T_2	100 % RDF	8.09 ± 0.01	8.10 ± 0.02	8.10	39.10 ± 0.11	41.23 ± 0.10	40.17
T_3	75 % RDF + ST-3	8.06 ± 0.03	8.06 ± 0.04	8.06	39.81 ± 0.10	39.75 ± 0.05	39.78
T_4	100 % RDF + ST-3	8.11 ± 0.03	8.10 ± 0.01	8.11	39.09 ± 0.10	41.66 ± 0.08	40.38
T_5	75 % RDF + BGS + ST-3	8.12 ± 0.02	8.13 ± 0.03	8.13	40.82 ± 0.05	39.72 ± 0.17	40.27
T_6	100 % RDF + BGS + ST-3	8.26 ± 0.01	8.27 ± 0.03	8.27	42.02 ± 0.18	39.15 ± 0.11	40.59
T_7	75 % RDF + VC + ST-3	8.17 ± 0.01	8.18 ± 0.03	8.18	39.93 ± 0.12	39.13 ± 0.17	39.53
T_8	100 % RDF + VC + ST-3	8.29 ± 0.03	8.35 ± 0.01	8.32	39.62 ± 0.19	41.82 ± 0.12	40.72
T_9	75 % RDF + FYM + biomix	8.25 ± 0.04	8.24 ± 0.05	8.25	42.35 ± 0.15	39.96 ± 0.12	41.16
T_{10}	100 % RDF + FYM + biomix	8.34 ± 0.03	8.35 ± 0.02	8.35	41.06 ± 0.11	41.48 ± 0.16	41.27
T_{11}	75 % RDF + VC + biomix	8.18 ± 0.02	8.22 ± 0.03	8.20	38.67 ± 0.11	41.13 ± 0.10	39.90
T_{12}	100 % RDF + VC + biomix	8.33 ± 0.02	8.35 ± 0.03	8.34	40.91 ± 0.16	39.59 ± 0.08	40.25
C.D. (p=0.05)		NS	NS	NS	NS	NS	NS

RDF= recommended dose of fertilisers; ST-3= *Azotobacter chroococcum*; BGS= biogas slurry; VC= vermicompost; FYM= farm yard manure; INM= integrated nutrients management; NS= non significant

Table 7. Effect of INM on grain and stover yield (q ha^{-1}) of pearl millet under saline water irrigation

Code	Treatments	Grain yield			Stover yield		
		2022-23	2023-24	Mean	2022-23	2023-24	Mean
T_1	75 % RDF	20.13 ± 0.10	18.40 ± 0.11	19.27	44.49 ± 0.31	42.47 ± 0.10	43.48
T_2	100 % RDF	21.20 ± 0.14	21.02 ± 0.18	21.11	47.47 ± 0.23	46.25 ± 0.19	46.86
T_3	75 % RDF + ST-3	20.64 ± 0.14	20.71 ± 0.19	20.68	45.00 ± 0.42	45.98 ± 0.17	45.49
T_4	100 % RDF + ST-3	22.14 ± 0.18	22.73 ± 0.11	22.44	50.92 ± 0.39	53.19 ± 0.41	52.06
T_5	75 % RDF + BGS + ST-3	23.78 ± 0.11	24.57 ± 0.08	24.18	56.36 ± 0.35	60.20 ± 0.34	58.28
T_6	100 % RDF + BGS + ST-3	25.57 ± 0.10	26.48 ± 0.15	26.03	69.04 ± 0.28	71.50 ± 0.26	70.27
T_7	75 % RDF + VC + ST-3	24.30 ± 0.15	24.63 ± 0.14	24.47	60.75 ± 0.17	64.12 ± 0.28	62.44
T_8	100 % RDF + VC + ST-3	26.33 ± 0.16	27.25 ± 0.11	26.79	72.33 ± 0.24	76.21 ± 0.33	74.27
T_9	75 % RDF + FYM + biomix	25.19 ± 0.14	26.09 ± 0.12	25.64	62.98 ± 0.22	67.83 ± 0.36	65.40
T_{10}	100 % RDF + FYM + biomix	26.82 ± 0.17	28.03 ± 0.14	27.43	75.10 ± 0.28	81.29 ± 0.38	78.19
T_{11}	75 % RDF + VC + biomix	24.08 ± 0.14	24.89 ± 0.15	24.49	60.20 ± 0.33	64.71 ± 0.24	62.46
T_{12}	100 % RDF + VC + biomix	26.79 ± 0.17	27.81 ± 0.18	27.30	73.72 ± 0.36	77.98 ± 0.29	75.85
C.D. (p=0.05)		2.56	4.02	1.27	5.32	6.34	3.87

RDF= recommended dose of fertilisers; ST-3= *Azotobacter chroococcum*; BGS= biogas slurry; VC= vermicompost; FYM= farm yard manure; INM= integrated nutrients management

Table 8. Effect of INM on grain and straw yield (q ha^{-1}) of wheat under saline water irrigation

Code	Treatments	Grain yield			Straw yield		
		2022-23	2023-24	Mean	2022-23	2023-24	Mean
T_1	75 % RDF	40.21 ± 1.27	37.10 ± 1.26	38.66	57.10 ± 4.19	53.26 ± 2.37	55.18
T_2	100 % RDF	42.75 ± 3.33	41.09 ± 3.29	41.92	67.35 ± 5.25	69.09 ± 5.73	68.22
T_3	75 % RDF + ST-3	41.32 ± 5.39	42.13 ± 1.23	41.73	67.12 ± 3.24	68.00 ± 3.65	67.56
T_4	100 % RDF + ST-3	44.04 ± 2.44	44.58 ± 1.18	44.31	71.77 ± 1.33	70.90 ± 7.61	71.34
T_5	75 % RDF + BGS + ST-3	45.71 ± 1.41	46.49 ± 2.54	46.10	76.79 ± 4.46	79.03 ± 5.34	77.91
T_6	100 % RDF + BGS + ST-3	48.17 ± 3.17	49.18 ± 1.26	48.68	83.82 ± 6.71	87.29 ± 2.58	85.55
T_7	75 % RDF + VC + ST-3	46.45 ± 2.26	47.24 ± 3.44	46.85	80.36 ± 3.14	84.09 ± 1.95	82.22
T_8	100 % RDF + VC + ST-3	48.00 ± 5.28	49.78 ± 5.32	49.02	84.48 ± 6.76	89.07 ± 6.33	87.03
T_9	75 % RDF + FYM + biomix	48.02 ± 4.23	49.11 ± 2.18	48.57	80.67 ± 2.89	84.21 ± 5.22	82.44
T_{10}	100 % RDF + FYM + biomix	49.31 ± 1.38	51.29 ± 1.42	50.30	92.21 ± 8.33	97.26 ± 4.19	94.73
T_{11}	75 % RDF + VC + biomix	47.11 ± 2.35	48.07 ± 1.37	47.59	78.20 ± 5.47	82.17 ± 2.08	80.19
T_{12}	100 % RDF + VC + biomix	49.13 ± 1.37	50.61 ± 2.34	49.87	86.96 ± 7.35	91.10 ± 1.56	89.03
C.D. (p=0.05)		4.25	5.13	2.30	5.08	4.41	4.08

RDF= recommended dose of fertilisers; ST-3= *Azotobacter chroococcum*; BGS= biogas slurry; VC= vermicompost; FYM= farm yard manure; INM= integrated nutrients management

significantly from each other.

Electrical conductivity (EC)

The data related to the EC of the saturation extract of soil (EC_e) has been presented in Table 9. The EC_e increased significantly with the addition of various organic manures in combination with inorganic fertilisers during both years of experimentation under saline water irrigation. The lowest mean value of EC_e was recorded under treatment T_{10} (RDF + FYM at 10 t ha^{-1} + biomix) viz. 7.36 and 7.72 dS m^{-1}, which was being at par with treatment T_{12} (RDF + VC at2.5 t ha^{-1} + biomix) viz. 7.45 and 7.87 dS m^{-1}, T_8 (RDF + VC at 2.5 t ha^{-1} + ST-3) viz. 7.51 and 7.97 dS m^{-1} and T_6 (RDF + BGS at 2.5 t ha^{-1} + ST-3) viz. 7.64 and 8.05 dS m^{-1}, after harvest of pearl millet and wheat, respectively However, significantly higher value of EC_e was observed under treatment T_1 (75 % RDF), viz. 8.87 and 9.55 dS m^{-1} and T_2 (RDF), viz. 8.59 and 9.19 dS $m^{-1,}$ after harvest of pearl millet and wheat, respectively, after two years of experimentation, as compared to other treatments. The EC_e was 17 and 19.2 % lower under treatment T_{10} and 16 and 17.7 % lower with treatment T_{12} as compared to treatment T_1 after pearl millet and wheat harvest, respectively. The treatments T_1, T_2, T_3 and T_4 varied non-significantly with each other and treatment T_4 recorded the lowest EC_e (8.41 and 8.93 dS m^{-1}) after harvest of both pearl millet and wheat, respectively.

Soil organic carbon (SOC)

The data related to SOC content (%) of soil presented in Table 10 revealed that SOC was significantly affected by the application of

Table 9. Effect of INM on EC, EC_e (dS m^{-1}) under saline water irrigation after harvest of pearl millet and wheat

Code	Treatments	Initial	Pearl millet			Wheat		
			2022-23	2023-24	Mean	2022-23	2023-24	Mean
T_1	75 % RDF	8.34	8.73	9.01	8.87	9.14	9.97	9.55
T_2	RDF	8.11	8.46	8.72	8.59	8.81	9.56	9.19
T_3	75 % RDF + ST-3	8.29	8.66	8.93	8.80	9.06	9.84	9.45
T_4	RDF + ST-3	7.95	8.27	8.54	8.41	8.58	9.28	8.93
T_5	75 % RDF + BGS + ST-3	7.62	7.91	8.15	8.03	8.17	8.79	8.48
T_6	RDF + BGS + ST-3	7.33	7.57	7.70	7.64	7.83	8.27	8.05
T_7	75 % RDF + VC + ST-3	7.51	7.76	7.97	7.87	8.05	8.64	8.34
T_8	RDF + VC + ST-3	7.25	7.43	7.59	7.51	7.77	8.17	7.97
T_9	75 % RDF + FYM + biomix	7.35	7.60	7.77	7.69	7.86	8.35	8.11
T_{10}	RDF + FYM + biomix	7.14	7.29	7.43	7.36	7.56	7.87	7.72
T_{11}	75 % RDF + VC + biomix	7.43	7.71	7.86	7.79	7.91	8.44	8.18
T_{12}	RDF + VC + biomix	7.21	7.37	7.52	7.45	7.68	8.05	7.87
C.D. (p=0.05)		0.37	0.41	0.33	0.10	0.30	0.37	0.28

RDF= recommended dose of fertilisers; ST-3= *Azotobacter chroococcum*; BGS= biogas slurry; VC= vermicompost; FYM= farm yard manure; INM= integrated nutrients management

Table 10. Effect of INM on SOC content (%) of soil under saline water irrigation after harvest of pearl millet and wheat

Code	Treatments	Pearl millet				Wheat		
		Initial	2022-23	2023-24	Mean	2022-23	2023-24	Mean
T_1	75 % RDF	0.58	0.58	0.57	0.58	0.58	0.58	0.58
T_2	RDF	0.59	0.59	0.58	0.59	0.59	0.58	0.59
T_3	75 % RDF + ST-3	0.60	0.60	0.59	0.60	0.59	0.59	0.59
T_4	RDF + ST-3	0.60	0.60	0.60	0.60	0.60	0.60	0.60
T_5	75 % RDF + BGS + ST-3	0.65	0.66	0.68	0.67	0.68	0.69	0.69
T_6	RDF + BGS + ST-3	0.70	0.71	0.73	0.72	0.73	0.75	0.74
T_7	75 % RDF + VC + ST-3	0.65	0.67	0.69	0.68	0.68	0.70	0.69
T_8	RDF + VC + ST-3	0.73	0.74	0.76	0.75	0.75	0.78	0.77
T_9	75 % RDF + FYM + biomix	0.69	0.70	0.71	0.71	0.71	0.72	0.72
T_{10}	RDF + FYM + biomix	0.75	0.76	0.79	0.78	0.78	0.81	0.80
T_{11}	75 % RDF + VC + biomix	0.68	0.68	0.70	0.69	0.70	0.72	0.71
T_{12}	RDF + VC + biomix	0.74	0.75	0.77	0.76	0.76	0.79	0.78
C.D. (p=0.05)		0.04	0.02	0.03	0.01	0.03	0.02	0.02

RDF= recommended dose of fertilisers; ST-3= *Azotobacter chroococcum*; BGS= biogas slurry; VC= vermicompost; FYM= farm yard manure; INM= integrated nutrients management

organic manures along with inorganic fertilisers under saline water irrigation after two years of experimental study. The mean SOC content of soil varied from 0.58 to 0.78 % and 0.58 to 0.80 % after harvest of pearl millet and wheat, respectively, during experimental years 2022-23 and 2023-24 under saline water irrigation.

The highest mean value of SOC (0.78 and 0.80 %) has been recorded with the application of RDF along with FYM and biomix, i.e., treatment T_{10}, followed by the treatment T_{12} (RDF + VC + biomix), viz., 0.76 and 0.78 %, after harvest of pearl millet and wheat, respectively. The treatment T_5 (75 % RDF + BGS + ST-3), T_7 (75 % RDF + VC + ST-3), T_9 (75 % RDF + FYM + biomix) and T_{11} (75 % RDF + VC + biomix) recorded significantly higher SOC viz. 0.67 and 0.69 %, 0.68 and 0.69 %, 0.71 and 0.72 %, 0.69 and 0.71 %, as compared to treatment T_1 (75 % RDF) viz. 0.58 and 0.58 %, after harvest of pearl millet and wheat, respectively. The treatments T_1 (75 % RDF), T_2 (RDF), T_3 (75 % RDF + ST-3) and T_4 (RDF + ST-3) varied non-significantly under saline water irrigation. The SOC content in treatment T_6, T_8 and T_{12} was significantly 7.7, 3.8 and 2.6 % lower under pearl millet and 7.5, 3.8 and 2.5 % lower under wheat as compared to treatment T_{10}. Similarly, the SOC content was recorded 1.7, 3.4 and 3.4 %; and 1.7, 1.7 and 3.4 % higher under treatment T_2, T_3 and T_4 as compared to treatment T_1 after harvest of pearl millet and wheat, respectively. The treatment T_{10} was found to be significantly at par with T_{12}, which was significantly superior to T_6 and T_8. The SOC content in treatments T_1, T_2, T_3 and T_4 varied non-significantly and recorded the highest in treatment T_4.

Discussion

The yield attributes viz., number of effective tillers per meter row length, earhead/spike length, plant height, test weight, grain and straw/stover yield, were significantly improved with INM in both pearl millet and wheat crops in both experimental years, i.e., 2022-23 to 2023-24. However, the yield and yield attributes non-significantly decreased with increasing salinity level under sole application of inorganic fertilisers, viz. RDF and 75 % RDF. The reduction in the number of effective tillers per meter row length, earhead/spike length and plant height, test weight, grain and stover/straw yield was due to increasing salt stress in the root zone can be attributed to continuous use of saline water for irrigation. The increased salt concentration/ osmotic pressure of the soil solution interferes with the extraction of water as well as nutrients by the plants (22).

The increased salinity level also results in reduced organic carbon as well as available micro and macro nutrient content of the soil, which ultimately leads to a reduction in plant growth. The accumulation of excessive salts in the cell wall that regulates the cell wall elasticity leads to enhanced cellular rigidity and reduced turgor pressure that interferes with cell enlargement under saline conditions and eventually results in reduced plant height (23). Research has demonstrated similar results in the previous study (24, 25).

The grain and stover yield of pearl millet was increased by 4.51 and 8.24 % respectively; and grain and straw yield of wheat was increased by 4.02 and 5.48 %, respectively from year 2022-23 to 2023-24 under saline water irrigation in treatment T_{10} (RDF + FYM + biomix). The increase in yield and yield attributes of both pearl millet and wheat with the addition of organic manures was because increased organic matter content reduced the salt stress in the root zone by binding with soluble ions and forming chelated complexes with these salts. Also, the increased organic matter content resulted in increased decomposition rate and released various plant available macro and micronutrients in the soil for plant uptake. The higher growth and yield were observed in treatments having seed inoculation of biomix as compared to ST-3 because of synergetic interaction among *Azotobacter*, *Azospirillum* and PSB. The seed inoculation with important soil bacteria (*Azotobacter* and *Azospirillum*) in cereals and pulses resulted in enhanced agronomic yield and yield attributes, nutrient contents and their uptake, growth and developmental indices; and reduced the incidences of insect, pest and disease infestations (26, 27).

The percent increase in grain and stover/straw yield was higher in the Kharif season as compared to the Rabi season because of higher rainfall that leaches down the salts from the root zone. The variation in yield and yield attributes in treatments with various organic manures was due to the variation in their nutrient composition, rate of decomposition and C: N ratio that will affect the mineralisation of various plant available nutrients (28). *Azospirillum brasilense* improved water status in wheat seedlings under salt and osmotic stresses, which promotes the shoot growth and a faster elongation in inoculated wheat (29). The better plant growth with biofertilizer treatment (T_3 and T_4) as compared to sole application of inorganic fertilisers (T_1 and T_2) might be because the bacteria stimulate the production of nitrogen, phosphorus and indole-3-acetic acid in the rhizosphere (30). These microbial inocula enhance nutrient assimilation by plants as well as improve the soil properties (31). The microbial inoculums not only remove nutrient deficiency but also improve plant development through the production of plant growth regulators at the root interface and better root development of plants resulted in better absorption of water and nutrients from soil (32). Research indicates that *Azotobacter chrococcum* alleviated the salt stress and resulted in maximum biomass production of *Sporobolus virginicus Dixi*, followed by soil yeast (*Rhodotorula glutinis*) and vesicular-arbuscular mycorrhizas (33). Similarly, biofertilizer treatment reduced the harmful effects of saline water irrigation on plant growth (34).

The soil EC increased after two years of experimentation under saline water irrigation in the pearl millet-wheat cropping system. However the percent increase in soil EC_e was lower with RDF + FYM + biomix (T_{10}), followed by T_{12} (RDF + VC + biomix), T_8 (RDF + VC + ST-3) and T_6 (RDF + BGS + ST-3). The lower EC under integrated application of organic manures and inorganic fertilisers might be because organic manures act as a chelated complex and will bind the soluble salts with it and thus reduce their concentration in soil solution. The highest increase in EC of soil was found with treatment T_1 (75 % RDF), followed by T_3 (75 % RDF + ST-3) and T_4 (RDF). The continuous application of saline water leads to an increase in the salt concentration of the soil and thus the EC of the soil. Significantly higher EC was observed during Rabi 2022-23 and 2023-24 as compared to Kharif 2022-23 and 2023-24, which was due to higher rainfall occurrence during the Kharif season that leached down the salts from the upper soil layer. Research has demonstrated the similar findings (35-37). The organic carbon content was reduced under increasing salinity with the sole application of inorganic fertilisers from the start of the experiment to the end of the experiment. The reduction in organic carbon content with increasing salinity might be due to the dispersing effect of Na ions under continuous application of saline water irrigation. The soil aggregates will disperse will uncovering the soil organic matter, which is liable to microbial degradation. Also, the reduction was due to the lesser vegetative growth under saline conditions that ultimately reduced the carbon input to the soil (38-40).

The organic carbon content was increased by integrating the application of organic manures along with inorganic fertilisers and bio-fertilisers. The addition of organic manures, viz., farm yard manure, vermicompost and biogas slurry, resulted in increased organic matter content of soil and better soil aggregation (41). This increment in SOC content with the addition of organic manures might be due to increased organic matter content and increased microbial activities (42, 43). Higher aggregation and SOC stock were observed under saline conditions (44). The organic manures will reduce the salinity effect and thus organic carbon content was increased after two years of experimental study. The highest organic carbon content was recorded with treatment T_{10} (RDF + FYM + biomix), followed by T_{12} (RDF + VC + biomix) and T_6 (RDF + BGS + ST -3). The variation in OC content among various organic manures might be due to variation in their organic matter content, rate of decomposition and their chemical composition. The farm yard manure was superior over vermicompost and biogas slurry under saline conditions due to the fact that FYM is more bulky in nature, which will improve soil aggregation better than vermicompost and biogas slurry. Also, the release of polysaccharides via decomposition of FYM resulted in improved aggregate stability, enhanced the soil aeration and thus comparatively better plant growth and more root biomass and microbial activities under FYM application (40, 45-48).

Conclusion

The continuous use of saline water for irrigation in sandy loam textured soil resulted in increased salt concentration in the soil from 2022-23 to 2023-24. The grain and stover/straw yield were increased from 2022-23 to 2023-24 with INM. The highest percent increase in grain yield of pearl millet (3.43 %) and wheat (4.02 %) from year 2022-23 to 2023-24 was reported with treatment T_{10}. The addition of various organic manures along with inorganic fertilisers resulted in improvement of yield and yield attributes of both pearl millet and wheat crops under saline water irrigation during both years of experimentation. The seed inoculation with biofertilizer, i.e., biomix and ST-3, also resulted in better plant growth as compared to the sole application of inorganic fertilisers. The treatment T_4 recorded 8.03 and 5.07 % higher grain yield of pearl millet and wheat, respectively, as compared to treatment T_2, in which seed inoculation with ST-3 is not done. The treatment T_{10} was found to be superior to others. The difference among various organic manures, i.e., FYM, VC and BGS, might be due to their chemical composition, decomposition rate and release pattern of nutrients for plant growth. The study is very helpful for farmers to save unnecessary cost on chemical fertilisers, as application of organic manures reduces 25 % application of chemical fertilisers. Also, the use of biofertilizers as seed treatment with saline water irrigation improves yield, which is not much costlier and easy to apply.

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Authors' contributions

AV carried out the study, contributed to manuscript writing, performed statistical analysis and participated in revision and finalization of the manuscript. PKY supervised the study and contributed to manuscript writing. RP supervised the study and contributed to statistical analysis, revision and finalization of the manuscript. AK contributed to manuscript writing. KQ and CS contributed to statistical analysis, revision and finalization of the manuscript. RY contributed in revision and finalization of the manuscript. All authors read and approved the final manuscript.

Compliance with ethical standards

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