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Effect Of Straw Mulching On Soil Moisture, Salt Accumulation, And Beetroot Growth On Saline Soil Under Greenhouse Condition

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Abstract
Saltwater intrusion has increasingly impacted soil quality and crop productivity in the Mekong River Delta (MRD), Vietnam. This study investigated the effects of rice straw mulching on mitigating salinity accumulation, conserving soil moisture, and improving the yield of beetroot (Beta vulgaris) under greenhouse conditions. The experiment was designed with two factors: three irrigation salinity levels (S1: 0‰, S2: 2‰, and S3: 4‰ of NaCl) and four rates of straw mulch application (M1: 0, M2: 3.5, M3: 7.0, and M4: 10.5 tons ha $^{-1}$*).The results showed that rice straw mulching significantly enhanced soil moisture retention by up to 25% compared to the non-mulched control. Applying rice straw mulch at a moderate rate (M3) reduced salt accumulation, exchangeable* Na^+*, exchangeable sodium percentage (ESP), and sodium adsorption ratio (SAR), while improving plant growth, beetroot yield, and water use efficiency. However, excessive mulching (M4) temporarily increased soil salinity, possibly due to ion release from straw decomposition. Therefore, applying straw mulch at a moderate rate (M3) is recommended as an effective soil management practice to enhance beetroot growth, productivity, and soil quality in salt-affected areas of the MRD*
Keywords: *Beta vulgaris, mulching, soil salinity, water use efficiency*

1. INTRODUCTION

The Mekong River Delta is the most important region for food security in Vietnam, with the largest area of rice cultivation and vegetable production. Recently, salinity intrusion has increased in agricultural production in the MRD due to climate change, sea level rise, and drought during the dry season (Loc et al., 2021; Morton et al., 2023). Salinity intrusion can increase the risk of salt accumulation in agricultural soils, leading to inhibited water uptake, nutrient imbalances, and reduced crop yields (Machado & Serralheiro, 2017; Majeed & Muhammad, 2019; Zörb et al., 2019).

Several studies have focused on mitigating the effects of saline intrusion on soil properties, water use efficiency (WUE), and crop productivity through agronomic and soil management practices (Demo & Asefa Bogale, 2024; Dong et al., 2018; Farzi et al., 2017; Memon et al., 2017; Wang et al., 2018; Wang et al., 2025; Zhang et al., 2020). Among these, mulching - the use of crop residues to cover the soil surface - has been recognized as an effective technique for maintaining soil moisture and improving crop productivity. Numerous studies have reported that the application of mulching has had a positive impact on various crops, including wheat (Yang et al., 2018), maize (Li et al., 2018), sorghum (Mupangwa et al., 2012), tomato (Mendonça et al., 2021), turmeric (Choudhary & Kumar, 2019; Kumar et al., 2017), sunflower (Liang et al., 2015), and sesame (Behzadnejad et al., 2020; Teame et al., 2017). Organic mulching can reduce soil water loss primarily by decreasing the soil surface temperature caused by solar radiation and reducing evaporation.

In addition, covering the soil with crop residues can improve soil organic carbon content (Song et al., 2025; Zhou et al., 2019). Mulching tends to slow the decomposition of crop residues and enhance the soil environment for microbial activity by maintaining stable soil temperature and moisture (Wang et al., 2021; Zhang et al., 2025). Moreover, the application of plant residues also reduces soil disturbance, limits the microbial oxidation of organic matter, and thereby promotes greater retention of soil organic matter in the topsoil (Chang & Zhang, 2023; Zhang et al., 2022).

Beetroot (*Beta vulgaris* L.), a root vegetable of the *Amaranthaceae* family, is widely cultivated in tropical and subtropical regions due to its adaptability and high nutritional value. In Vietnam, beetroot is typically grown during the dry season in southern provinces, especially in the MRD. However, beetroot cultivation systems have recently been adversely affected by salinity intrusion and freshwater shortages during the dry season (Tran et al., 2025). Soil salinity can lead to stunted beetroot growth and decreased yields (He et al., 2022).

Several studies have demonstrated that organic mulching can increase beetroot yields by 7.8–9.3% compared to systems without crop residue application (Acharyya et al., 2020; Yordanova & Gerasimova, 2016). Furthermore, water use efficiency (WUE) in beetroot cultivation has been reported to improve under optimized water management practices such as drip irrigation, organic amendments, and mulching (Gadelha et al., 2021; Ribeiro et al., 2024; Zhang et al., 2009). Although some studies suggest that beetroot possesses a certain level of salinity tolerance, research specifically examining the effects of crop residue mulching on soil moisture, plant development, and yield under saline irrigation conditions in the MRD remains limited.

Therefore, this study aimed to evaluate the effects of varying straw mulch application rates on soil moisture dynamics, salinity accumulation, WUE, and the growth and yield of beetroot under different saline irrigation regimes.

II. MATERIALS AND METHODS

2.1 Characteristics of the experimental soil

Soil samples were collected from the top layer (0–20 cm) in the paddy field located in Tran De district, Soc Trang province, Vietnam. The area has been frequently affected by salinity intrusion and rice cultivation in the dry season is unfeasible. The soil was slightly acidic (pH = 5.07), saturated electrical conductivity (ECe) was approximately 5.42 mS cm^{-1}; soil texture was classified as silty clay with the contents of sand, silt and clay were 28.5%, 42.6%, 29.0%, respectively.

2.2 Experimental design and management

The experiment was arranged in pots under greenhouse conditions.at Can Tho University. A completely randomized design (CRD) was used with two factors and three replicates. The two experimental factors were: Salinity levels of irrigation water (S): S1 (0‰, control), S2 (2‰), and S3 (4‰); and Straw mulch application rates (M): M1 (0 tons ha^{-1}, control), M2 (3.5 tons ha^{-1}), M3 (7.0 tons ha^{-1}), and M4 (10 tons ha^{-1}).

Soil sample was collected in January 2023, before after harvesting the autumn-winter rice crop in Long Phu district ($9^0$58'22.53" N $106^0$13'05.01" E), Soc Trang province, MRD. Soil samples were collected at the surface layer of 0 -15 cm separately of the affected saline rice soil in the dry season. The soil samples were treated by drying and chopping, mixed with organic fertilizer and lime at the ratio of 3 tons ha^{-1} and 2 tons ha^{-1}, respectively. Approximately 8 kg of soil was placed in pots (27 × 32 cm) and moistened with freshwater to reach field capacity.

For the initial soil, soil pH was measured at a ratio of 1:5 (soil:deionized water), soil-saturated electric conductivity (ECe), available N, and available P, exchangeable Na^+, the exchangeable sodium percentage (ESP) and the cation exchange capacity (CEC). The properties of the initial soil are shown in Table 1.

Table 1. Initial physicochemical properties of the experimental soil

Parameters	Unit	Value
pH (1:5 H_2O)		5.91
ECe	mS/cm	5.42
Available nitrogen	mg/kg	17.8
Available phosphorus	mg/kg	11.2
Exchangeable Na^+	cmol kg^{-1}	1.33
The exchangeable sodium percentage (ESP)	%	7.91
The cation exchange capacity (CEC)	cmol kg^{-1}	15.6

All pots were initially irrigated with freshwater at 80% of field capacity for the first two weeks. Then, saline irrigation treatments were imposed using 2‰ and 4‰ salinity levels at 14 days after sowing (DAS). The non-saline treatment (0‰) continued to receive freshwater irrigation throughout the experiment and served as the control.

The saline water used in this study was derived from seawater collected in Soc Trang Province, Vietnam the same location from which the soil samples were obtained. This seawater was diluted with freshwater under greenhouse conditions to achieve the desired salinity concentrations.

Beetroot (*Beta vulgaris* L.), which is known for its moderate tolerance to saline conditions (Yolcu et al., 2021), was selected for this study. The variety used is resistant to bacterial leaf spot (Sharma et al., 2024), produces smooth, dark red roots with a sweet flavor, and is rich in nutrients. Its growth period ranges from 75 to 95 days, and the seeds were sourced from East-West Seed Vietnam.

2.3 Sampling and analyses

Soil moisture content and soil electrical conductivity were measured at 0, 15, 30, 45, 60, 75, and 90 DAS. Soil moisture content was determined using the oven-drying method (Rayment & Higginson, 1992). Soil salinity was measured using an EC meter with a soil-to-deionized water ratio of 1:5 (soil:water) and a conductivity probe (Rayment & Lyons, 2011). The measured $EC_{1:5}$ values were then converted to ECe based on soil texture, following the method of Slavich & Petterson (1993).

At harvest, soil samples were collected to determine the levels of exchangeable sodium (Na^+), exchangeable potassium (K^+), ESP, and sodium adsorption ratio.

Exchangeable cations (Na^+, K^+, Ca^{2+}, Mg^{2+}): that were obtained by subtracting soluble cations from extractable cations. Extractable cations were analyzed by extracting soil sample (2.5 g) three times with 0.1 M $BaCl_2$ solution (each time 30 ml) and with 1 hour shaking and determined with flame photometry.

The exchangeable sodium percentage (ESP) was calculated asESP (%) = $\text{Exch Na}^+/\text{CEC} \times 100$ (Richards, 1954) where the cation exchange capacity (CEC) is expressed in cmol kg^{-1} (Gillman, 1979).

The sodium adsorption ratio (SAR) was calculated using the formula from Kamphorst & Bolt (1978):

$$0.015 \text{ x SAR} = \frac{\text{ESP}}{(100 - \text{ESP})}$$

Water use efficiency (WUE, g L^{-1}) was calculated as the ratio of total beetroot yield per pot to the total amount of water used during the experiment as the following formula (Jensen, 1983):

$$\text{WUE}=\frac{\text{fruit yield (kg ha}^{-1})}{\text{water applied (m}^3\text{ ha}^{-1})}$$

Leaching requirement (LR) - Minimum leaching fraction: The minimum leaching fraction, also referred to as the leaching requirement (LR), is the minimum amount of water needed to prevent salt accumulation above a threshold level in the root zone. Although various formulas exist for estimating LR, they all reflect the functional relationship between irrigation water salinity and crop yield. In this study, LR was calculated based on FAO guidelines using the following equation $LR = ECw / (5 \times ECe - ECw)$ where ECw is the electrical conductivity of the irrigation water (dS m^{-1}), and ECe is the electrical conductivity of the soil saturation extract (dS m^{-1}) (Ayers & Westcot, 1985).

Total annual crop water demand (ET) was estimated using the following formula $AW = ET / (1 - LR)$ where ET is the total crop evapotranspiration or annual water demand (mm), and AW is the applied water requirement (mm) (Ayers & Westcot, 1985).

At harvest, yield-related parameters were recorded, including plant height (cm), leaf area (cm^2), SPAD chlorophyll index, fresh biomass (g pot^{-1}), and beetroot yield (g pot^{-1}).

2.4 Statistical analysis

The effects of salinity levels of irrigation water, straw mulch rates and their interaction were performed using Minitab software (ver. 20.0). When significant treatment effects were detected, Tukey's test was performed with a significance level of 5%.

RESULTS AND DISCUSSION

3.1 Soil moisture content

In general, soil moisture content was affected by both of saltwater irrigation and straw mulch rates, particularly at 30, 45, 60, and 75 days after sowing (DAS) (Table 2). Soil moisture content generally increased in the higher salinity levels, especially the S3 salinity treatment showed a significantly higher value than the S1 and S2 treatments at 30, 60, and 75 DAS ($p<0.05$). An increase in soil moisture content corresponding with rising salinity levels can explain by the enhanced water retention capacity in the saline soils. The presence of high soluble salts concentration increase the osmotic potential of the soil solution, and reduce soil water potential (Marschner, 2017; Sheldon et al., 2017; Weil & Brady, 2017). This result agreed with Pachepsky et al., (2024), who reported that a strong relationship between the logarithm of the soil moisture content and the osmotic potential with osmotic potential decreasing as salinity increases, limiting water uptake by plants.

In addition, applying straw mulch at a rate of 10 tons ha^{-1} (M4) resulted in significantly higher soil moisture content than the treatments received fewer mulching rates (M1 and M2) at 45 DAS (p<0.05). At 60 DAS, soil moisture content in the treatment mulched rice straw at a rate of 7 tons ha^{-1} (M3) was significantly higher than the treatment with no rice straw mulch (p<0.05). There was no significant difference in soil moisture content among the mulching treatments at 0, 15, 30, 75, and 90 DAS (p>0.05). This can be explained by the fact that the water requirement characteristics of beetroot vary across different growth stages. The crop coefficient (Kc) values for beetroot are 0.15, 1.1, and 0.5 for the initial (Kc ini), mid-season (Kc mid), and late season stages, respectively (Feddesl et al., 1985). Water demand during the mid-season stage was significantly higher, which influenced soil moisture levels under different straw mulch treatments (Heilman et al., 1982; Allen et al., 1198; Allen et al., 2003). Statistically significant differences in soil moisture were observed between 30 and 60 days after DAS. In contrast, during the initial and late growth stages, the crop's water requirement was lower, leading to no significant differences in soil moisture among the various mulching treatments. The results of this study demonstrated that rice straw residues mulching can reduce evaporation and improve soil water retention. Previous studies also confirmed that the application of plant residues mulch increased soil moisture content (Demo & Asefa Bogale, 2024; Teame et al., 2017; Yang et al., 2018).

Table 2. Soil moisture under applied saline water irrigation and straw mulch rates at the different growing stages of beetroot

Factors		Soil moisture content (%)						
		0 DAS	15 DAS	30 DAS	45 DAS	60 DAS	75 DAS	90 DAS
Salinity (S)	S1	22.1	32.6	25.5^{b}	26.4	23.0^{c}	30.7^{b}	30.11
	S2	22.7	32.4	27.2^{ab}	26.2	27.5^{b}	28.7^{b}	27.95
	S3	22.1	32.1	28.8^{a}	29.2	34.7^{a}	31.0^{a}	31.04
Mulching (M)	M1	22.0	32.9	26.3	24.5^{b}	26.2^{b}	32.0	28.71
	M2	22.3	31.7	27.7	25.0^{b}	27.7^{ab}	31.6	29.72
	M3	22.8	33.0	26.7	27.4^{ab}	30.7^{a}	33.0	30.73
	M4	21.7	31.8	27.9	32.1^{a}	28.9^{ab}	32.5	30.63
S		ns	ns	**	ns	**	**	ns
M		ns	ns	ns	*	**	ns	ns
S × M		ns	**	ns	ns	**	ns	ns

ns: p>0.05; * p<0.05; ** p<0.01; In the same column, means followed by the different letters (a, b) are significantly different at 5% by Tukey's test.

3.2 Soil electrical conductivity

The effects of saline water irrigation and straw mulch rates on soil ECe are shown in Table 3. The results showed that soil ECe tended to increase over the beetroot growing time, especially under saline water irrigation (S2 and S3). Generally, irrigating saline water at S2 and S3 levels resulted in significantly higher soil ECe than the treatment applied fresh water at 15, 45, 60, 75 and 90 DAS (p<0.05). Previous studies also indicated that applying saline irrigation increased soil ECe and reduced crop yields compared to the treatment without applied saline irrigation (Han et al., 2024; Nagaz et al., 2012; Wang et al., 2022).

Rice straw mulching at a rate of 3.5–10 tons ha^{-1} did not significantly affect soil ECe at 0, 15, and 30 DAS (p>0.05). However, a significant difference of soil ECe was found in the mulching treatments at 45, 60, 75, and 90 DAS.–At 90 DAS, the results indicated that soil ECe in the M3 and M4 treatments was significantly lower than in the treatment without mulching straw. Moreover, a significant interaction between saline irrigation and straw mulch was observed at 45, 60, 75, and 90 DAS (p < 0.05). These results confirmed that applying straw mulch can effectively mitigate salt accumulation in the soil. (Chen et al., 2021; El-Beltagi et al., 2022; Haque et al., 2018).

Table 3. Soil ECe under applied saline irrigation and straw mulch rates at the different growing stages of beetroot

Factors		ECe (mS cm^{-1})						
		0 DAS	15 DAS	30 DAS	45 DAS	60 DAS	75 DAS	90 DAS
Salinity (S)	S1	0.94	1.29^{ab}	2.06	2.06^{b}	2.78^{b}	2.89^{c}	3.30^{c}
	S2	0.90	1.17^{b}	2.70	4.70^{a}	5.64^{a}	7.41^{b}	9.02^{b}
	S3	1.04	2.03^{a}	2.47	4.65^{a}	5.42^{a}	8.96^{a}	9.77^{a}
Mulching (M)	M1	0.77	1.29	2.41	4.18^{a}	4.81^{a}	6.54^{a}	8.42^{a}
	M2	0.81	1.77	2.45	4.02^{a}	4.47^{ab}	6.94^{a}	7.70^{ab}
	M3	0.80	1.18	2.23	3.53^{b}	4.19^{b}	6.68^{a}	7.19^{b}
	M4	0.81	1.37	2.57	4.35^{a}	4.98^{a}	5.53^{b}	6.13^{c}
S		ns	*	ns	**	**	**	**
M		ns	ns	ns	**	**	**	**
S × M		ns	ns	ns	**	*	**	**

ns: p>0.05; * p<0.05; ** p<0.01; In the same column, means followed by the different letters (a, b) are significantly different at 5% by Tukey's test.

3.3 Exchangeable Na, ESP, SAR and K+/Na+ ratio

At the harvest stage, the saline irrigation and straw mulching treatments had significant impact on exchangeable Na^+, ESP, SAR and K^+/Na^+ ratio (Table 4). The results showed that increasing saline irrigation levels from 2–4‰ resulted in a significant increase exchangeable Na^+, ESP, and SAR compared to the treatment used freshwater for irrigation ($p<0.05$). In contrast, K^+/Na^+ ratio in treatment S1 was significantly higher than that in treatments S2 and S3 ($p<0.05$).

Similarly, the application of rice straw mulching also had a positively significant impacts on exchangeable Na^+, ESP, and SAR. The results indicated that applying straw mulch at 3.5–10 tons ha^{-1} significantly decreased exchangeable Na^+, ESP, and SAR parameters as compared to the treatment without straw mulching. In additions, the application of 10 tons ha^{-1} (M4) straw mulching resulted in significantly higher K^+/Na^+ ratio as compared with the treatment with no applied rice straw mulch. The mechanisms for reducing salt accumulation via straw mulching under saline irrigation included the inhibition of upward salt movement by limiting soil water evaporation, and the enhancement of salt leaching by improving physical soil properties such as bulk density (Huang et al., 2019; Samui et al., 2020; Zhang et al., 2022).

Table 4. Exchangeable Na^+, ESP, SAR and K^+/Na^+ ratio under applied saline irrigation and straw mulch rates at the harvest stage of beetroot

Factors		Exchangeable Na^+ (cmol kg^{-1})	ESP (%)	SAR	K^+/Na^+ ratio
Salinity (S)	S1	0.80^{c}	3.41^{c}	2.36^{c}	4.80^{a}
	S2	2.37^{b}	12.2^{b}	9.43^{b}	0.92^{b}
	S3	3.26^{a}	23.0^{a}	21.7^{a}	1.42^{b}
Mulching (M)	M1	2.53^{a}	18.5^{a}	18.2^{a}	1.23^{b}
	M2	2.10^{ab}	11.8^{b}	9.44^{b}	1.91^{ab}
	M3	2.08^{b}	11.1^{b}	8.84^{b}	1.92^{ab}
	M4	1.88^{b}	10.2^{b}	8.09^{b}	2.76^{a}
S		**	**	**	**
M		**	**	**	*
S × M		**	**	**	ns

ns: p>0.05; * p<0.05; ** p<0.01; In the same column, means followed by the different letters (a, b) are significantly different at 5% by Tukey's test.

3.4 Leaching requirement (LR), total annual crop water demand (ET) and water use efficiency (WUE)

The effects of different straw mulching rates on leaching requirement (LR), total evapotranspiration (ET) and water use efficiency (WUE) under varying saline irrigation levels were statistically significant ($p < 0.001$) (Table 5).
The LR values significantly increased in the S2 and S3 treatments as compared to S1 under saline irrigation conditions. This indicated that under higher salinity levels, crops require greater amounts of water to leach accumulated salts from the root zone, thereby preventing salinity from exceeding harmful thresholds. These findings are consistent with the recommendations of FAO (Ayers & Westcot, 1985), which emphasize that maintaining an appropriate LR is essential to mitigate the risk of salt accumulation in agricultural soils. Meanwhile, ET values declined as salinity levels increased, suggesting that higher osmotic stress reduced the plant's ability to absorb and transpire water. The decreased water demand reflects a physiological response of plants to salinity stress, which limits fresh biomass accumulation and inhibits growth (Munns, 2002; Jabeen & Ahmad, 2012). Addition,_ increasing WUE in the salinity conditions is the strategy employed by moderate tolerance crops to mitigate high salt concentrations in the crop cultivation (Oliveira et al., 2022; Ribeiro et al., 2024). In this study, the application of freshwater increased WUE up to 43.6% than the saline irrigation. Recent studies also reported that the WUE increased in the treatments which were reduced salt water irrigation levels (Ribeiro et al., 2024; Sousa et al., 2022).
Under saline conditions, straw mulching not only reduces ET but also helps maintain LR at an effective level without requiring additional irrigation water. The experimental results suggested that straw mulching is an effective agronomic practice for improving irrigation WUE and enhancing salt control in cultivated soils. The combination of straw mulching and proper adjustment of LR according to salinity levels presents a promising strategy for increasing crop productivity in salt-affected areas while ensuring sustainable water resource use. According to Li et al. (2018), the use of various mulching materials significantly increased soil moisture content compared to non-mulched treatments. Specifically, straw mulching improved soil moisture by 62–66% relative to bare soil. Similarly, Wang et al. (2018) reported that straw mulch reduced daily average evapotranspiration by 25%–41% in wheat as compared to the treatments without mulch.

Table 5. LR, ET and WUE under applied saline water irrigation and straw mulch rates at the harvest stages of beetroot

Factors		LR	ET	WUE (g L^{-1})
Salinity (S)	S1	0.01^{c}	9.26^{a}	6.06^{a}
	S2	0.08^{b}	8.65^{b}	5.88^{b}
	S3	0.16^{a}	7.91^{c}	4.22^{c}
Mulching (M)	M1	0.06^{c}	8.81^{a}	5.33^{ab}
	M2	0.07^{bc}	8.66^{b}	5.43^{ab}
	M3	0.8^{b}	8.59^{b}	5.50^{a}
	M4	0.10^{a}	8.37^{c}	5.28^{b}
S		***	***	***
M		***	***	**
S × M		***	***	ns

ns: $p>0.05$; * $p<0.05$; ** $p<0.01$; In the same column, means followed by the different letters (a, b) are significantly different at 5% by Tukey's test.

3.5 The beetroot growth parameters and yield

The results presented in Table 6 demonstrate the significant effects of salinity in irrigation water ($p < 0.001$) on all measured agronomic parameters, including plant height, leaf area, chlorophyll content (SPAD), fresh biomass, root yield, and Brix value. Increasing saline levels in irrigation from S1 to S3 led to a significant reduction in beetroot growth and productivity across all treatments.
Straw mulching significantly influenced leaf development, fresh biomass accumulation, and root yield under saline conditions. Treatments with moderate mulching rates (S2 and S3) produced higher values

for leaf area, chlorophyll content, Brix, and yield as compared to both the no-mulch control (S1) and the highest mulching rate (S4), with differences being statistically significant ($p < 0.05$).

Notably, leaf area, fresh biomass, and root yield in M3 rate of straw mulch were highest as compared to the other mulching treatments. There were no significant differences in plant height, SPAD values, or Brix among the mulching treatments, indicating that straw mulching primarily affected yield through improvements in leaf area and biomass accumulation rather than through changes in physiological parameters.

The application of straw mulch did not significantly affect plant height and SPAD at the harvest stage. However, leaf area and fresh biomass of M3 treatment were significantly higher than the control treatment (M1). Besides, beetroot yield in the treatment applied 7.0 tons straw mulching ha^{-1} significantly higher than the treatment applied 10 tons straw mulching ha^{-1} ($p<0.05$). Previous studies also reported that beetroot yield when being mulched was significantly higher than the treatment without organic mulching (Acharyya et al., 2020; Yordanova & Gerasimova, 2016).

Table 6. Beetroot growth parameters, yield under applied saline water irrigation and straw mulch rates at the harvest stages of beetroot

Factors		**Plant height (cm)**	**Leaf area (cm^2)**	**SPAD**	**Fresh biomass (g pot^{-1})**	**Yield (g pot^{-1})**
Salinity (S)	S1	23.4^{a}	165^{a}	54.6^{a}	65.3^{a}	56.9^{a}
	S2	22.8^{a}	132^{b}	52.4^{ab}	63.6^{b}	55.1^{b}
	S3	20.9^{b}	96.1^{c}	49.4^{b}	48.1^{c}	39.6^{c}
Mulching (M)	M1	22.0	119^{b}	50.5	57.4^{b}	50.4^{ab}
	M2	23.1	140^{a}	52.9	59.4^{ab}	51.0^{ab}
	M3	22.3	138^{a}	53.5	59.9^{a}	51.4^{a}
	M4	22.1	128^{ab}	51.6	57.8^{b}	49.4^{b}
S		***	***	**	***	***
M		ns	*	ns	*	*
S × M		*	ns	ns	ns	ns

ns: $p>0.05$; * $p<0.05$; ** $p<0.01$; In the same column, means followed by the different letters (a, b) are significantly different at 5% by Tukey's test

4. CONCLUSION

In this study, we investigated the influences of saline water irrigation levels and rice straw mulching rates on soil characteristics, beetroot growth and yield, and WUE under greenhouse conditions. This study demonstrated that rice straw mulching can effectively improve soil moisture content, reduce salt accumulation, and enhance the growth and productivity of beetroot under saline irrigation of 0, 2, and 4‰ levels. The findings highlighted that the medium mulching (7.0 tons ha^{-1}) was the most effective rate, which can maintain soil water retention, reduce soil ECe, ESP, SAR. In addition, the application of rice straw mulch significantly improved fresh biomass, beetroot productivity, and WUE in the saline conditions.

Conflict Of Interest

All authors declare that there are no conflicts of interest regarding the publication of this paper.

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REFERENCES

1. Acharyya, P., Banerjee, A., Mukherjee, D., Mandal, J., & Sahoo, B. (2020). Impact of different types of organic mulch on growth, yield, soil dynamics and weed infestation in beetroot (Beta vulgaris L. cv. Detroit Dark Red) plots. *Int. J. Curr. Microbiol. App. Sci*, *9*(7), 1419-1427.

2. Allen, R. G., Morse, A., & Tasumi, M. (2003). Application of SEBAL for western US water rights regulation and planning. In *Proc. ICID Int. Workshop on Remote Sensing*.
3. Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. *Fao, Rome*, *300*(9), D05109.
4. Ayers, R.S. and Westcot, D.W. (1985). Water quality for agriculture. FAO Irrigation and D*rainage Paper 29 Food and Agric.* Organization (FAO) of the United Nation, Rome, Italy
5. Behzadnejad, J., Tahmasebi-Sarvestani, Z., Aein, A., & Mokhtassi-Bidgoli, A. (2020). Wheat straw mulching helps improve yield in sesame (Sesamum indicum L.) under drought stress. *International Journal of Plant Production, 14*(2), 389-400.
6. Bremner, J. M., and Keeney, D. R. (1966). Determination and isotope-ratio analysis of different forms of nitrogen in soils: 3. Exchangeable ammonium, nitrate, and nitrite by extraction-distillation methods. Soil Science Society of America Journal, 30(5), 577-582.
7. Jensen, M.E., 1983. Design and Operation of Farm Irrigation Systems. *ASAE, Michigan, USA*, pp. p. 82
8. Chang, F.-d., & Zhang, H.-y. (2023). Maize straw application as an interlayer improves organic carbon and total nitrogen concentrations in the soil profile: A four-year experiment in a saline soil. *Journal of Integrative Agriculture, 22*(6), 1870-1882.
9. Chen, N., Li, X., Šimůnek, J., Shi, H., Hu, Q., & Zhang, Y. (2021). Evaluating the effects of biodegradable and plastic film mulching on soil temperature in a drip-irrigated field. *Soil and Tillage Research, 213*, 105116.
10. Choudhary, V., & Kumar, P. S. (2019). Weed suppression, nutrient leaching, water use and yield of turmeric (Curcuma longa L.) under different land configurations and mulches. *Journal of Cleaner Production, 210*, 795-803.
11. Demo, A. H., & Asefa Bogale, G. (2024). Enhancing crop yield and conserving soil moisture through mulching practices in dryland agriculture. *Frontiers in Agronomy, 6*, 1361697.
12. Dong, Q. g., Yang, Y., Yu, K., & Feng, H. (2018). Effects of straw mulching and plastic film mulching on improving soil organic carbon and nitrogen fractions, crop yield and water use efficiency in the Loess Plateau, China. *Agricultural Water Management, 201*, 133-143.
13. El-Beltagi, H. S., Basit, A., Mohamed, H. I., Ali, I., Ullah, S., Kamel, E. A., Shalaby, T. A., Ramadan, K. M., Alkhateeb, A. A., & Ghazzawy, H. S. (2022). Mulching as a sustainable water and soil saving practice in agriculture: A review. *Agronomy, 12*(8), 1881.
14. Farzi, R., Gholami, M., Baninasab, B., & Gheysari, M. (2017). Evaluation of different mulch materials for reducing soil surface evaporation in semi-arid region. *Soil Use and Management, 33*(1), 120-128.
15. Feddesl, R. A., & Lenselink, K. J. (1985). Evapotranspiration. *Dev. Water Sci.*, *21*, 223-291.
16. Gillman, G.P. (1979). A proposed method for the measurement of exchange properties of highly weathered soils. *Aust J Soil Res 17*, 129-139
17. Gadelha, B. B., Freire, M. H. d. C., Sousa, H. C., Costa, F. H., Lessa, C. I., & Sousa, G. G. d. (2021). Growth and yield of beet irrigated with saline water in different types of vegetable mulching. *Revista Brasileira de Engenharia Agrícola e Ambiental, 25*(12), 847-852.
18. Han, X., Li, D., Kang, Y., & Wan, S. (2024). Effect of saline water drip irrigation on tomato yield and quality in semi-humid area and arid area of China. *Irrigation Science, 42*(2), 387-400.
19. Haque, M. A., Jahiruddin, M., & Clarke, D. (2018). Effect of plastic mulch on crop yield and land degradation in south coastal saline soils of Bangladesh. *International soil and water conservation research*, *6*(4), 317-324.
20. Hardie, M., & Doyle, R. (2012). Measuring soil salinity. *Plant salt tolerance: methods and protocols*, 415-425.
21. He, H., Zhou, W., Lü, H., & Liang, B. (2022). Growth, leaf morphological and physiological adaptability of leaf beet (Beta vulgaris var. cicla) to salt stress: A soil culture experiment. *Agronomy, 12*(6), 1393.
22. Heilman, J. L., Heilman, W. E., & Moore, D. G. (1982). Evaluating the crop coefficient using spectral reflectance.
23. Huang, M., Zhang, Z., Zhai, Y., Lu, P., & Zhu, C. (2019). Effect of straw biochar on soil properties and wheat production under saline water irrigation. *Agronomy, 9*(8), 457.
24. Kamphorst, A., and Bolt, G.H., (1978). Saline and sodic soils. In: G.H. Bolt and M.G.M.Bruggen Wert, Eds. Soil chemistry.A. Basic elements. 2nd ed. Elsevier Scientific. *Amsterdam.* Pages 171-191.
25. Kumar, R., Kumar, J., Brar, A., Walia, S., & Gill, B. (2017). Effect of straw mulch and integrated nitrogen management on yield and quality of turmeric under North Indian plains. *Indian Journal of Horticulture, 74*(2), 240-244.
26. Li, S., Li, Y., Lin, H., Feng, H., & Dyck, M. (2018). Effects of different mulching technologies on evapotranspiration and summer maize growth. *Agricultural Water Management, 201*, 309-318.
27. Liang, J., Shi, H., Li, R., Yang, S., Xin, J., & Wang, Z. (2015). Improving effect of mulching methods on moderately saline soil and sunflower yield. *Chinese Journal of Eco-Agriculture, 23*(4), 416-424.
28. Loc, H. H., Van Binh, D., Park, E., Shrestha, S., Dung, T. D., Son, V. H., Truc, N. H. T., Mai, N. P., & Seijger, C. (2021). Intensifying saline water intrusion and drought in the Mekong Delta: From physical evidence to policy outlooks. *Science of the Total Environment, 757*, 143919.
29. Machado, R. M. A., & Serralheiro, R. P. (2017). Soil salinity: effect on vegetable crop growth. Management practices to prevent and mitigate soil salinization. *Horticulturae, 3*(2), 30.
30. Majeed, A., & Muhammad, Z. (2019). Salinity: a major agricultural problem—causes, impacts on crop productivity and management strategies. In *Plant abiotic stress tolerance: Agronomic, molecular and biotechnological approaches* (pp. 83-99). Springer.
31. Marschner, P. (2017). Impact of salinity on respiration and organic matter dynamics in soils is more closely related to osmotic potential than to electrical conductivity. *Pedosphere, 27*(5), 949-956.

32. Memon, M., Zhou, J., Guo, J., Ullah, F., Hassan, M., Ara, S., & Ji, C. (2017). Comprehensive review for the effects of ridge furrow plastic mulching on crop yield and water use efficiency under different crops. *International Agricultural Engineering Journal, 26*(2), 58-67.
33. Mendonça, S. R., Ávila, M. C. R., Vital, R. G., Evangelista, Z. R., de Carvalho Pontes, N., & dos Reis Nascimento, A. (2021). The effect of different mulching on tomato development and yield. *Scientia Horticulturae, 275*, 109657.
34. Morton, L. W., Nguyen, N. K., & Demyan, M. S. (2023). Salinity and acid sulfate soils of the Vietnam Mekong Delta: Agricultural management and adaptation. *Journal of Soil and Water Conservation, 78*(4), 85A-92A.
35. Mupangwa, W., Twomlow, S., & Walker, S. (2012). Reduced tillage, mulching and rotational effects on maize (Zea mays L.), cowpea (Vigna unguiculata (Walp) L.) and sorghum (Sorghum bicolor L.(Moench)) yields under semi-arid conditions. *Field Crops Research, 132*, 139-148.
36. Nagaz, K., Masmoudi, M. M., & Mechlia, N. B. (2012). Impacts of irrigation regimes with saline water on carrot productivity and soil salinity. *Journal of the Saudi Society of Agricultural Sciences, 11*(1), 19-27.
37. Oliveira, F. R. d., Sousa, G. G. d., Sousa, J. T. M. d., Leite, K. N., Guilherme, J. M. d. S., & Nogueira, R. d. S. (2022). Physiological responses of the beet crop under agricultural environment and saline stress. *Revista Ambiente & Água, 17*(6), e2868.
38. Pachepsky, Y., Yakirevich, A., Ponizovsky, A., & Gummatov, N. (2024). The osmotic potential of soil solutions in salt tolerance studies: Following M. Th. van Genuchten's innovation. *Vadose Zone Journal, 23*(4), e20299.
39. Rayment, G., & Higginson, F. R. (1992). *Australian laboratory handbook of soil and water chemical methods*.
40. Rayment, G. E., & Lyons, D. J. (2011). *Soil chemical methods: Australasia* (Vol. 3). CSIRO publishing.
41. Ribeiro, R., Sousa, G., Barbosa, A., Matos, E., Viana, T., Leite, K., Costa, F., Cambissa, P., Sales, J., & Santos, S. (2024). The impact of saline and water stress on the agronomic performance of beet crops. *Brazilian Journal of Biology, 84*, e276278.
42. Samui, I., Skalicky, M., Sarkar, S., Brahmachari, K., Sau, S., Ray, K., Hossain, A., Ghosh, A., Nanda, M. K., & Bell, R. W. (2020). Yield response, nutritional quality and water productivity of tomato (Solanum lycopersicum L.) are influenced by drip irrigation and straw mulch in the coastal saline ecosystem of Ganges delta, India. *Sustainability, 12*(17), 6779.
43. Sharma, P., Murphy, S., Kikkert, J. R., & Pethybridge, S. J. (2024). Susceptibility of table beet cultivars to foliar diseases in New York. *Plant Health Progress, 25*(4), 399-409.
44. Sheldon, A. R., Dalal, R. C., Kirchhof, G., Kopittke, P. M., & Menzies, N. W. (2017). The effect of salinity on plant-available water. *Plant and Soil, 418*(1), 477-491.
45. Slavich, P.G., & Petterson, G.H. (1993). Estimating the electrical conductivity of saturated paste extracts from 1:5 soil, water suspensions and texture. *Soil Research, 31(1)*, 73-81.
46. Song, Y., Gao, M., & Li, Z. (2025). Impacts of straw return methods on crop yield, soil organic matter, and salinity in saline-alkali land in North China. *Field Crops Research, 322*, 109752.
47. Sousa, H. C., Sousa, G. G. d., Cambissa, P. B., Lessa, C. I., Goes, G. F., da Silva, F. D., Abreu, F. d. S., & Viana, T. V. d. A. (2022). Gas exchange and growth of zucchini crop subjected to salt and water stress. *Revista Brasileira de Engenharia Agrícola e Ambiental, 26*, 815-822.
48. Teame, G., Tsegay, A., & Abrha, B. (2017). Effect of organic mulching on soil moisture, yield, and yield contributing components of sesame (Sesamum indicum L.). *International journal of agronomy, 2017*(1), 4767509.
49. Tran, B. T. N., Nguyen, U. H., Deolu-Ajayi, A. O., Nguyen, P. M., & Siegmund-Schultze, M. (2025). The effect of brackish water irrigation on crops cultivated in the Vietnamese Mekong Delta. *Australian Journal of Crop Science, 19*(1), 99-S93.
50. Wang, D., Feng, H., Liu, X., Li, Y., Zhou, L., Zhang, A., & Dyck, M. (2018). Effects of gravel mulching on yield and multilevel water use efficiency of wheat-maize cropping system in semi-arid region of Northwest China. *Field Crops Research, 218*, 201-212.
51. Wang, H., Feng, D., Zhang, A., Zheng, C., Li, K., Ning, S., Zhang, J., & Sun, C. (2022). Effects of saline water mulched drip irrigation on cotton yield and soil quality in the North China Plain. *Agricultural Water Management, 262*, 107405.
52. Wang, R., Cao, H., Kang, S., Du, T., Tong, L., Kang, J., Gao, J., & Ding, R. (2025). Agronomic measures improve crop yield and water and nitrogen use efficiency under brackish water irrigation: A global meta-analysis. *Agricultural Systems, 226*, 104304.
53. Wang, S., Ding, L., Liu, W., Wang, J., & Qian, Y. (2021). Effect of plastic mulching on soil carbon and nitrogen cycling-related bacterial community structure and function in a dryland spring maize field. *Agriculture, 11*(11), 1040.
54. Weil, R., & Brady, N. C. (2017). *The nature and properties of soils*. Pearson Publisher. 1104 pages.
55. Yang, Y., Ding, J., Zhang, Y., Wu, J., Zhang, J., Pan, X., Gao, C., Wang, Y., & He, F. (2018). Effects of tillage and mulching measures on soil moisture and temperature, photosynthetic characteristics and yield of winter wheat. *Agricultural Water Management, 201*, 299-308.
56. Yolcu, S., Alavilli, H., Ganesh, P., Asif, M., Kumar, M., & Song, K. (2021). An insight into the abiotic stress responses of cultivated beets (Beta vulgaris L.). *Plants, 11*(1), 12.
57. Yordanova, M., & Gerasimova, N. (2016). Effect of mulching on weed infestation and yield of beetroot (Beta vulgaris ssp. rapaceae atrorubra Krass). *Organic agriculture, 6*(2), 133-138.
58. Zhang, P., Wei, T., Han, Q., Ren, X., & Jia, Z. (2020). Effects of different film mulching methods on soil water productivity and maize yield in a semiarid area of China. *Agricultural Water Management, 241*, 106382.
59. Zhang, Q. T., Ahmed, O. A. B., Inoue, M., Saxena, M. C., Inosako, K., & Kondo, K. (2009). Effects of mulching on evapotranspiration, yield and water use efficiency of Swiss chard (Beta vulgaris L. var. flavescens) irrigated with diluted seawater. *J. Food Agric. Environ, 7*(3-4), 650-654.

60. Zhang, R., Wang, Y., Zhang, X., Luo, F., Wei, X., Li, M., Li, H., Zhao, X., Duan, Z., & Song, X. (2025). Mulching increases soil organic carbon via plant inputs and its microbial transformation. *Biology and Fertility of Soils*, 1-16.
61. Zhang, Z., Zhang, Z., Feng, G., Lu, P., Huang, M., & Zhao, X. (2022). Biochar amendment combined with straw mulching increases winter wheat yield by optimizing soil water-salt condition under saline irrigation. *Agriculture, 12*(10), 1681.
62. Zhou, Z., Zeng, X., Chen, K., Li, Z., Guo, S., Shangguan, Y., Yu, H., Tu, S., & Qin, Y. (2019). Long-term straw mulch effects on crop yields and soil organic carbon fractions at different depths under a no-till system on the Chengdu Plain, China. *Journal of Soils and Sediments, 19*(5), 2143-2152.
63. Zörb, C., Geilfus, C. M., & Dietz, K. J. (2019). Salinity and crop yield. *Plant biology, 21*, 31-38.