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Evaluating the effects of diverse mulches on maize yield, water use efficiency, and economic viability under varying saline drip irrigation regimes

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Abstract
The scarcity of quality irrigation water in coastal regions necessitates alternative strategies for sustaining crop productivity. A field experiment was conducted during *rabi* 2024-25 at Agricultural College Farm, Bapatla, Andhra Pradesh to investigate the effect of saline water irrigation and mulching on maize yield, water use efficiency (WUE) and economics. The experiment followed a split-plot design with three replications, comprising four salinity levels [Best Available Water (BAW, 0.4 dS m^{-1}), 2 dS m^{-1}, 4 dS m^{-1}, 6 dS m^{-1}] as main plots and three mulch treatments (no mulch, straw mulch, plastic mulch) as sub-plots. The results revealed that BAW irrigation significantly enhanced kernel yield of 7418 kg ha^{-1}, which were statistically on par with 2 dS m^{-1} and 4 dS m^{-1} salinity levels. Plastic mulch recorded significantly higher growth, yield and WUE compared to no mulch and straw mulch. Economic analysis indicated that BAW with plastic mulch achieved the highest net returns (₹1,45,085 ha^{-1}) and B:C ratio (2.87). The study concludes that integrating saline water irrigation up to 4 dS m^{-1} with mulching, especially plastic mulch, improves maize productivity and profitability in saline-prone coastal areas.

Keywords: Maize, Saline water irrigation, Mulching, Water use efficiency, Soil properties, Yield

Introduction
Maize (*Zea mays L.*) ranks as the third most important cereal crop globally, serving as a crucial source of food, feed and industrial raw materials. In India, maize contributes significantly to food security, with an area of 11.24 million hectares producing 37.67 million tonnes during 2023-24 (DES, 2023-24). In Andhra Pradesh, maize is cultivated on 0.292 million hectares with an impressive productivity of 6225 kg ha^{-1} (des.ap.gov.in, 2023-24) [5].
However, the escalating scarcity of quality irrigation water, particularly in coastal regions, poses a major challenge to sustainable maize production. Increasing reliance on saline groundwater for irrigation has aggravated soil salinization problems, adversely impacting crop growth, nutrient uptake and yield (Elsiddig *et al*., 2022 and Ibrahim *et al*., 2018) [6, 10]. Maize is moderately sensitive to salinity, with optimal yield obtained when irrigation water EC remains below 1.7 dS m^{-1} (Ayers and Westcot, 1999) [2].
Drip irrigation has emerged as a promising technique to mitigate salt stress by delivering water precisely to the root zone, thereby minimizing salt accumulation (Kang, 1998) [11]. Additionally, mulching with organic (straw) or inorganic (plastic) materials improves soil moisture retention, reduces evaporation, modifies soil temperature, and prevents salt buildup (Lessa *et al.,* 2019; Barbosa *et al*., 2021) [12, 3]. Plastic mulch, in particular, enhances water use efficiency and nutrient availability, contributing to better crop performance under saline irrigation. Given these considerations, the present study aimed to evaluate the interactive effects of saline water irrigation and mulching on maize growth, yield, WUE, soil properties, and economics under coastal agro-climatic conditions.

Materials and Methods
The field experiment was carried out during *rabi* 2024–25 at Agricultural College Farm, Bapatla (15°54' N, 80°30' E, 5.49 m MSL) under Krishna agro-climatic zone with 12 treatments. The experiment was laid out in a split-plot design with three replications. The main plot treatments comprised four salinity levels: M_1: Best Available Water (0.4 dS m^{-1}),

M_2: 2 dS m⁻¹, M_3: 4 dS m⁻¹, and M_4: 6 dS m⁻¹. The subplot treatments included: S_1: No mulch, S_2: Straw mulch (applied at 3000 kg ha⁻¹ to a depth of 5 cm), and S_3: Plastic mulch (black polyethylene with 30 microns). The experimental site was sandy loam in texture, uniform in topography, homogeneously fertile, and neutral in pH (7.2) with EC 0.46 dS m⁻¹, low in organic carbon (0.35%), low in available nitrogen (165 kg ha⁻¹), high in phosphorus (28 kg ha⁻¹) and potassium (315 kg ha⁻¹).

The hybrid maize PAC 751 was used for the study. Sowing was done on 23rd November 2024 with a spacing of 20/30 cm × 50 cm. Irrigation was provided through a drip irrigation system using 16 mm inline laterals fitted with 2.0 L h⁻¹ emitters at 50 cm intervals. Control valves were installed for plot-wise water application. A filtration unit with screen and disc filters was used to remove impurities, and pressure gauges ensured consistent emitter pressure. Saline water of EC 2, 4, and 6 dS m⁻¹ was prepared by diluting seawater (49 dS m⁻¹) with fresh water (0.4 dS m⁻¹) to achieve the required EC levels. These treatments were imposed from 20 DAS onward based on the calculated crop water requirement using the IW/CPE ratio. Meteorological observations during the crop period indicated a mean maximum temperature of 31.5 °C, minimum temperature of 20.4 °C, mean relative humidity of 67.5% to 87.0%, and a total rainfall of 20.3 mm over 3 rainy days. Plants were selected randomly, and their growth was observed. Attributed yield was recorded at harvest using kernel yield and harvest index, and water use efficiency were calculated. Gross net returns and benefit-cost ratios were calculated using the cost of cultivation. Based on the field data, the data collected for crop growth, yield attributes and yield were statistically analyzed for variance.

Results and Discussion

Maize Kernel yield

Kernel yield varied significantly among treatments. BAW recorded significantly the highest yield (8200 kg ha⁻¹), followed by 2 dS m⁻¹ (7704 kg ha⁻¹) and 4 dS m⁻¹ (7216 kg ha⁻¹), while 6 dS m⁻¹ recorded the lowest (5238 kg ha⁻¹). The reduction in yield under high salinity is due to energy diversion from yield formation to stress mitigation. These results align with those of Shehzad *et al*. (2020) [16] and Feng *et al*. (2017) [8]. Among mulch treatments, plastic mulch recorded significantly higher kernel yield (7552 kg ha⁻¹), followed by straw mulch (7084 kg ha⁻¹), and no mulch (6632 kg ha⁻¹). Absy *et al*. (2020) [1], who reported that the use of black plastic mulch stimulated root growth through enhanced soil temperature and moisture conservation, ultimately leading to improved grain yield per plant. The interaction between salinity and mulch was significant. Significantlythe highest kernel yield (8846 kg ha⁻¹) was obtained under BAW with plastic mulch, and the lowest (4930 kg ha⁻¹) under 6 dS m⁻¹ with no mulch.

Stover yield followed a similar trend, with significantlythe highest yield (9284 kg ha⁻¹) recorded under BAW, which was on par with 2 dS m⁻¹ (8794 kg ha⁻¹) and 4 dS m⁻¹ (8289 kg ha⁻¹). Significantlythe lowest (6659 kg ha⁻¹) was recorded at 6 dS m⁻¹. The lower stover yields noticed with saline water could be due to reduced leaf number and existence of high salt concentration near root zone in saline water irrigation treatment. The results were in line with the findings of Govada *et al*. 2024[9]. Among mulching treatments, plastic mulch recorded significantly higher stover yield (8646 kg ha⁻¹), followed by straw mulch (8286 kg ha⁻¹), and no mulch (7836 kg ha⁻¹). The interaction was significant, with BAW and plastic mulch recording significantly the highest (9939 kg ha⁻¹), and 6 dS m⁻¹ with no mulch the lowest (6316 kg ha⁻¹).

Table 1: Effect of saline water irrigation and mulching on kernel yield (kg ha⁻¹) of maize

Salinity levels (dS m⁻¹)	Mulch			Mean
	S_1: Without Mulch	**S_2: Straw Mulch**	**S_3: Plastic Mulch**	
M_1: BAW	7556	8198	8846	8200
M_2: 2 EC	7308	7792	8011	7704
M_3: 4 EC	6734	7244	7669	7216
M_4: 6 EC	4930	5103	5681	5238
Mean	6632	7084	7552	
	SEm (±)	CD(0.05)	CV (%)	
MAIN PLOT	289.9	1003	12.3	
SUB PLOT	162.6	487	9.9	
Interaction				
S at same level of M (S X M)	325.1	975		
M at same or different level of S(M X S)	393.1	1277		

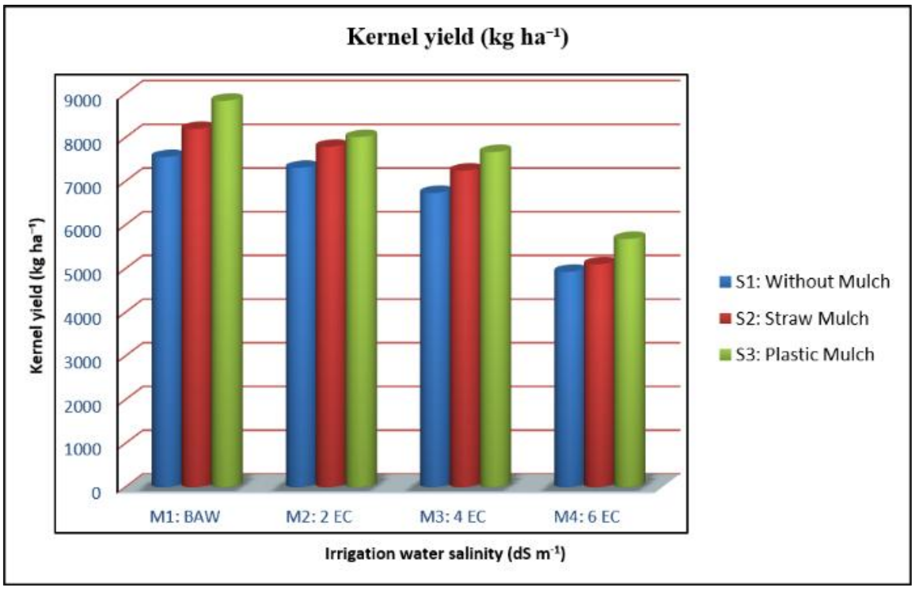

Fig 1: Effect of saline water irrigation and mulching on kernel yield (kg ha^{-1}) of maize

Table 2: Effect of saline water irrigation and mulching on stover yield (kg ha^{-1}) of maize

Salinity levels (dS m^{-1})	Mulch			Mean
	S_1: Without Mulch	S_2: Straw Mulch	S_3: Plastic Mulch	
M_1: BAW	8471	9437	9939	9282
M_2: 2 EC	8389	8857	9135	8794
M_3: 4 EC	8167	8296	8403	8289
M_4: 6 EC	6316	6556	7105	6659
Mean	7836	8286	8646	
	SEm (+)	CD (0.05)	CV (%)	
MAIN PLOT	292.4	1012	10.6	
SUB PLOT	235.9	707	9.9	
Interaction				
S at same level of M (S X M)	471.8	1415		
M at same or different level of S (M X S)	483.7	1532		

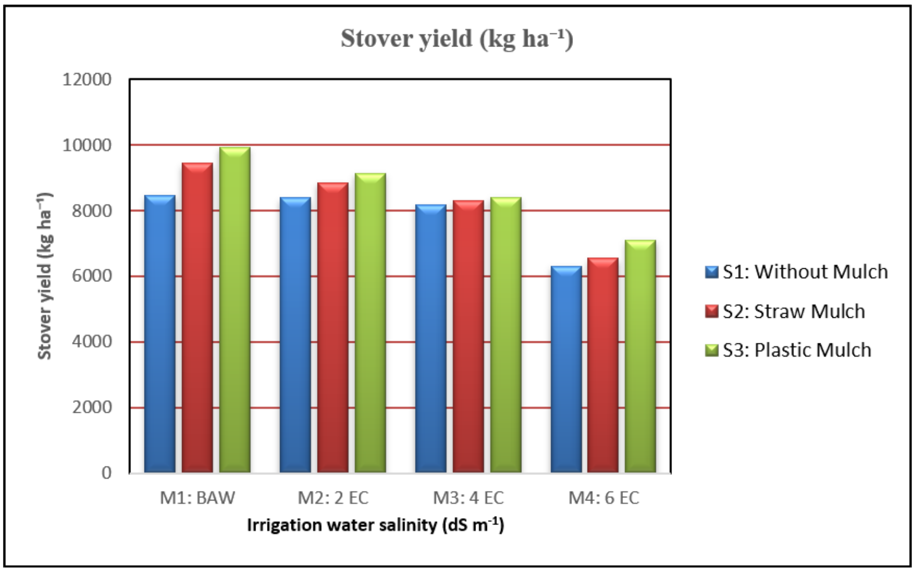

Fig 2: Effect of saline water irrigation and mulching on stover yield (kg ha^{-1}) of maize

Water use efficiency (WUE):

Significantly higher WUE was recorded under BAW (21.5 kg ha^{-1} mm^{-1}), which was statistically on par with 2 dS m^{-1} (19.3 kg ha^{-1} mm^{-1}) and 4 dS m^{-1} (18.1 kg ha^{-1} mm^{-1}), while significantly the lowest WUE was observed at 6 dS m^{-1} (13.1 kg ha^{-1} mm^{-1}) (Table.3 & Fig.3). The consistent water application by drip system minimized deep percolation losses and maintained optimal root zone moisture, even under saline conditions. This aligns with findings by Wang *et al.* (2021) [17] and Mrudhula *et al.* (2021) [14]. Among mulching treatments, plastic mulch recorded significantly the highest WUE (20.3 kg ha^{-1} mm^{-1}), followed by straw mulch (19.1 kg ha⁻¹ mm⁻¹), which were significantly superior to no mulch (17.2 kg ha⁻¹ mm⁻¹). The increase in WUE under mulched conditions may be due to soil warming and enhanced early crop growth, which boosted biomass and yield, as reported by Zhang *et al.* (2011) [18]. The interaction between salinity and mulch was significant, with the highest WUE (22.9 kg ha⁻¹ mm⁻¹) recorded under BAW with plastic mulch and the lowest (12.6 kg ha⁻¹ mm⁻¹) under 6 dS m⁻¹ with no mulch.

Table 3: Effect of saline water irrigation and mulching on Water Use Efficiency (kg ha^{-1} mm^{-1}) in maize

Salinity levels (dS m^{-1})	Mulch			Mean
	S_1: Without Mulch	**S_2: Straw Mulch**	**S_3: Plastic Mulch**	
M_1: BAW	18.9	20.5	22.1	20.5
M_2: 2 EC	18.3	19.5	20.0	19.3
M_3: 4 EC	16.9	18.1	19.2	18.1
M_4: 6 EC	12.3	12.8	14.2	13.1
Mean	16.6	17.7	18.9	
	SEm (±)	CD(0.05)	CV (%)	
MAIN PLOT	0.72	2.5	12.3	
SUB PLOT	0.41	1.2	9.9	
Interaction				
S at same level of M(S X M)	0.82	NS		
M at same or different level of S (M X S)	0.98	3.2		

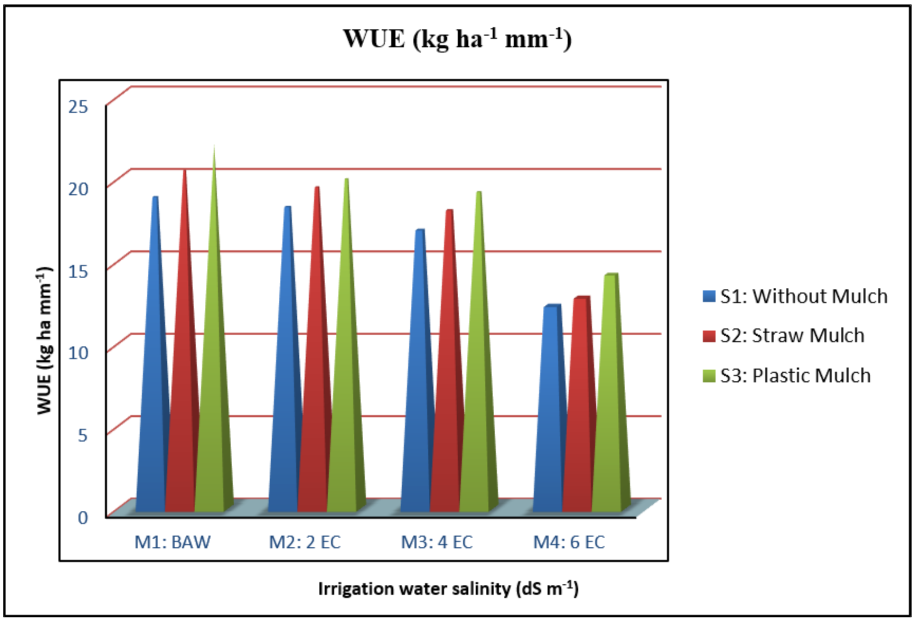

Fig 3: Effect of saline water irrigation and mulching on water use efficiency (kg ha^{-1} mm^{-1}) in maize

Economics

Gross returns, net returns, and benefit-cost (B:C) ratio were significantly influenced by salinity and mulching treatments. The highest gross returns (₹1,95,698 ha⁻¹), net returns (₹1,04,048 ha⁻¹), and B:C ratio (2.2) were recorded under BAW with plastic mulch, while the lowest gross returns (₹1,09,849 ha⁻¹), net returns (₹29,289 ha⁻¹), and B:C ratio (1.4) were observed under 6 dS m⁻¹ without mulch (Table 4,5 and 6 and Fig 4, 5 and 6). The improvement in returns with best available water was mainly due to increased kernel and stover yields. Similar reductions in returns under high salinity were reported by Emdad and Fardad (2000) [7], while Rawal (2013) [15] observed a steep decline in net income under elevated salinity levels. Among the mulching treatments, plastic mulch resulted in the highest gross and net returns due to its effect on crop growth and water conservation. However, straw mulch recorded the highest B:C ratio (1.9), which was statistically on par with plastic mulch (1.8), both being superior to no mulch (1.8). Although plastic mulch improved yield and income, its higher cost reduced profitability, making straw mulch more cost-effective. These results are in line with Mondal *et al.* (2008) [13], who reported the highest gross returns under black polythene mulch, and Cai *et al.* (2015) [4], who emphasized the role of straw mulch in improving yield and economic efficiency under saline conditions.

Table 4: Effect of saline water irrigation and mulching on gross returns of maize

Salinity levels (dS m^{-1})	Mulch			Mean
	S_1: Without Mulch	**S_2: Straw Mulch**	**S_3: Plastic Mulch**	
M_1: BAW	167156	181604	195698	181486
M_2: 2 EC	161862	172493	177372	170576
M_3: 4 EC	149591	160411	169458	159820
M_4: 6 EC	109849	113709	126406	116655

Mean	147115	157054	167234	
	SEm (+)	CD (0.05)	CV (%)	
MAIN PLOT	5915.4	20471	11.3	
SUB PLOT	3312.1	9930	7.3	
Interaction				
S at same level of M (S X M)	6624.2	19860		
M at same or different level of S (M X S)	8015.3	26050		

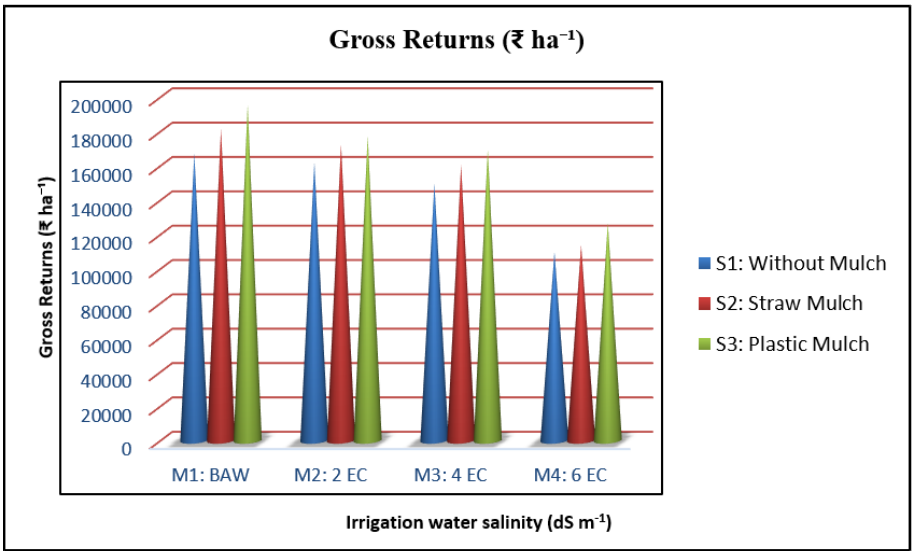

Fig 4: Effect of saline water irrigation and mulching on gross returns (Rs. ha^{-1}) of maize

Table 5: Effect of saline water irrigation and mulching on net return of maize

Salinity levels (dS m^{-1})	Mulch			Mean
	S_1: Without Mulch	S_2: Straw Mulch	S_3: Plastic Mulch	
M_1: BAW	86596	97454	104048	96033
M_2: 2 EC	81969	89343	87389	86234
M_3: 4 EC	69031	76261	77808	74367
M_4: 6 EC	29289	29559	34756	31201
Mean	66721	73154	76000	
	Sem (+)	CD (0.05)	CV (%)	
MAIN PLOT	2848.2	9856	11.9	
SUB PLOT	2397.6	7188	11.5	
Interaction				
S at same level of M (S X M)	4795.2	14377		
M at same or different level of S (M X S)	4841.6	15291		

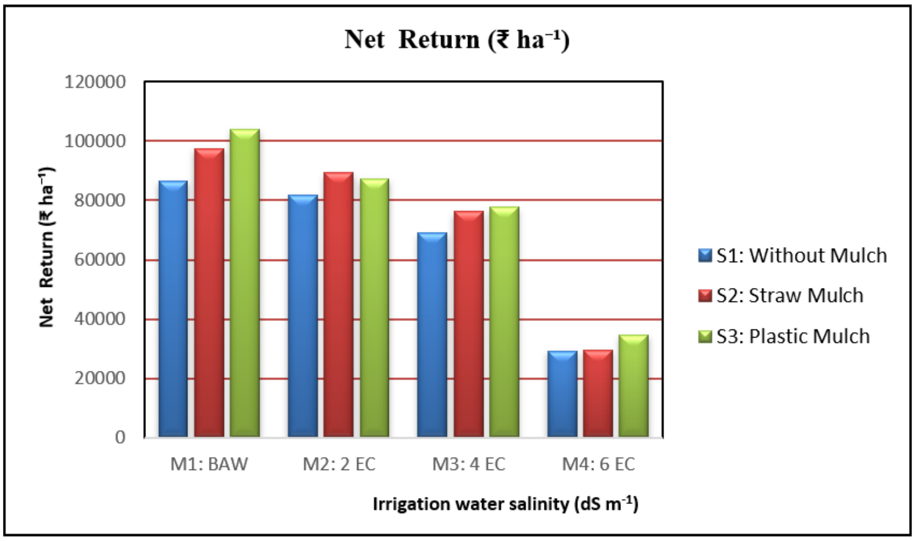

Fig 5: Effect of saline water irrigation and mulching on net returns (Rs. ha^{-1}) of maize ha^{-1}) in maize stover

Table 6: Effect of saline water irrigation and mulching on B:C ratio of maize

Salinity levels (dS m^{-1})	Mulch			Mean
	S_1: Without Mulch	S_2: Straw Mulch	S_3: Plastic Mulch	
M_1: BAW	2.1	2.2	2.1	2.1
M_2: 2 EC	2.0	2.0	1.9	2.0
M_3: 4 EC	1.9	1.9	1.9	1.9
M_4: 6 EC	1.4	1.4	1.4	1.4
Mean	1.8	1.9	1.8	
	Sem (±)	CD (0.05)	CV (%)	
MAIN PLOT	0.07	0.2	11.6	
SUB PLOT	0.04	0.1	7.7	
Interaction				
S at same level of M (S X M)	0.08	NS		
M at same or different level of S (M X S)	0.09	0.3		

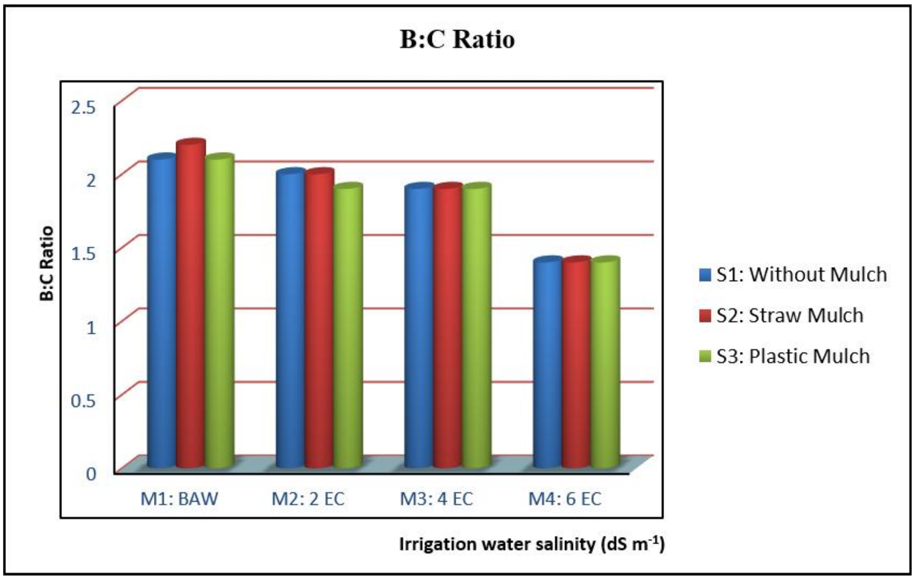

Fig 6: Effect of saline water irrigation and mulching on B:C ratio of maize.

Conclusion

The present study highlights the significance of combining saline water irrigation with appropriate mulching to sustain maize productivity in coastal regions. Drip irrigation with saline water up to 4 dS m^{-1} did not significantly reduce maize growth, yield or WUE compared to BAW irrigation, indicating the crop's tolerance to moderate salinity under precise water application. Mulching, particularly plastic mulch, significantly improved soil moisture conservation, minimized salt accumulation, enhanced nutrient uptake, and boosted yield and WUE compared to no mulch and straw mulch. The integration of moderate saline water irrigation ($\leq$ 4 dS m^{-1}) with plastic mulch proved to be the most effective strategy, achieving higher maize yields, improved soil health, greater WUE, and superior economic returns. These findings support the adoption of mulching and efficient drip irrigation to overcome water scarcity and salinity challenges for maize cultivation in coastal agro-ecosystems.

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