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RESEARCH ARTICLE

Evaluation of saline water effects on use efficiency and soil nutrient availability of maize (*Zea mays* L.) under drip fertigation

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Abstract

A field experiment was conducted during the *rabi* season of 2022-23 at the Saline Water Scheme, Agricultural College Farm, Bapatla. The study's objective was to evaluate the effects of saline water on nutrient use efficiency and soil nutrient availability in maize under drip fertigation. The experiment consisted of eight treatments and four replications, arranged in a randomized block design. Irrigation with the best available water along with the application of a recommended dose of fertilizer (240-80-80 NPK kg ha^{-1}) recorded the highest uptake of N (88.2 and 62.4 kg ha^{-1}), P (21.2 and 16.20 kg ha^{-1}), and K (25.4 and 126.7 kg ha^{-1}) in grain and stover of maize, respectively, which were at par with the alternate use of fresh water with saline water of 2 dS m^{-1}. Nutrient use efficiencies, *i.e.,* agronomic efficiency (7.4, 18.4, and 18.4 kg kg^{-1}), physiological efficiency (85.2, 225.3, and 159.4 kg kg^{-1}), apparent recovery efficiency (22.5, 17.0 and 48.7 %) and utilization efficiency (15.7, 39.1 and 39.1 kg kg^{-1}) of N, P, and K, respectively, were also observed to be the highest under irrigation with the best available water along with a recommended dose of fertilizer application. Soil pH remained unaffected with saline water irrigation, whereas the EC of the soil was the highest under irrigation with saline water of 4 dS m^{-1} without the application of fertilizers. Soil-available nitrogen, phosphorous, and potassium were most elevated under irrigation with the best available water, with values of 152.5, 36.3, and 352.8 kg ha^{-1} respectively. The lowest values of nutrient uptake, nutrient use efficiencies, and soil available nutrients were recorded under irrigation with a water salinity of 4 dS m^{-1} without applying fertilizers. The use of a cyclical approach in utilizing both freshwater and saline water has demonstrated its effectiveness in mitigating the adverse effects of salts, resulting in enhanced efficiency in nutrient utilization and greater accessibility of soil nutrients.

Keywords

fertilizer; fresh water; irrigation; nutrient use efficiency; saline water; uptake

Introduction

One of the primary issues confronting modern agriculture is the declining supply of high-quality irrigation water in tropical ecosystems. Farmers increasingly turn to low-quality saline water for crop production, with increasing demand and a limited supply of high-quality water. Saline water is characterized by a high concentration of soluble salts, which is a fundamental component that has a significant impact on agricultural productivity and sustainability. While some salt is natural and tolerated by some plant species, the buildup of excessive salt creates significant issues for farmers and threatens food security in many parts of the world. Furthermore, the economic and social ramifications of lower agricultural productivity from salinity stress can impact farmer's livelihoods and community food security. Currently, salinity impacts approximately 20% of the total land area (1). There has been global damage to 45 m ha of irrigation land due to the accumulation of surface salts (2). Thirty percent of agricultural land is projected to be lost within the next 25 years, with a potential total loss of 50% by the year 2050 (3). The use of saline water for irrigation, particularly in low -lying coastal regions of various countries, has been recognized as a notable constraint on crop productivity (4). Improper irrigation practices can result in elevated salt levels in the root zone and reduced soil matric potential (SMP), thereby impeding crop water absorption and causing soil salinization in the cultivated layer (5). Recognizing the gravity of the salinity problem, agricultural scientists and researchers have attempted to create novel ways to mitigate the negative impacts of saline water irrigation on crops. These include the selection and development of salt-tolerant crop types, as well as the use of sophisticated irrigation techniques.

One such irrigation technique to reduce the negative impact of saline water irrigation is drip irrigation, which is a highly effective method for reducing the detrimental effects of saline water irrigation on crops. This strategy entails supplying tiny amounts of water directly to the root zone of plants over an extended period, thereby maintaining ideal soil moisture and compensating for the loss of osmotic potential induced by saline water (6). Unlike other irrigation technologies, drip irrigation keeps salt accumulation at the border of the wetting zone, which usually has a lower salt content, creating a more favorable environment for crop growth (7). Drip irrigation is commonly recognized as the most effective approach for irrigating crops with saline water due to its capacity to manage water application and minimize salt buildup in the soil (8). It supplies appropriate water to crops and helps in maintaining a higher total water potential, which is necessary for optimal plant growth. Another strategy for mitigating the adverse effects of saline water on crops is the cyclic use of water sources with variable salt contents (9-10).

On the other hand, nutritional management is critical for crops to reach their full output potential. Drip fertigation systems that are well-planned can optimize crop water and fertilizer uptake while avoiding nutrient leaching. Drip fertigation has been demonstrated to boost crop yields (11, 12) in three different ways: mitigating salt impacts, improving nutrient distribution in the root zone, and increasing nutrient usage efficiency while using the same amount of water (13). Cereals provide for a substantial portion of the world's dietary energy supply, accounting for 44.8 percent of total energy, with maize (*Zea mays* L.) accounting for at least 15.56 percent in developing nations (14), indicating maize's critical importance as a food source for many countries. With rising demand for maize seed, interest in nutritionally fortified goods, and its usage as animal feed, maize is emerging as India's third most important crop after rice and wheat. Despite its enormous importance, maize is known to be salt-sensitive. However, little information about maize's tolerance to saline waters is known. Hence, the present experiment is proposed to study the effects of saline water irrigation on maize, either in alternate or continuous usage, on nutrient use efficiency and soil nutrient availability under drip fertigation.

Materials and Methods

The study was carried out at the Saline Water Scheme, Agricultural College Farm, Bapatla, India, during *Rabi* (November-March), 2022-23 with eight treatments (plot size 25m × 2m) *viz.,* T_1: Irrigation with Best Available Water (BAW) (< 1 dS m^{-1}), T_2: Irrigation with 2 dS m^{-1}, T_3: Irrigation with 4 dS m^{-1}, T_4: Irrigation with BAW + Recommended Dose of Fertilizer (RDF), T_5: Irrigation with 2 dSm^{-1} + RDF, T_6: Irrigation with 4 dS m^{-1} + RDF, T_7: Irrigation with 2 dS m^{-1} + RDF with alternate use of fresh water, T_8: Irrigation with 4 dS m^{-1} + RDF with alternate use of fresh water in a randomized block design and was replicated four times. The RDF of 240-80-80 NPK kg ha^{-1} was applied, respectively (15). Nitrogen in the form of urea, phosphorus in the form of Di Ammonium Phosphate (DAP), and potassium as Murate of Potash (MOP) were applied through fertigation using ventury at scheduled stages of the crop. A uniform quantity of N was applied at the basal, knee-high stage, and flowering stages, whereas the entire P and 50% K were applied at the time of sowing as basal, and the remaining 50% of K was applied at the time of flowering. The experimental site was sandy loam in texture, uniform in topography, homogeneously fertile, and slightly alkaline in reaction (7.2), Electrical Conductivity (EC) was non-saline (0.46 dS m^{-1}), low in available nitrogen (151 kg ha^{-1}), high in available phosphorus (34 kg ha^{-1}) and available potassium (345 kg ha^{-1}).

The drip irrigation system was installed using 16 mm inline laterals with 2.0 L hr^{-1} discharge emitters spaced at 50 cm. A separate valve arrangement was installed to deliver irrigation and fertilizer to individual plots. Screen and disc filters were installed after the pumping and fertigation units to filter pollutants from irrigation water. A venturi as a fertilizer injection device was connected to the system before the filter unit to administer fertilizers via the drip system. Waters with differing EC levels (2 and 4 dS m^{-1}) were created artificially by diluting seawater of 34 dS m^{-1} with 0.6 dS m^{-1} available fresh water to achieve the appropriate EC level.

The maize variety 'Pioneer 3396' was sown using the dibbling method. Irrigation was scheduled based on pan evaporation replenishment. Irrigation water was applied to all plots based on pan evaporation data and was set to 100% at three-day intervals. During the crop growth, 64.6 mm of rainfall was received in 5 days. During rainy days, the amount of water applied to each treatment was modified to account for the rain received.

Nitrogen content (%) in the kernel and stover was estimated using the modified microkjeldhal method (16). The plant samples were digested with a diacid mixture consisting of HNO_3: $HclO_4$ (9:4) and the phosphorus content in the diacid digest was determined by the Vanadomolybdo phosphoric acid yellow color method (16) and the potassium content in the diacid digest was determined by using the flame photometer method (17). Nutrient uptakes were calculated using the following formula (Eqs. 1 and 2) and expressed in kg ha^{-1} (18).

$$\text{Nutrient uptake in Grain (kg ha}^{-1}\text{)} = \frac{\text{Nutrient content (\%)} \times \text{Kernel yield (kg ha}^{-1}\text{)}}{100} \qquad \text{(Eq.1)}$$

$$\text{Nutrient uptake in Stover (kg ha}^{-1}\text{)} = \frac{\text{Nutrient content (\%)} \times \text{Stover yield (kg ha}^{-1}\text{)}}{100} \qquad \text{(Eq.2)}$$

Nutrient use efficiencies, including Agronomic efficiency (AE), Physiological efficiency (PE), Apparent recovery efficiency (ARE), and Utilization efficiency (EU) were worked out for nutrients N, P, and K using the following formulas (Eqs. 3 to 6, respectively).

$$\text{AE} = \frac{\text{[Grain yield (kg ha}^{-1}\text{) in fertilized plot]} - \text{[Grain yield (kg ha}^{-1}\text{) in control plot]}}{\text{Nutrient applied (kg ha}^{-1}\text{)}} \qquad \text{(Eq.3)}$$

$$\text{PE} = \frac{\text{[Biological yield in fertilized plot]} - \text{[Biological yield in control plot]}}{\text{[Nutrient uptake (kg ha}^{-1}\text{) in fertilized plot]} - \text{[Nutrient uptake (kg ha}^{-1}\text{) in control plot]}} \qquad \text{(Eq.4)}$$

$$\text{ARE} = \frac{\text{[Nutrient uptake (kg ha}^{-1}\text{) in fertilized plot]} - \text{[Nutrient uptake (kg ha}^{-1}\text{) in control plot]}}{\text{Nutrient applied (kg ha}^{-1}\text{)}} \qquad \text{(Eq.5)}$$

$$\text{UE} = \frac{\text{[Biological yield (kg ha}^{-1}\text{) in fertilized plot]} - \text{[Biological yield (kg ha}^{-1}\text{) in control plot]}}{\text{Nutrient applied (kg ha}^{-1}\text{)}} \qquad \text{(Eq.6)}$$

The available nitrogen in the soil was determined by the alkaline potassium permanganate method (19), the available phosphorus status in the soil was analyzed by Olsen's method (20), and the available potassium in the soil was determined by using a neutral normal ammonium acetate extract using a flame photometer (17), which was expressed in kg ha^{-1}. Soil pH was measured in 1:2.5 soil water suspensions using a pH meter. After the pH measurement, the suspension was undisturbed overnight to measure EC. The EC of the supernatant was measured by inserting the conductivity cell of the EC Bridge (17).

The data generated on various parameters during the investigation were subjected to statistical analysis of variance (ANOVA) using the CRAN package of R software. The least significant difference (LSD) test was carried out to analyze mean square errors. The procedure provides for a single LSD value at a 5% level of significance, which serves as a boundary between significant and non-significant differences between any pair of treatment means.

Results

Nutrient content (%) and uptake

The highest nitrogen content (1.20 and 0.65 %) and uptake (88.2 and 62.4 kg ha^{-1}) in the kernel and stover of maize (Table 1 and Fig.1) were reported under irrigation with the best available water along with a recommended dose of fertilizer application. The grain nutrient content of nitrogen was significantly superior in the T_4 treatment, which was at par with the rest of the treatments except T_2 and T_3. Stover nutrient content of N was significantly superior in the T_4 treatment which was on par with T_5, T_7, and T_8. A significant difference in the content and uptake of both kernel and stover was observed with increasing the salinity level of irrigation water in the continuous method compared to cyclic usage.

Table 1. Effect of saline water on grain and stover NPK content (%) in maize under drip fertigation

Treatments	Grain nutrient content (%)			Stover nutrient content (%)		
	N	P	K	N	P	K
T_1: BAW (Best Available Water) (< 1 dS m^{-1})	1.12	0.24	0.30	0.50	0.12	1.20
T_2: Irrigation with 2 dS m^{-1}	1.01	0.13	0.29	0.41	0.10	1.18
T_3: Irrigation with 4 dS m^{-1}	0.91	0.12	0.26	0.33	0.08	1.13
T_4: Irrigation with BAW + RDF	1.20	0.29	0.35	0.65	0.17	1.30
T_5: Irrigation with 2 dS m^{-1} + RDF	1.17	0.28	0.34	0.58	0.15	1.26
T_6: Irrigation with 4 dS m^{-1} + RDF	1.15	0.26	0.33	0.54	0.14	1.25
T_7: Irrigation with 2 dS m^{-1} + RDF with alternate use of fresh water	1.19	0.29	0.35	0.63	0.16	1.28
T_8: Irrigation with 4 dS m^{-1} + RDF with alternate use of fresh water	1.17	0.28	0.34	0.61	0.16	1.27
SE±	0.06	0.01	0.01	0.03	0.01	0.04
CD (0.05)	0.18	0.04	0.04	0.08	0.02	0.11

*N: Nitrogen; P: Phosphorus; K: Potassium; SE: Standard error; CD: Critical difference; RDF:Recommended dose of Fertilizers; dS m^{-1}: Decisiemens per meter

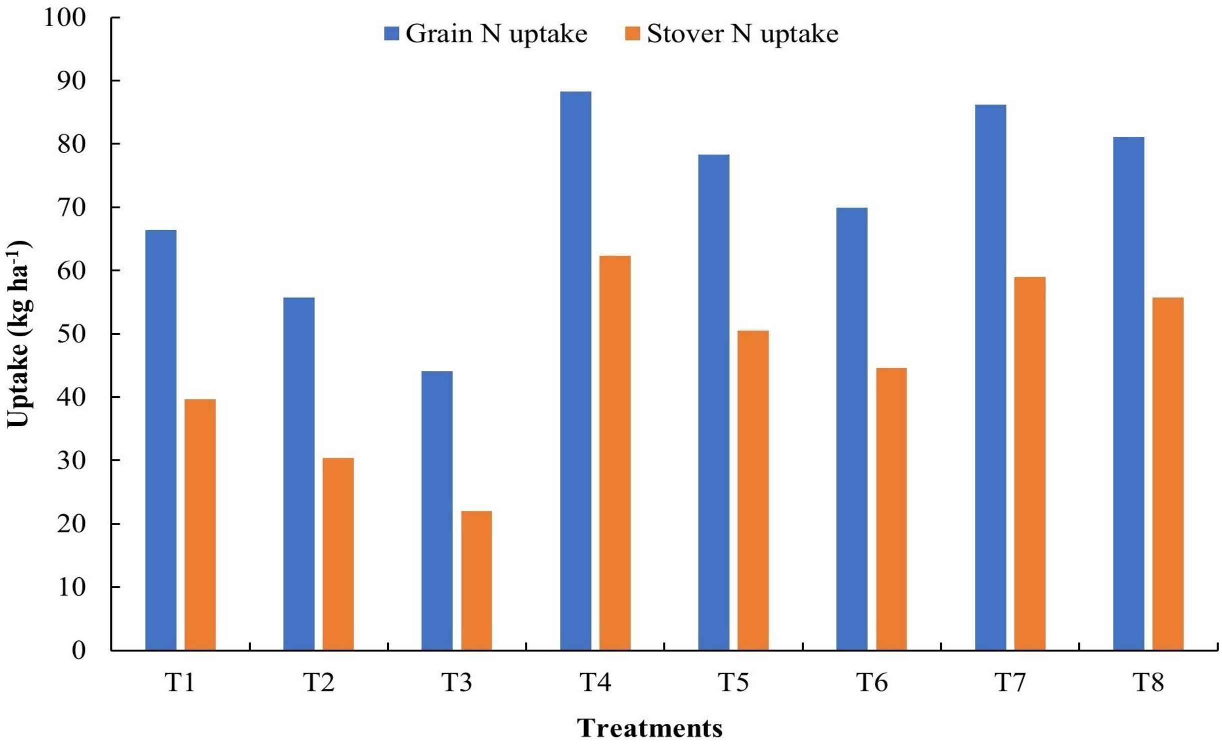

Fig. 1. Effect of saline water on nitrogen uptake (kg ha^{-1}) of maize under drip fertigation

The grain nutrient content of P_2O_5 was significantly superior in the T_4 and T_7 treatments, which were on par with T_5, T_6, and T_8 (Table 1). The Stover nutrient content of P was significantly superior in T_4 treatment, which was on par with T_7, and T_8. The phosphorous content of maize in grain (0.29 %) and stover (0.17 %) was observed to be significantly highest under irrigation with the best available water along with a recommended dose of fertilizer application. Similarly, uptake of phosphorous (Fig 2) in grain (21.2 kg ha^{-1}) and stover (16.0 kg ha^{-1}) was reported to be highest under irrigation with the best available water along with a recommended dose of fertilizer application.

The grain nutrient content of K_2O was significantly superior in the T_4 and T_7 treatments, which were on par with T_5, T_6, and T_8. The Stover nutrient content of K was significantly superior in the T_4 treatment, which was on par with the rest of the treatments except T_2 and T_3. A perusal of the data (Table 1 and Fig. 3) reveals that the highest potassium content (0.35 and 1.30 %) and uptake (25.4 and 126.7 kg ha^{-1}) in the kernel and stover of maize (Table 2 and Fig.3) were reported under irrigation with the best available water along with a recommended dose of fertilizer application. A significant difference in the content and uptake of both kernel and stover was observed with increasing the salinity level of irrigation water in the continuous method compared to cyclic usage.

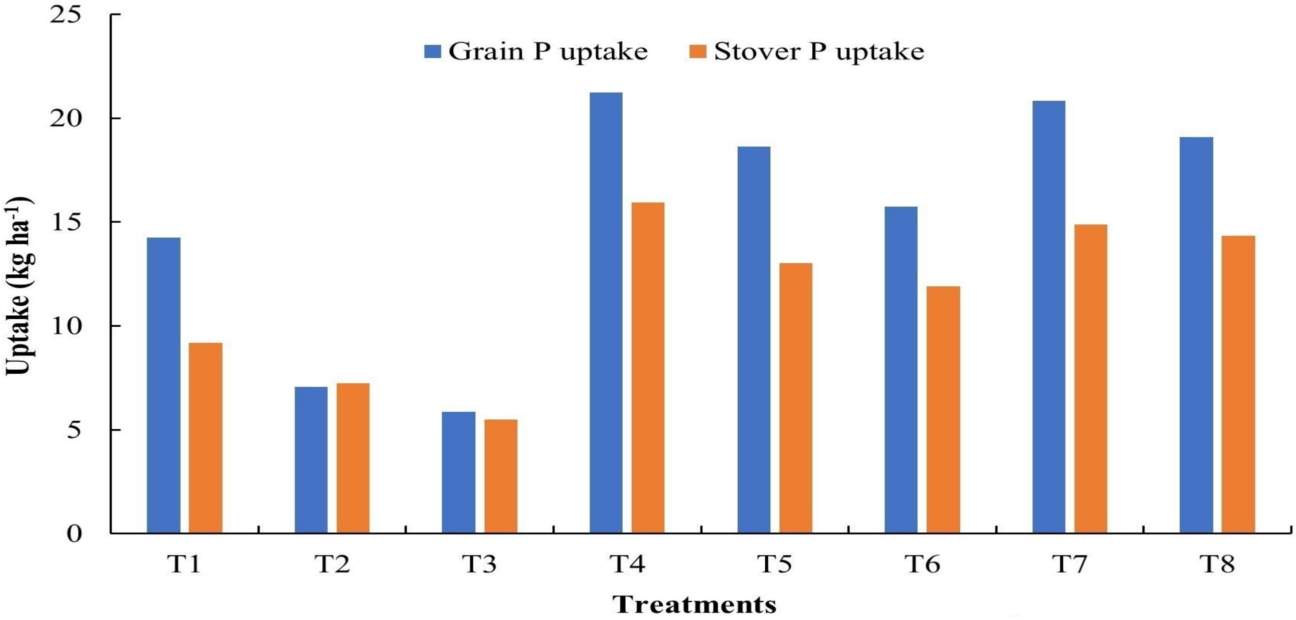

Fig. 2. Effect of saline water on phosphorous uptake (kg ha^{-1}) of maize under drip fertigation

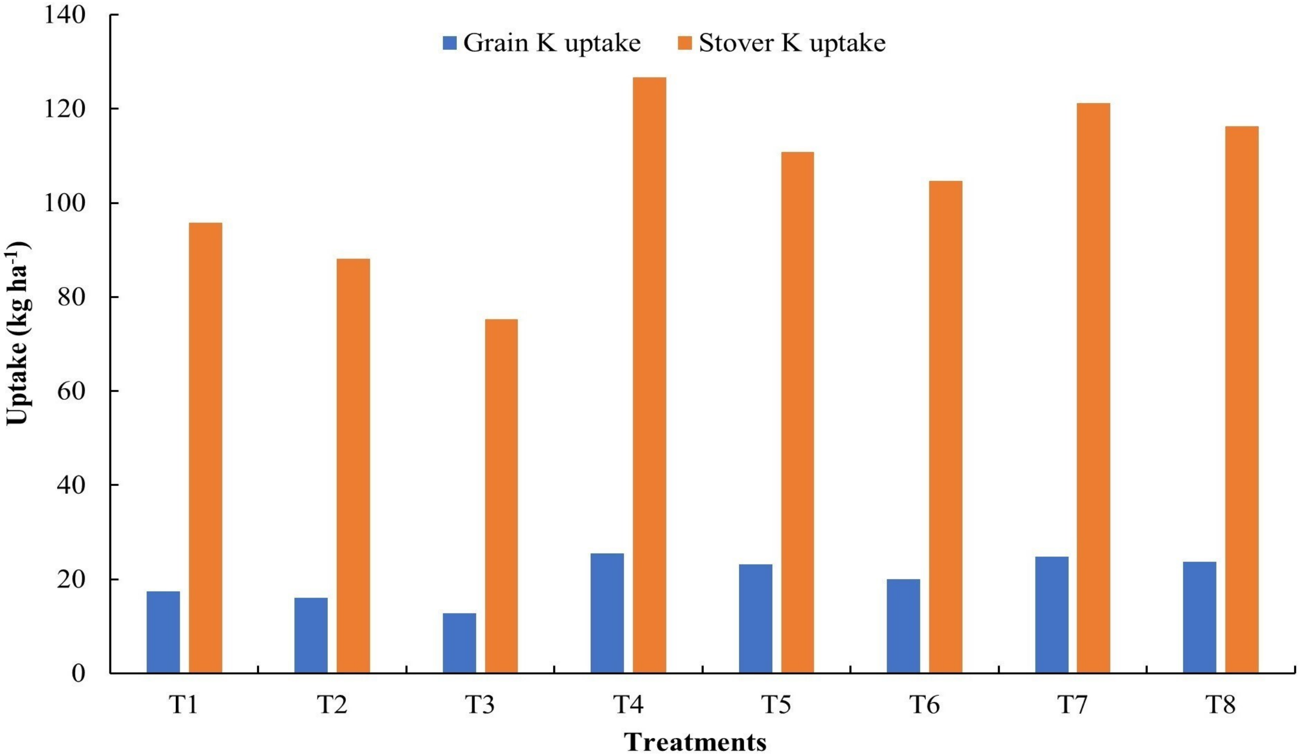

Fig. 3. Effect of saline water on potassium uptake (kg ha^{-1}) of maize under drip fertigation

Nutrient Use Efficiency

Nitrogen use efficiencies (Table 2), *viz.,* Agronomic Efficiency (AE) of nitrogen in terms of kg grain obtained per kg of nitrogen, Physiological efficiency (PE) of nitrogen in terms of kg biological yield obtained per kg nitrogen uptake, Apparent recovery efficiency (ARE) of nitrogen (%), and Utilization efficiency (UE) of nitrogen in terms of kg biological yield obtained per kg nitrogen applied were recorded as significantly highest (7.4, 85.2, 22.5, and 15.7, respectively) under irrigation with the best available water along with the recommended dose of fertilizer application. The AE and PE of applied nitrogen were significantly superior in the T_4 treatment as compared to the rest of the treatments. The ARE and UE of nitrogen use efficiency were significantly superior in the T4 treatment and were on par with the T_7 treatment. Similarly, the use of salt water reduces the rate of AE in the spinach crop (30). The phosphorus use efficiency in terms of AE, ARS, and UE was significantly superior in the T_4 treatment which was on par with the T_7 treatment. The PE of phosphorus was

Table 2. Effect of saline water on maize nutrient use efficiency under drip fertigation

Treatments	Nitrogen use efficiency				Phosphorous use efficiency				Potassium use efficiency			
	AE (kg kg^{-1})	PE (kg kg^{-1})	ARE (%)	UE (kg kg^{-1})	AE (kg kg^{-1})	PE (kg kg^{-1})	ARE (%)	UE (kg kg^{-1})	AE (kg kg^{-1})	PE (kg kg^{-1})	ARE (%)	UE (kg kg^{-1})
T_1: BAW (Best Available Water) (< 1 dS m^{-1})	0	0	0	0	0	0	0	0	0	0	0	0
T_2: Irrigation with 2 dS m^{-1}	0	0	0	0	0	0	0	0	0	0	0	0
T_3: Irrigation with 4 dS m^{-1}	0	0	0	0	0	0	0	0	0	0	0	0
T_4: Irrigation with BAW + RDF	7.4	85.2	22.5	15.7	18.4	225.3	17.0	39.1	18.4	159.4	48.7	39.1
T_5: Irrigation with 2 dS m^{-1} + RDF	4.2	82.0	11.4	8.5	10.6	210.0	10.3	21.2	10.6	89.9	26.1	21.2
T_6: Irrigation with 4 dS m^{-1} + RDF	1.1	52.8	4.4	3.0	2.7	157.5	5.2	7.6	2.7	49.9	14.3	7.6
T_7: Irrigation with 2 dS m^{-1} + RDF with alternate use of fresh water	6.3	67.1	19.6	13.7	15.8	214.5	15.4	34.3	15.8	74.1	41.0	34.3
T_8:Irrigation with 4 dS m^{-1} + RDF with alternate use of fresh water	5.0	72.7	15.3	10.9	12.5	222.9	12.5	27.3	12.5	78.2	33.5	27.3
SE±	0.31	3.91	0.97	0.72	0.78	12.30	0.65	1.79	0.78	5.76	1.98	1.79
CD (0.05)	0.9	11.5	2.9	2.1	2.3	36.2	1.91	5.3	2.3	16.9	5.8	5.3

*SE: Standard error; CD: Critical difference; RDF:Recommended dose of Fertilizers; dS m^{-1}: Decisiemens per meter; AE: agronomic efficiency; PE: physiological efficiency; ARE: apparent recovery efficiency; UE: utilization efficiency significantly superior in the T_4 treatment which was on par with the T_5, T_7, and T_8 treatments. The phosphorous use efficiencies (Table 2) *viz.,* AE, PE, ARE and UE were proved to be significantly highest under irrigation with the best available water along with a recommended dose of fertilizer application with values of (18.4, 225.3, 17.0, and 39.1 respectively). The AE, PE, ARS, and UE of applied potassium were significantly superior in the T_4 treatment, which was on par with the rest of the treatments (Table 2). Potassium use efficiencies of AE (18.4), PE (159.4), ARE (48.7), and UE (39.1) were registered highest under irrigation with the best available water along with a recommended dose of fertilizer application.

Yield correlation with Nutrient use efficiency

Linear equations were derived to establish the relationship between yield as the independent variable and nitrogen use efficiencies as the dependent variables. These findings are depicted in Fig. 4. Based on the data analysis, it has been observed that there is a positive correlation between yield and various nitrogen use efficiencies. This implies that any change in yield in a particular direction is accompanied by a corresponding change in nitrogen use efficiency in the same direction. The study observed a strong positive correlation (R^2 = 0.99) between yield and agronomic efficiency of nitrogen. In contrast, the correlation between yield and physiological efficiency was found to be moderate (R^2 = 0.55). A strong correlation was observed between the yield relation and the utilization efficiency (R^2 value of 0.99) as well as the apparent recovery efficiency (R^2 value of 0.98).

Between yield as the independent variable and phosphorous use efficiencies as the dependent variables, linear equations have been derived (Fig. 5). The data indicates a positive correlation between yield and different phosphorous use efficiencies. This suggests that a change in yield in one direction corresponds to a change in phosphorous use efficiency in the same direction. The study observed a strong positive correlation between yield and agronomic efficiency of phosphorous, with an R^2 value of 0.99. Similarly, a significant correlation was found between yield and physiological efficiency, with an R^2 value of 0.82. A strong correlation was observed between the yield relation and the utilization efficiency (R^2 value of 0.99) as well as the apparent recovery efficiency (R^2 value of 0.99).

The relationship between yield as the independent variable and potassium use efficiencies as the dependent variables was derived using simple linear models (Fig. 6). The data indicates a positive correlation between yield and different potassium use efficiencies, suggesting that changes in yield in one direction correspond to changes in potassium use efficiency in the same direction. The study observed a strong positive correlation (R^2 = 0.99) between the yield and agronomic efficiency of potassium. In contrast, the correlation between yield and physiological efficiency was found to be moderate (R^2 = 0.57). A strong correlation was observed between the yield relation and the utilization efficiency (R^2 value of 0.99) as well as the apparent recovery efficiency (R^2 value of 0.97).

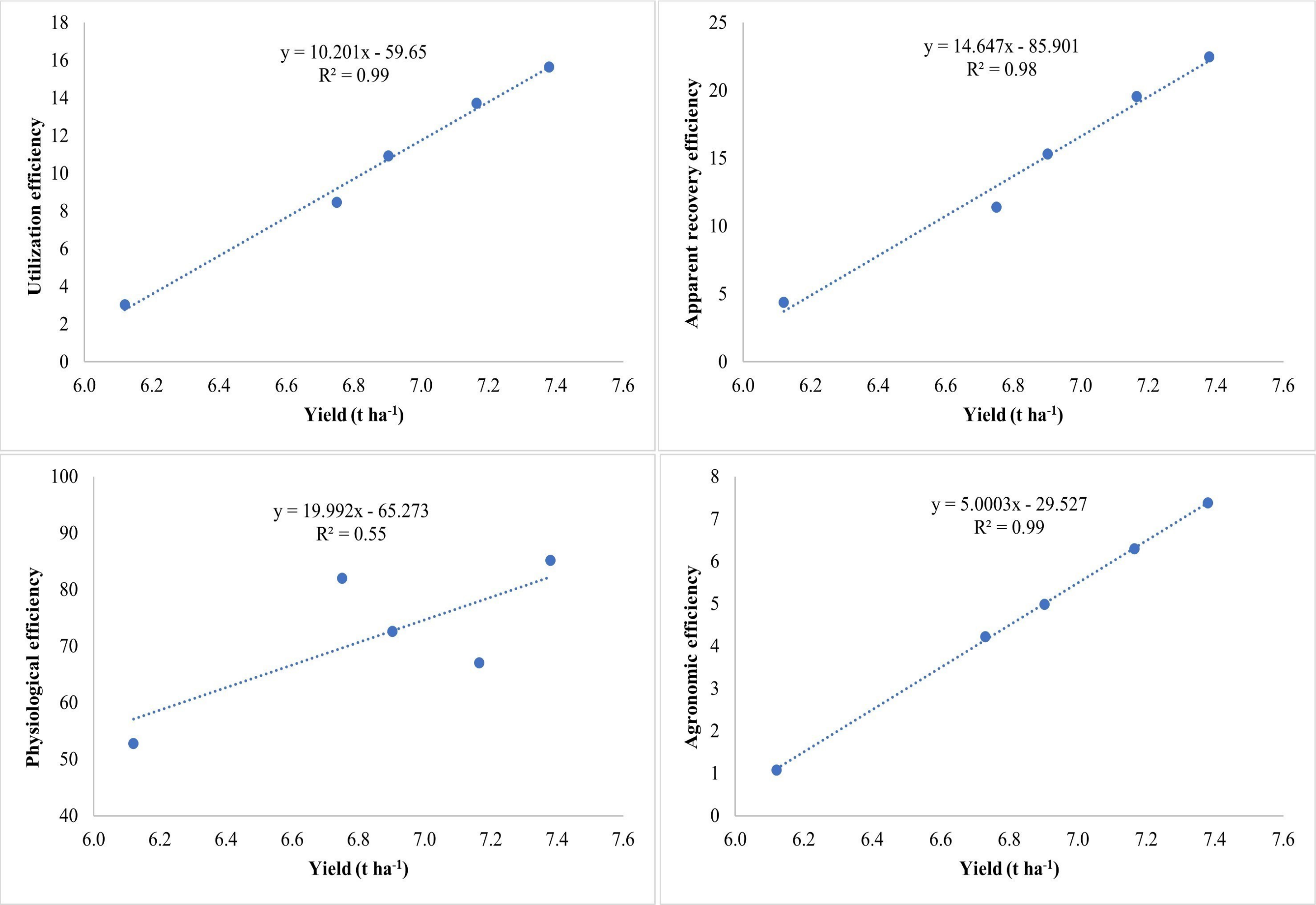

Fig. 4. Efficiency of nitrogen use and maize crop yield

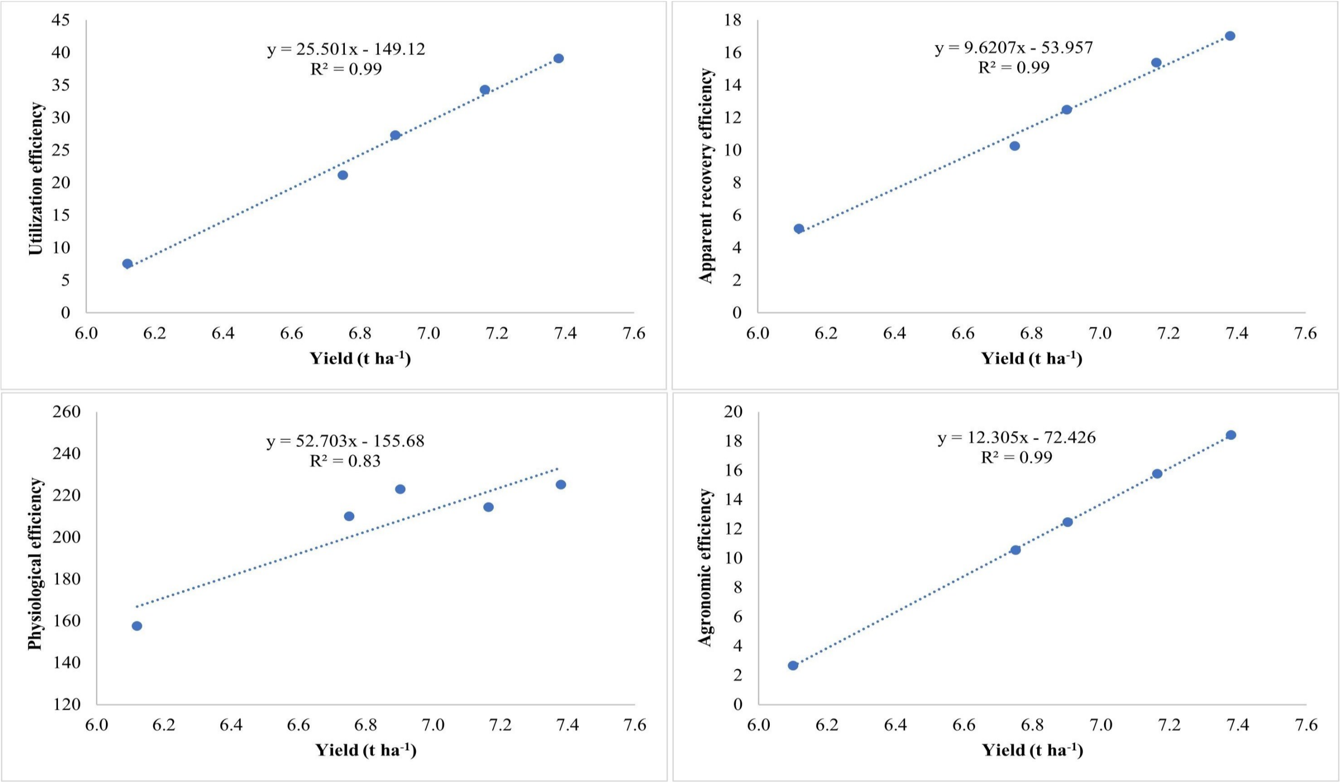

Fig. 5. Efficiency of phosphorous use and maize crop yield

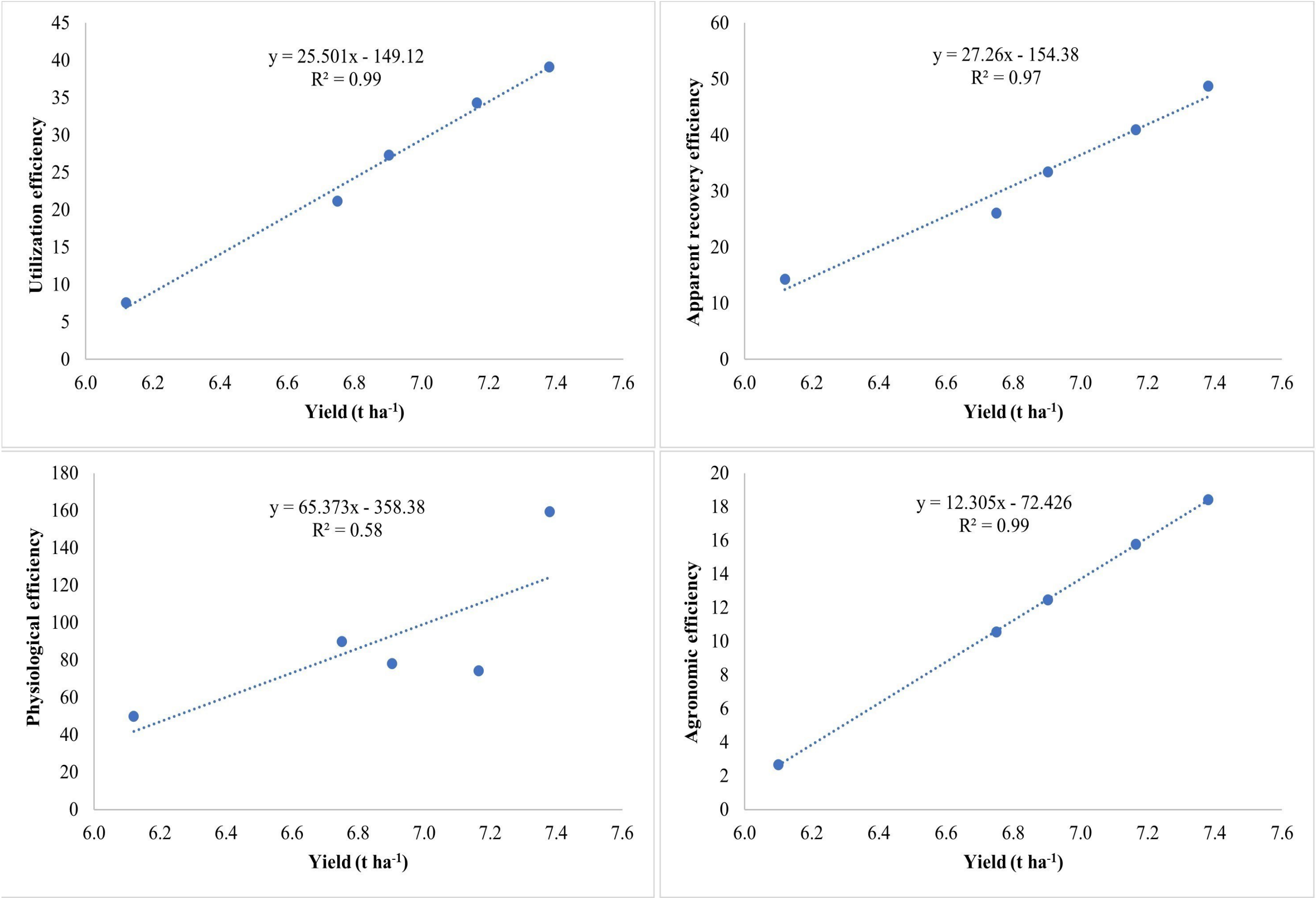

Fig. 6. Efficiency of potassium use and maize crop yield

Soil nutrient availability and chemical properties

The findings from Table 3 demonstrate that soil available N and P were significantly superior in the T_4 treatment which was at par with the rest of the treatments whereas the soil available K was significantly superior in the T_4 treatment which was on par with the T_7 treatment. Utilizing optimal irrigation practices and adhering to the recommended dosage of fertilizer application resulted in the highest levels of available N, P, and K (152.5, 36.3, and 352.8 kg ha^{-1}) respectively when compared to the other treatments.

Table 3. Effect of saline water on soil available N, P_2O_5 and K_2O (kg ha^{-1}) after harvest of maize under drip fertigation

Treatments	N (kg ha^{-1})	P_2O_5 (kg ha^{-1})	K_2O (kg ha^{-1})
T_1: BAW (Best Available Water) (< 1 dS m^{-1})	104.0	23.8	268.8
T_2: Irrigation with 2 dS m^{-1}	90.5	21.9	256.3
T_3: Irrigation with 4 dS m^{-1}	88.0	20.1	244.4
T_4: Irrigation with BAW + RDF	152.5	36.3	352.8
T_5: Irrigation with 2 dS m^{-1} + RDF	116.3	25.1	310.8
T_6: Irrigation with 4 dS m^{-1} + RDF	104.8	24.3	277.2
T_7: Irrigation with 2 dS m^{-1} + RDF with alternate use of fresh water	133.8	29.8	341.1
T_8:Irrigation with 4 dS m^{-1} + RDF with alternate use of fresh water	119.5	28.3	327.6
SE±	5.72	1.50	21.22
CD (0.05)	16.8	4.4	62.4

According to the data presented in Table 4, it can be observed that the irrigation of saline water, whether used continuously or alternately, does not substantially impact the soil's pH. However, there is a significant increase in the EC of the soil as the salinity level of the irrigation water increases. The observed increase in EC was relatively lower in the cyclic usage of saline and freshwater, as compared to the continuous usage of saline water and the EC values were on par with the best available water treatment. The soil exhibited the highest EC measurement of 2.92 dS m^{-1} following the maize harvest. This observation was made when irrigating with water having an EC of 4 dS m^{-1}, without the application of any fertilizers.

Discussion

The high osmotic pressures and the amounts of soluble salts may have influenced plant growth by inhibiting the uptake of water and nutrients by plant roots, hence affecting the nitrogen content in grain and stover. Furthermore, higher salinity causes a decrease in nitrate reductase activity, which is critical in converting nitrate to ammonium (21), resulting in lower N content in grain and stover (22, 23). Reduced N uptake by grain and stover at high salinity levels could be attributed to osmatic stress of salinity-induced reductions in the synthesis of nitrate reductase (NR), glutamine synthetase (GS), and glutamate synthetase (GOGAT) enzymes (24) involved in N metabolism, or to a lack of substrate in the root medium and nutritional imbalance. Excess salt in the soil may have reduced overall N uptake by plants (25).

The P content and uptake were the highest in alternate usage of saline water and freshwater compared to continuous use of saline water. Inadequate root growth and plant dry matter build-up could be the cause of the decrease in P content and uptake under saline water irrigation. Nutritional imbalance, which lowers phosphate activity or causes low solubility of phosphorous-containing salts, could also be the cause of low absorption. Under salt -stress circumstances, crop plants lose their ability to absorb and transport critical nutritional elements (26, 27). Similar results were reported in wheat, where grain nutrient P_2O_5 content increased with increased fertigation. (25, 28).

Salinity levels have a substantial impact on potassium content and uptake. Potassium uptake was significantly reduced at high salinity levels. In general, the presence of Ca, Mg, and Na cations in the rhizosphere reduces K availability. K, Mg, and Ca all have the same purpose in plant nutrition, acting as a buffer system for plant cells, and can thus be substituted for one another. Similarly, increasing the availability of Ca, Mg, and Na from additional salts inhibited K absorption by plants at high salinity levels (29).

Table 4. Effect of saline water on pH and EC of soil after harvest of maize under drip

Treatments	pH	EC (dS m^{-1})
T_1: BAW (Best Available Water) (< 1 dS m^{-1})	7.18	0.80
T_2: Irrigation with 2 dS m^{-1}	7.15	1.16
T_3: Irrigation with 4 dS m^{-1}	7.05	2.92
T_4: Irrigation with BAW + RDF	7.28	0.79
T_5: Irrigation with 2 dS m^{-1} + RDF	7.15	1.14
T_6: Irrigation with 4 dS m^{-1} + RDF	7.10	2.59
T_7: Irrigation with 2 dS m^{-1} + RDF with alternate use of fresh water	7.23	0.83
T_8: Irrigation with 4 dS m^{-1} + RDF with alternate use of fresh water	7.25	0.84
SE±	0.38	0.10
CD (0.05)	NS	0.28

* SE: Standard error; CD: Critical difference; RDF:Recommended dose of Fertilizers; dS m^{-1}: Decisiemens per meter

All the efficiencies of nitrogen, phosphorous, and potassium were recorded lowest under saline water irrigation of 4 dS m^{-1}; however, the alternate use of fresh water with different saline water levels recorded higher efficiencies than continuous use of saline water. Compared to continuous usage, alternate use of fresh water with saline water might have reduced the negative impact of low osmotic potential on plants and improved root growth and enhanced nutrient balance, thereby improving the nutrient uptake, which in turn resulted in higher grain yield, ultimately improving the nutrient use efficiency.

As salinity levels increased, soil nutrients became scarcer. The lowest values were observed under saline water irrigation with a salinity level of 4 dS m^{-1} in the absence of fertilizer application, in comparison to treatments where fertilizers were applied. Nevertheless, the alternating use of saline and freshwater resulted in higher levels of N, P, and K availability when compared to the continuous use of saline water. An elevation in salinity levels leads to an augmentation in the sodium content within the soil, potentially resulting in the displacement of available potassium and subsequently reducing its availability within the soil. The reduced availability of nitrogen and phosphorous in saline water treatments may be attributed to the fixation of nutrients and precipitation, resulting in a decrease in soil nutrient availability. The higher availability of nutrients observed with the application of the recommended dose of fertilizers may be attributed to the increased application of fertilizers, which results in residual nutrients remaining in the soil. Furthermore, the crop's uptake of nutrients plays a role in this phenomenon, particularly when compared to treatments without fertilizer application. Similar results were also observed (31).

Any change in crop productivity in a certain direction is always accompanied by a corresponding change in the use, utilization, and recovery efficiencies of nitrogen and potassium nutrients in the same direction. Changes in crop productivity are directly proportional to changes in phosphorus use efficiencies.

The soil EC experienced a slight increase after the harvest of the crop, in comparison to its initial state. The observed rise in soil EC may be attributed to the utilization of saline water, leading to the accumulation of salts in the soil and a decrease in salt leaching. The effectiveness of irrigation for leaching was limited because irrigation water was solely utilized to fulfill crop needs (32-33).

Conclusion

Based on the findings of the current study, it can be inferred that the use of saline water for irrigation, with an electrical conductivity of 4 dS m^{-1}, in the absence of the recommended dose of fertilizers, harmed the nutrient composition and uptake in both the grain and stover of maize. The nutrient uptake and nutrient use efficiencies of nitrogen (N), phosphorus (P), and potassium (K) were found to be higher when irrigation was conducted using the highest quality water available, in combination with the application of a recommended amount of fertilizers. Conversely, these uptakes and efficiencies decreased as the salinity levels of the irrigation water increased. The results indicate that the alternate use of saline and freshwater led to significant improvements in these parameters, in contrast to the continuous use of saline waters. In general, the utilization of both freshwater and saline water in a cyclical manner has proven to mitigate the negative impacts of salts, leading to improved efficiency in nutrient utilization and increased availability of soil nutrients.

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Authors' contributions

DSG conducted the research and technical write-up, MKA, RG, and KBG guided the student to conduct the research and write-up, and SKM and SNB guided the student in the technical writing of the research article.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

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