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Impact of saline irrigation water on sorghum productivity, nutrient uptake, economic returns, and soil properties

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Abstract

A field experiment was conducted during the *rabi* season, 2025–26 to understand the responses of sorghum varieties irrigated with saline water under a drip irrigation system. The experiment consisted of five irrigation water salinity levels, namely Best Available Water (BAW), 3, 6, 9 and 12 dS m⁻¹ and three sorghum varieties (NTJ 5, SVT 55 and SVT 68), arranged in a split-plot design with three replications. Increasing salinity significantly reduced yield, nutrient uptake, gross returns, net returns while among soil properties electrical conductivity increased and saturated hydraulic conductivity decreased progressively. Soil SAR, ESP, bulk density was not influenced significantly due to saline water irrigation. Among the tested varieties, NTJ 5 exhibited superior yield, nutrient uptake, higher economic returns.

Keywords: Saline water irrigation, nutrient uptake, economics, sorghum

Introduction

Salinity is a major environmental stress that severely limits agricultural productivity across the globe. The increasing use of saline groundwater for irrigation has accelerated the expansion of salt-affected soils, particularly in arid and semi-arid regions. Sorghum can tolerate soil and water salinity up to 6.8 and 4.5 dS m⁻¹ of electrical conductivity respectively (Ayers & Westcot, 1985)^[2], beyond these threshold levels yield reductions occur. Irrigation with saline water affects the growth of the plant as it causes osmotic stress, reducing water availability to the plants and nutrient imbalances, reduced nutrient uptake which can lead to a significant reduction in crop yield, reducing productivity (Mrudhula *et al.* 2025)^[13]. There is a necessity to identify various methods for saline water usage in order to reduce salinity impact on crop production.

Sorghum cultivated area is 4 million hectares in India with production and productivity of 4.95 million tonnes and 1240 kg ha⁻¹ respectively and Andhra Pradesh has an area, production and productivity of 0.08 million hectares, 0.29 million tonnes and 3459 kg ha⁻¹ respectively (Agricultural Statistics at a Glance, 2024-25)^[1].

Materials and Methods

A field experiment was carried out during the *rabi* season of 2025–26 at the Agricultural College Farm, Bapatla, Andhra Pradesh, using a split-plot design with three replications. The experiment consisted of three sorghum varieties (NTJ 5, SVT 55 and SVT 68) assigned to the main plots and five irrigation water salinity levels, namely Best Available Water (0.6 dS m⁻¹), 3, 6, 9 and 12 dS m⁻¹, allotted to the sub-plots. The experimental soil was sandy loam in texture, neutral in reaction (pH 7.1) and non-saline (EC 0.7 dS m⁻¹), with low available nitrogen, medium phosphorus and high potassium status. A recommended fertilizer dose of 100:60:40 kg N, P₂O₅, K₂O ha⁻¹ was applied through urea, single superphosphate and muriate of potash, respectively. Saline irrigation water of the desired electrical conductivity levels was prepared by diluting seawater (38 dS m⁻¹) with fresh water (0.6 dS m⁻¹). Salinity treatments were initiated from 20 days after sowing and applied through a drip irrigation system scheduled at 100% pan evaporation at three-day intervals.

Attributed yield was recorded at harvest using grain yield. Gross and net returns, benefit-cost

ratio were calculated using the cost of cultivation. Nitrogen content (%) in grain and stover was determined using the modified micro-Kjeldahl method as described by Piper *et al.* (1966) [15]. Plant samples were digested using a diacid mixture of nitric acid and perchloric acid (HNO₃, HClO₄;9:4). Phosphorus content in the digest was estimated by the vanadomolybdophosphoric acid yellow colour method, while potassium content was determined using a flame photometer following the procedure of Jackson *et al.* (1966) [5]. Nitrogen, phosphorus and potassium uptake were calculated based on nutrient concentration and corresponding grain and stover yields expressed in kg ha⁻¹.

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

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

Bulk density: Soil bulk density was determined by the core cutter method. Undisturbed soil samples collected using a cylindrical core cutter were oven-dried at 105 °C for 24 h, and bulk density was calculated as the ratio of oven-dry soil mass to the core volume.

$$\rho = \frac{M}{V}$$

Where, ρ = Bulk density of soil, mgcm⁻³.
M = Weight of oven dried soil, mg; and
V = Volume of core sampler, cm³

Saturated hydraulic conductivity, was determined from undisturbed soil cores using the constant head permeameter method (Jalota *et al.*,1998) [6]. After saturation, conductivity (cm h⁻¹) was calculated as

$K = QL/\Delta HAT$, where Q is the volume of water collected, L is the soil column length, ΔH is the hydraulic head, A is the cross-sectional area and T is the flow time.

Sodium adsorption ratio (SAR): Soil SAR was determined from the concentrations of Na⁺, Ca²⁺ and Mg²⁺ in the saturated soil extract prepared according to Richards (1954) [16]. Sodium was estimated using a flame photometer, while calcium and magnesium were determined by the EDTA titration method (Jackson, 1973) [5]. SAR was calculated using the standard equation:

$$\text{SAR} = \frac{Na^+}{\sqrt{\frac{Ca^{+2} + Mg^{+2}}{2}}}$$

Exchangeable sodium percentage (ESP): Exchangeable sodium was extracted with ammonium acetate following Black (1973) [3] and estimated using a flame photometer. ESP was calculated as the percentage of exchangeable sodium relative to the cation exchange capacity (CEC).

$$\text{ESP} = \frac{\text{Exchangeable sodium [c mol (p}^+\text{)kg}^{-1}\text{ soil]}}{\text{CEC (c mol (p}^+\text{)kg}^{-1}\text{ soil)}} \times 100$$

Results and Discussion

Effect of saline water irrigation on grain yield of sorghum varieties

Grain yield was significantly affected by sorghum varieties,

salinity levels and their interaction. Among the varieties, NTJ 5 recorded the highest grain yield (4822 kg ha⁻¹), while SVT-68 produced the lowest yield (3489 kg ha⁻¹). The higher yield of NTJ-5 may be due to its better genetic potential and grain filling ability, which agrees with Sahar *et al.* (2024) [17] and Jayalakshmi *et al.* (2024) [7].

Among the salinity levels, BAW recorded the highest grain yield (4716 kg ha⁻¹), which was on par with 3 and 6 dS m⁻¹, whereas 12 dS m⁻¹ produced the lowest yield (3167 kg ha⁻¹). The reduction in yield at higher salinity was mainly due to salinity-induced stress that reduced water and nutrient uptake, as reported by Mageed *et al.* (2018) [12] and Govada *et al.* (2024) [4]. The highest grain yield (5667 kg ha⁻¹) was recorded with NTJ-5 under BAW, while the lowest (2870 kg ha⁻¹) was observed in SVT-68 under 12 dS m⁻¹ salinity, which is in agreement with Kausar and Gull (2019) [9].

Effect of saline water irrigation on nutrient uptake of sorghum varieties

Nitrogen, phosphorus and potassium uptake in both grain and stover were significantly influenced by sorghum varieties, salinity levels and their interaction. Among the varieties, NTJ 5 recorded the highest uptake of N, P and K, whereas SVT 68 recorded the lowest. The higher nutrient uptake in NTJ-5 may be attributed to its superior yield potential and nutrient use efficiency, which is in agreement with Kumar (2024) [10] and Ju *et al.* (2021) [8].

Among the salinity treatments, Best Available Water (BAW) recorded the highest nutrient uptake and was statistically on par with 3 and 6 dS m⁻¹, while 12 dS m⁻¹ resulted in the lowest uptake. The reduction in nutrient uptake at higher salinity levels may be due to restricted water and nutrient absorption, impaired root activity and ionic imbalance under salt stress, as reported by Unno *et al.* (2002) [20] and Vincent *et al.* (2025) [21].

The interaction effect was significant, with NTJ 5 under BAW recording the highest uptake of N, P and K in both grain and stover, whereas SVT 68 under 12 dS m⁻¹ recorded the lowest uptake.

Effect of saline water irrigation on economics of sorghum varieties

Gross returns, net returns and benefit-cost ratio were significantly influenced by sorghum varieties, salinity levels and their interaction. Among the varieties, NTJ-5 recorded the highest gross returns (₹121,647 ha⁻¹), net returns (₹61,285 ha⁻¹) and B ratio (1.05), while SVT-68 recorded the lowest values. The superior economic performance of NTJ 5 was mainly attributed to its higher grain yield, corroborating the findings of Sujathamma *et al.* (2015) [19] and Jayalakshmi *et al.* (2024) [7].

Among the salinity treatments, Best Available Water (BAW) recorded the highest gross returns (₹118,987 ha⁻¹), net returns (₹58,625 ha⁻¹) and B ratio (0.91), which were statistically on par with 3 and 6 dS m⁻¹. The lowest economic returns were recorded under 12 dS m⁻¹ salinity due to reduced crop productivity, in agreement with Singh *et al.* (2019) [18] and Kumari (2015) [11].

The interaction effect was significant, with NTJ-5 irrigated with BAW recording the highest gross returns (₹142,970 ha⁻¹), net returns (₹82,608 ha⁻¹) and B ratio (1.48), whereas SVT-68 under 12 dS m⁻¹ salinity recorded the lowest economic returns and B ratio.

Effect of sorghum varieties and saline water irrigation on soil properties

Post-harvest soil SAR, ESP and bulk density were not

significantly affected by sorghum varieties, salinity levels or their interaction.

Saturated hydraulic conductivity was not significantly influenced by sorghum varieties or their interaction with salinity levels. However, salinity levels had a significant effect, with the

highest hydraulic conductivity recorded under Best Available Water (2.33 cm h⁻¹) and the lowest under 12 dS m⁻¹ salinity (2.00 cm h⁻¹), indicating a decline in soil water conductivity with increasing salinity reported by Mrudhula *et al.* 2025^[14].

Table 1: Effect of saline water irrigation on grain yield (kg ha⁻¹) of sorghum varieties

Varieties	Salinity levels (dS m ⁻¹)					Mean
	S ₁ : BAW	S ₂ : 3 EC	S ₃ : 6 EC	S ₄ : 9 EC	S ₅ : 12 EC	
V ₁ : NTJ-5	5667	5519	5007	4304	3611	4822
V ₂ : SVT-55	4370	4185	4085	3204	3018	3773
V ₃ : SVT-68	4111	3778	3667	3019	2870	3489
Mean	4716	4494	4253	3509	3167	
	SEm (+)	CD (0.05)	CV (%)			
MAIN PLOT	140.2	421	10.3			
SUB PLOT	192.3	576	14.7			
Interaction						
S at same level of V (S X V)	324.7	972				
V at same or different level of S (V X S)	240.9	1020				

Table 2: Effect of saline water irrigation on nitrogen uptake (kg ha⁻¹) in grain and stover of sorghum varieties

Varieties	Grain Nitrogen uptake (kg ha ⁻¹)					Mean	Stover Nitrogen uptake (kg ha ⁻¹)					Mean
	Salinity levels (dS m ⁻¹)						Salinity levels (dS m ⁻¹)					
	S ₁ : BAW	S ₂ : 3 EC	S ₃ : 6 EC	S ₄ : 9 EC	S ₅ : 12 EC		S ₁ : BAW	S ₂ : 3 EC	S ₃ : 6 EC	S ₄ : 9 EC	S ₅ : 2 EC	
V ₁ : NTJ-5	55.7	54.6	53.6	36.9	24.4	45.1	51.9	48.7	43.8	32.6	18.2	39.0
V ₂ : SVT-55	48.8	46.5	45.4	27.7	18.1	37.3	43.3	38.4	37.5	22.3	14.7	31.2
V ₃ : SVT-68	47.2	42.5	41.7	26.7	17.4	35.1	41.3	37.4	36.4	21.1	12.9	29.8
Mean	50.6	47.8	46.9	30.5	20.0		45.5	41.5	39.2	25.3	15.3	
	SEm (+)	CD (0.05)	CV (%)				SEm (+)	CD (0.05)	CV (%)			
MAIN PLOT	2.4	7.2	10.2				2.5	7.5	11.1			
SUB PLOT	1.4	4.2	5.9				2.9	8.7	13.1			
Interaction												
S at same level of V (S X V)	2.8	8.4					4.9	14.7				
V at same or different level of S (V X S)	3.1	9.3					4.3	12.9				

Table 3: Effect of saline water irrigation on phosphorus uptake (kg ha⁻¹) in grain and stover of sorghum varieties

Varieties	Grain Phosphorous uptake (kg ha ⁻¹)					Mean	Stover Phosphorous uptake (kg ha ⁻¹)					Mean
	Salinity levels (dS m ⁻¹)						Salinity levels (dS m ⁻¹)					
	S ₁ : BAW	S ₂ : 3 EC	S ₃ : 6 EC	S ₄ : 9 EC	S ₅ : 12 EC		S ₁ : BAW	S ₂ : 3 EC	S ₃ : 6 EC	S ₄ : 9 EC	S ₅ : 2 EC	
V ₁ : NTJ-5	21.2	21.0	20.4	19.6	15.8	19.6	14.4	14.1	13.7	9.9	9.0	12.2
V ₂ : SVT-55	19.4	18.9	18.7	15.7	12.9	17.1	14.0	13.4	13.3	8.7	6.7	11.2
V ₃ : SVT-68	18.9	17.6	17.1	14.9	12.7	16.3	12.2	11.3	11.0	7.5	5.8	9.6
Mean	19.8	19.2	18.7	16.7	13.8		13.5	12.9	12.6	8.7	7.2	
	SEm (+)	CD (0.05)	CV (%)				SEm (+)	CD (0.05)	CV (%)			
MAIN PLOT	0.7	2.2	12.4				0.2	0.7	6.2			
SUB PLOT	0.4	1.2	7.0				0.4	1.2	11.1			
Interaction												
S at same level of V (S X V)	0.9	2.7					0.7	2.2				
V at same or different level of S (V X S)	1.3	3.9					0.8	2.4				

Table 4: Effect of saline water irrigation on potassium uptake (kg ha⁻¹) in grain and stover of sorghum varieties

Varieties	Grain Potassium uptake (kg ha ⁻¹)					Mean	Stover Potassium uptake (kg ha ⁻¹)					Mean
	Salinity levels (dS m ⁻¹)						Salinity levels (dS m ⁻¹)					
	S ₁ : BAW	S ₂ : 3 EC	S ₃ : 6 EC	S ₄ : 9 EC	S ₅ : 12 EC		S ₁ : BAW	S ₂ : 3 EC	S ₃ : 6 EC	S ₄ : 9 EC	S ₅ : 2 EC	
V ₁ : NTJ-5	16.4	15.9	15.6	14.5	14.1	15.3	38.7	38.4	37.9	35.3	32.5	36.5
V ₂ : SVT-55	14.7	14.6	14.2	13.1	12.7	13.8	36.2	36.1	35.8	33.3	31.1	34.5
V ₃ : SVT-68	14.5	13.9	13.7	12.8	12.3	13.5	34.5	34.1	33.9	29.1	28.4	32.0
Mean	15.2	14.8	14.5	13.5	13.0		36.5	36.2	35.9	32.6	30.6	
	SEm (+)	CD (0.05)	CV (%)				SEm (+)	CD (0.05)	CV (%)			
MAIN PLOT	0.4	1.3	9.3				0.6	1.8	12.5			
SUB PLOT	0.3	0.9	5.5				0.4	1.2	7.4			
Interaction												
S at same level of V (S X V)	0.5	1.5					0.7	2.2				
V at same or different level of S (V X S)	0.8	2.4					1.0	3.0				

Table 5: Effect of sorghum varieties and saline water irrigation on gross returns (Rs.ha⁻¹)

Varieties	Salinity levels (dS m ⁻¹)					Mean
	S ₁ : BAW	S ₂ : 3 EC	S ₃ : 6 EC	S ₄ :9EC	S ₅ :12EC	
V ₁ : NTJ-5	142970	139236	126335	108582	91114	121647
V ₂ : SVT-55	110264	105596	103065	80829	76153	95181
V ₃ : SVT-68	103729	95311	92510	76161	72419	88026
Mean	118987	113381	107303	88524	79895	
	SEm (+)	CD (0.05)	CV (%)			
MAIN PLOT	2666.1	10470	10.2			
SUB PLOT	4827.1	14089	14.3			
Interaction						
S at same level of V (S X V)	7939.4	23817				
V at same or different level of S (V X S)	5962.7	32829				

Table 6: Effect of sorghum varieties and saline water irrigation on net returns (Rs. ha⁻¹)

Varieties	Salinity levels (dS m ⁻¹)					Mean
	S ₁ : BAW	S ₂ : 3 EC	S ₃ : 6 EC	S ₄ :9 EC	S ₅ :12 EC	
V ₁ : NTJ-5	82608	78874	65973	48220	30752	61285
V ₂ : SVT-55	49902	45234	42703	20467	15791	34819
V ₃ : SVT-68	43367	34949	32148	15799	12057	27664
Mean	58625	53019	46941	28162	19533	
	SEm (+)	CD (0.05)	CV (%)			
MAIN PLOT	2666.1	10470	10.3			
SUB PLOT	4827.1	14089	14.2			
Interaction						
S at same level of V (S X V)	7939.4	23817				
V at same or different level of S (V X S)	5962.7	32829				

Table 7: Effect of sorghum varieties and saline water irrigation on benefit-cost ratio

Varieties	Salinity levels (dS m ⁻¹)					Mean
	S ₁ : BAW	S ₂ : 3 EC	S ₃ : 6 EC	S ₄ :9 EC	S ₅ :12 EC	
V ₁ : NTJ-5	1.48	1.43	1.05	0.85	0.45	1.05
V ₂ : SVT-55	0.69	0.64	0.59	0.31	0.25	0.50
V ₃ : SVT-68	0.57	0.60	0.46	0.25	0.20	0.42
Mean	0.91	0.89	0.70	0.47	0.30	
	SEm (+)	CD (0.05)	CV (%)			
MAIN PLOT	0.03	0.09	14.9			
SUB PLOT	0.03	0.09	14.8			
Interaction						
S at same level of V (S X V)	0.06	0.18				
V at same or different level of S (V X S)	0.06	0.18				

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