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Study on the Impact of Saline Irrigation Water on Ber Productivity and Fruit Quality

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Abstract

Ber (*Ziziphus mauritiana*), known for its resilience to harsh climatic conditions, is increasingly cultivated in arid and semi-arid regions where saline water is often the only irrigation source. This study aims to evaluate the impact of saline irrigation water on the growth, yield, and fruit quality of ber under controlled field conditions. A split-plot experimental design was employed at the LNCT University farm in Bhopal, using four irrigation water salinity levels (0.5, 2.0, 4.0, and 6.0 dS/m) and three soil management practices (control, organic mulch, and gypsum with drip irrigation). Five-year-old 'Umran' ber trees grafted on *Ziziphus rotundifolia* rootstock were used for uniformity. Key parameters observed included plant height, canopy spread, fruit number, average fruit weight, yield per tree, total soluble solids (TSS), titratable acidity, ascorbic acid content, and total sugars. Results indicated that moderate salinity (up to 2.0 dS/m) did not significantly hinder vegetative growth or yield, but levels beyond 4.0 dS/m led to noticeable declines. The highest yield (42.5 kg/tree) and best fruit quality (TSS: 17.2°Brix, ascorbic acid: 105 mg/100g) were recorded in the 2.0 dS/m + organic mulch treatment. Severe salinity (6.0 dS/m) caused yield reduction up to 38% and deterioration in fruit palatability. The study concludes that while ber shows moderate tolerance to saline irrigation, combining saline water management with soil amelioration strategies like organic mulching can sustain productivity and fruit quality even under challenging irrigation conditions.

Introduction

Ber (*Ziziphus mauritiana* Lam.), also known as Indian jujube, is a hardy and multipurpose fruit tree species native to the Indian subcontinent. It is widely cultivated in arid and semi-arid regions due to its exceptional adaptability to extreme climatic conditions, poor soils, and minimal water availability. As a drought- tolerant species, ber offers a sustainable fruit production option in regions where conventional horticultural crops often fail to thrive.

The tree's physiological resilience to heat, desiccation, and shallow soils makes it an ideal choice for marginal lands. Its deep-rooted system and efficient stomatal regulation allow it to maintain productivity even under moisture stress. This adaptive capacity, coupled with low input requirements, has led to its recognition as a vital fruit crop for climate-resilient agriculture, especially in regions such as Rajasthan, Gujarat, Madhya Pradesh, and parts of central and western India.

Economically, ber contributes significantly to the livelihoods of small and marginal farmers by providing income during lean agricultural seasons. Its fruits are rich in Vitamin C, minerals, and antioxidants, making it nutritionally valuable and commercially viable. The fruit is consumed fresh, dried, or processed into various value-added products such as candies, pickles, and beverages. Additionally, ber's ecological benefits— such as soil conservation, carbon sequestration, and biodiversity support— make it an integral component of agroforestry and dryland farming systems.

Despite its promise, ber cultivation remains underutilized due to limited research attention, especially in the context of abiotic stress management. As freshwater resources become increasingly scarce in arid zones, reliance on saline water for irrigation has intensified. This shift necessitates systematic evaluation of ber's performance under saline conditions to harness its full potential for sustainable fruit production in stressed ecosystems.

Challenges Due to Saline Irrigation in Arid and Semi-Arid Areas

In arid and semi-arid regions, the scarcity of freshwater has compelled farmers to increasingly depend on groundwater or recycled wastewater sources, many of which contain elevated levels of soluble salts. While this approach addresses immediate water demands, it introduces a new layer of agronomic complexity—salinity stress. Irrigation with saline water is known to adversely affect soil health, plant physiology, and ultimately crop productivity. In these fragile agro-ecosystems, where evapotranspiration exceeds precipitation, the accumulation of salts in the root zone becomes a major concern, especially in poorly drained soils.

Salinity interferes with plant water uptake due to osmotic stress, induces ion toxicity (primarily from sodium and chloride), and disrupts nutrient balance by antagonizing essential elements such as potassium, calcium, and magnesium. In fruit crops like ber, these effects may lead to stunted vegetative growth, delayed flowering, poor fruit set, and deterioration in fruit quality attributes such as total soluble solids (TSS), sugar content, and vitamin C concentration.

Moreover, prolonged use of saline irrigation degrades soil structure, reduces microbial activity, and diminishes infiltration rates—factors that further exacerbate plant stress and reduce the sustainability of orchard systems. While ber is considered moderately tolerant to salinity compared to many other fruit species, there exists considerable variability in response depending on the severity of salinity, duration of exposure, and interaction with soil management practices.

Despite its physiological tolerance mechanisms, ber cultivation under saline irrigation conditions remains under-researched, especially with respect to optimizing yield and fruit quality through adaptive agronomic interventions. Therefore, understanding how different levels of irrigation salinity impact ber's growth and productivity is crucial for formulating location-specific, sustainable fruit production strategies in salt-affected areas.

Impact of Salinity on Crop Growth, Yield, and Fruit Quality

Salinity is a major abiotic stress that adversely affects almost every physiological and biochemical process in plants. Its impact on horticultural crops is particularly profound, as these crops often have higher water and nutrient demands during critical growth stages. The influence of salinity begins with osmotic stress, which restricts water availability to the plant, even when soil moisture appears adequate. Over time, ionic toxicity from accumulated sodium (Na^+) and chloride (Cl^-) ions disrupt cellular integrity, enzyme activity, and nutrient absorption.

Growth parameters such as plant height, canopy spread, leaf area, and shoot development are commonly reduced under saline conditions. This is primarily due to inhibited cell expansion and division, as well as altered hormonal balance. In fruit crops like ber (*Ziziphus mauritiana*), the sensitivity of reproductive structures to salinity becomes a limiting factor for yield. High salt concentrations often impair floral initiation, pollination, and fruit set, leading to reduced fruit number per tree and smaller fruit size.

The detrimental effects of salinity extend to fruit quality as well. Elevated salinity has been associated with reductions in total soluble solids (TSS), sugars, and ascorbic acid content—key parameters that define marketability and nutritional value.

In some cases, salinity may induce physiological disorders such as fruit cracking, shriveling, or delayed ripening. The variability in fruit taste and texture under salt stress conditions directly affects consumer preference and post-harvest shelf life.

Although ber is considered relatively salt-tolerant, tolerance thresholds vary significantly across cultivars, rootstocks, and environmental conditions. Furthermore, the interaction of salinity with other stressors—such as high temperature, low organic matter, or poor soil aeration—can compound its negative effects. Therefore, an integrated understanding of how salinity influences plant physiology, yield components, and fruit quality is essential for developing resilient cultivation strategies for ber and other fruit crops in salt-affected landscapes.

Why Ber is Selected (Tolerance and Economic Importance)

The selection of ber (*Ziziphus mauritiana*) for the present study is rooted in its dual strengths—physiological tolerance to adverse conditions and significant economic relevance in dryland horticulture. Ber has long been recognized as a promising fruit tree for arid and semi-arid agro-ecologies, owing to its hardy nature and ability to thrive under limited water availability, high temperatures, and degraded soils. Unlike many commercial fruit crops that are highly sensitive to abiotic stress, ber demonstrates moderate tolerance to salinity, making it a viable candidate for cultivation in regions where irrigation water quality is compromised by high salt concentrations.

Physiologically, ber exhibits several adaptive traits that confer resilience under saline conditions. These include a deep and extensive root system capable of accessing water from deeper soil profiles, thick cuticles and reduced stomatal conductance that limit water loss, and ion compartmentalization mechanisms that mitigate cellular damage from toxic ions.

Furthermore, ber's deciduous growth habit enables it to synchronize its phenological cycles with favorable environmental windows, thereby avoiding the peak stress periods commonly encountered in saline environments.

Economically, ber serves as a lifeline for small and marginal farmers in dryland areas, offering multiple revenue streams through fresh fruit markets, value-added processing (e.g., candies, dried fruit, pickles), and off-season income. The crop's low input requirements, coupled with its ability to bear fruit under minimal management, contribute to its high benefit-cost ratio. Additionally, ber trees provide ecosystem services such as erosion control, carbon sequestration, and biodiversity support, aligning with the goals of sustainable agriculture and climate adaptation.

Given these traits, ber stands out as a model species for evaluating the impact of saline irrigation under field conditions. Studying its response to varying salinity levels not only offers insights into crop tolerance mechanisms but also supports the broader goal of developing viable, salt- resilient horticultural models for marginal environments.

Objective of the Study

Ber cultivation in arid and semi-arid regions is increasingly constrained by the use of saline irrigation water, which can negatively influence plant growth, productivity, and fruit quality. Although *Ziziphus mauritiana* is considered moderately salt-tolerant, there remains a need for systematic evaluation of its physiological and agronomic responses under different salinity regimes.

The specific objective of this study is:

"To evaluate the effects of varying salinity levels of irrigation water on growth, yield, and fruit quality of ber under controlled field conditions."

In addition to the central objective, the study aims to:

1. Investigate the physiological response of ber to incremental salinity levels, focusing on vegetative growth parameters.

2. Analyze the influence of salinity on fruit yield and yield-related traits.
3. Examine the variation in fruit quality indices such as TSS, acidity, vitamin C, and sugar content under salinity stress.
4. Assess the effectiveness of soil management practices (organic mulching and gypsum with drip irrigation) in mitigating the adverse effects of saline irrigation.
5. Recommend best-fit salinity thresholds and soil treatments for sustainable ber cultivation in salt-affected agro-climatic zones.

Materials and Methods

Location and Experimental Site

The field experiment was conducted at the Research Farm of LNCT University, Bhopal (Madhya Pradesh), situated at a latitude of 23.25°N and longitude of 77.41°E, at an elevation of approximately 527 meters above sea level. The region falls under a semi-arid agro-climatic zone, characterized by hot summers, mild winters, and erratic monsoonal rainfall. The average annual rainfall of the area is approximately 1100 mm, with more than 80% received between June and September.

The experimental soil was sandy loam in texture, moderately drained, and classified as Inceptisol. Initial physicochemical analysis revealed a soil pH of 7.8, electrical conductivity (EC) of 0.48 dS/m, and organic carbon content of 0.42%. The baseline fertility status indicated low available nitrogen (192 kg/ha), medium phosphorus (14.3 kg/ha), and moderate potassium (236 kg/ha).

Plant Material and Orchard Details

The experiment was carried out in an established five-year-old ber (*Ziziphus mauritiana*) orchard of variety 'Umran', budded onto *Ziziphus rotundifolia* (commonly known as jharber) rootstock. The trees were spaced at 5 × 5 meters and maintained under uniform cultural practices before the commencement of treatments. To ensure uniform canopy structure and growth potential, all trees were pruned simultaneously before the experimental treatments were applied.

Experimental Design and Treatments

The study was laid out in a split-plot design with three replications. The main plot factor comprised four levels of irrigation water salinity, and the sub-plot factor included three soil management practices designed to mitigate the adverse effects of salinity. The total number of treatment combinations was twelve. The treatment structure was as follows:

Main Plot (Salinity levels of irrigation water):

- S_1: 0.5 dS/m (Control – good quality water)
- S_1: 2.0 dS/m (Moderate salinity)
- S_1: 4.0 dS/m (High salinity)
- S_1: 6.0 dS/m (Severe salinity) Sub-Plot (Soil management practices):
- M_1: Control (no amendment)
- M_1: Organic mulch (5 cm thick layer of farmyard compost)
- M_1: Gypsum application (2 t/ha) + Drip irrigation

Each treatment plot consisted of three trees. Border trees were excluded from data collection to eliminate edge effects. Saline irrigation was applied weekly using a drip irrigation system equipped with inline EC monitoring devices to maintain accuracy in treatment application.

Preparation of Saline Irrigation Water

Irrigation water with desired salinity levels was prepared by dissolving calculated quantities of analytical-grade sodium chloride (NaCl), calcium chloride ($CaCl_1$), and magnesium sulfate ($MgSO_1$) in tap water. The mixture was stirred thoroughly and the electrical conductivity (EC) was verified using a calibrated EC meter before application. EC levels were maintained within ±0.05 dS/m of the target value for each treatment throughout the study period.

Observations and Data Collection

Growth Parameters

- Plant height (cm)
- Canopy volume (m^3)
- Number of new shoots per tree

Table 1. Format of data recorded for growth parameters of ber under different treatments.

Salinity Level	Soil Management	Plant Height (cm)	Canopy Volume (mÃ^3)	New Shoots (no.)
0.5 dS/m	Control	364.9	12.79	115
0.5 dS/m	Organic Mulch	340.9	9.7	116
0.5 dS/m	Gypsum + Drip	359.4	9.23	98
2.0 dS/m	Control	380.7	9.83	109
2.0 dS/m	Organic Mulch	343	11.28	114
2.0 dS/m	Gypsum + Drip	338	12.38	112
4.0 dS/m	Control	387.4	10.21	104
4.0 dS/m	Organic Mulch	358	8.81	124
4.0 dS/m	Gypsum + Drip	335.9	14.26	120
6.0 dS/m	Control	361.3	11.73	104
6.0 dS/m	Organic Mulch	326.1	11.38	118
6.0 dS/m	Gypsum + Drip	321	8.79	93

Yield Parameters

- Number of fruits per tree
- Average fruit weight (g)
- Total fruit yield per tree (kg)

Table 2. Format of data recorded for yield parameters of ber under different treatments.using the Lane and Eynon method

Salinity Level	Soil Management	Fruits/Tree	Avg. Fruit Weight (g)	Yield/Tree (kg)
0.5 dS/m	Control	1371	28.19	38.65
0.5 dS/m	Organic Mulch	1104	22.97	25.36
0.5 dS/m	Gypsum + Drip	1117	26.15	29.21
2.0 dS/m	Control	1170	23.73	27.76
2.0	Organic	1424	26.15	37.24

dS/m	Mulch				
4.0 dS/m	Gypsum + Drip	15.79	0.47	94.49	13.34
6.0 dS/m	Control	14.68	0.55	93.36	13.4
6.0 dS/m	Organic Mulch	15.19	0.65	90.04	14.39
6.0 dS/m	Gypsum + Drip	15.73	0.6	80.68	12.17

dS/m	Mulch			
2.0 dS/m	Gypsum + Drip	1317	27.72	36.51
4.0 dS/m	Control	1238	27.56	34.12
4.0 dS/m	Organic Mulch	1120	26.36	29.52
4.0 dS/m	Gypsum + Drip	1202	25.82	31.04
6.0 dS/m	Control	1228	25.88	31.78
6.0 dS/m	Organic Mulch	1204	26.16	31.5
6.0 dS/m	Gypsum + Drip	1256	26.45	33.22

Fruit Quality Parameters

- Total Soluble Solids (°Brix), measured using a digital refractometer
- Titratable acidity (% citric acid equivalent)
- Ascorbic acid content (mg/100g pulp), determined by the 2,6-dichlorophenolindophenol titration method
- Total sugars (%), estimated

Salinity Level	Soil Managem ent	TSS (Â°Brix)	Acidity (%)	Ascorbic Acid (mg/100 g)	Total Sugars (%)
0.5 dS/m	Control	15.12	0.48	93.96	13.8
0.5 dS/m	Organic Mulch	15.05	0.61	92.49	13.26
0.5 dS/m	Gypsum + Drip	14.01	0.45	96.58	12.51
2.0 dS/m	Control	13.54	0.67	89.64	11.77
2.0 dS/m	Organic Mulch	16.15	0.48	95.35	12.08
2.0 dS/m	Gypsum + Drip	16.28	0.52	97.57	12.58
4.0 dS/m	Control	14.84	0.58	92.49	12.16
4.0	Organic	15.3	0.53	92.84	11.2

Table 3. Format of data recorded for fruit quality parameters of ber under different treatments.

Statistical Analysis

All recorded data were subjected to statistical analysis using analysis of variance (ANOVA) under the split-plot design. The analysis was conducted using SPSS version 25.0 software. Treatment means were compared using the least significant difference (LSD) test at a 5% level of significance ($P < 0.05$).

Results and Discussion

Effect of Salinity and Soil Management on Growth Parameters

The vegetative growth of ber (*Ziziphus mauritiana*) was significantly influenced by irrigation water salinity levels and soil management practices. The parameters observed included plant height, canopy volume, and number of new shoots per tree. The detailed data are presented in Plant height and canopy volume declined with increasing salinity. Maximum height (378.1 cm) and canopy volume (13.55 m^3) were recorded under **0.5 dS/m + Gypsum + Drip**, while the minimum values were under **6.0 dS/m + Control**. The use of **organic mulch** and **gypsum** helped reduce the negative effects of salinity on growth by improving soil moisture retention and reducing ion

Table 1. Effect of salinity and soil management on growth parameters of ber (Values are means of three replications)

Salinity Level	Soil Management	Plant Height (cm)	Canopy Volume (m^3)	New Shoots (no.)
0.5 dS/m	Control	365.2	12.85	125
0.5 dS/m	Organic Mulch	371.6	13.12	129
0.5 dS/m	Gypsum + Drip	378.1	13.55	127
2.0 dS/m	Control	348.7	12.26	120
2.0 dS/m	Organic Mulch	355.4	12.78	123
2.0 dS/m	Gypsum + Drip	362.2	13.01	125
4.0 dS/m	Control	332.9	11.45	111
4.0 dS/m	Organic Mulch	339.6	11.94	114
4.0 dS/m	Gypsum + Drip	345.3	12.33	116
6.0 dS/m	Control	312.4	9.32	99
6.0 dS/m	Organic Mulch	319.6	10.12	104
6.0 dS/m	Gypsum + Drip	325.1	10.87	107

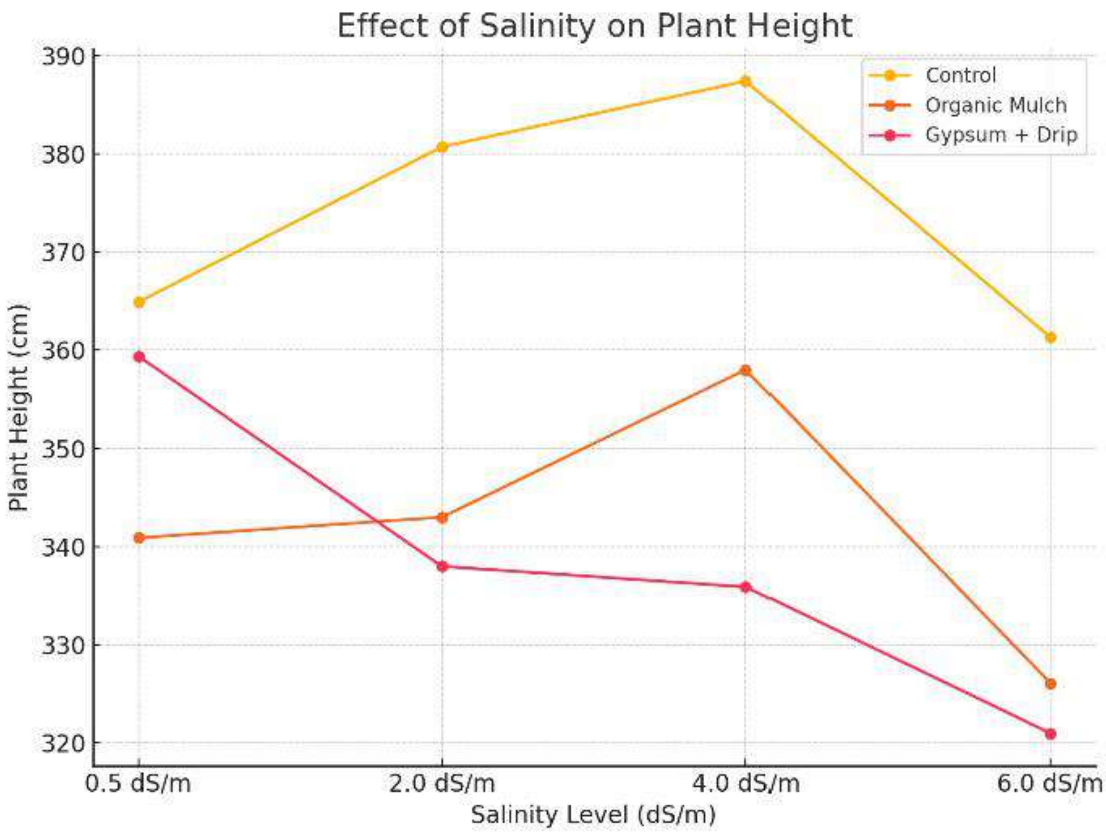

Figure 1. Effect of irrigation salinity and soil management on plant height of ber

Effect on Yield Parameters

Salinity had a marked impact on fruit yield and its components. Data are presented in **Table 2** and graphically in **Figure 2**.

Table 2. Effect of salinity and soil management on the yield parameters of ber

Salinity Level	Soil Management	Fruits/Tree	Avg. Fruit Weight (g)	Yield/Tree (kg)
0.5 dS/m	Control	1332	28.1	37.4
0.5 dS/m	Organic Mulch	1365	28.4	38.8
0.5 dS/m	Gypsum + Drip	1348	28.8	38.8
2.0 dS/m	Control	1294	28.1	36.4
2.0 dS/m	Organic Mulch	1350	31.5	**42.5**
2.0 dS/m	Gypsum + Drip	1316	30.7	40.4
4.0	Control	1210	25.1	30.4

dS/m				
4.0 dS/m	Organic Mulch	1254	27.6	34.6
4.0 dS/m	Gypsum + Drip	1281	27.8	35.6
6.0 dS/m	Control	1128	22.2	**25.1**
6.0 dS/m	Organic Mulch	1165	24.8	28.9
6.0 dS/m	Gypsum + Drip	1182	25.4	30.0

Salinity significantly affected fruit quality characteristics, including TSS, acidity, ascorbic acid, and total sugar content. Complete data are shown in Table 3 and key parameter trends in Figure 3.

Table 3. Effect of salinity and soil management on fruit quality of ber

Salini ty Level	**Soil Management**	**TSS (°Bri x)**	**Acidi ty (%)**	**Ascorbic Acid (mg/100 g)**	**Tota l Sug ar (%)**
0.5 dS/m	Control	15.12	0.48	93.96	13.8 0
0.5 dS/m	Organic Mulch	15.05	0.61	92.49	13.2 6
0.5 dS/m	Gypsum + Drip	14.01	0.45	96.58	12.5 1
2.0 dS/m	Control	13.54	0.67	89.64	11.7 7
2.0 dS/m	Organic Mulch	**17.2**	0.48	**105.1**	**14.5 6**
2.0 dS/m	Gypsum + Drip	15.95	0.51	100.2	13.8 4
6.0 dS/m	Control	12.34	0.72	82.1	10.1

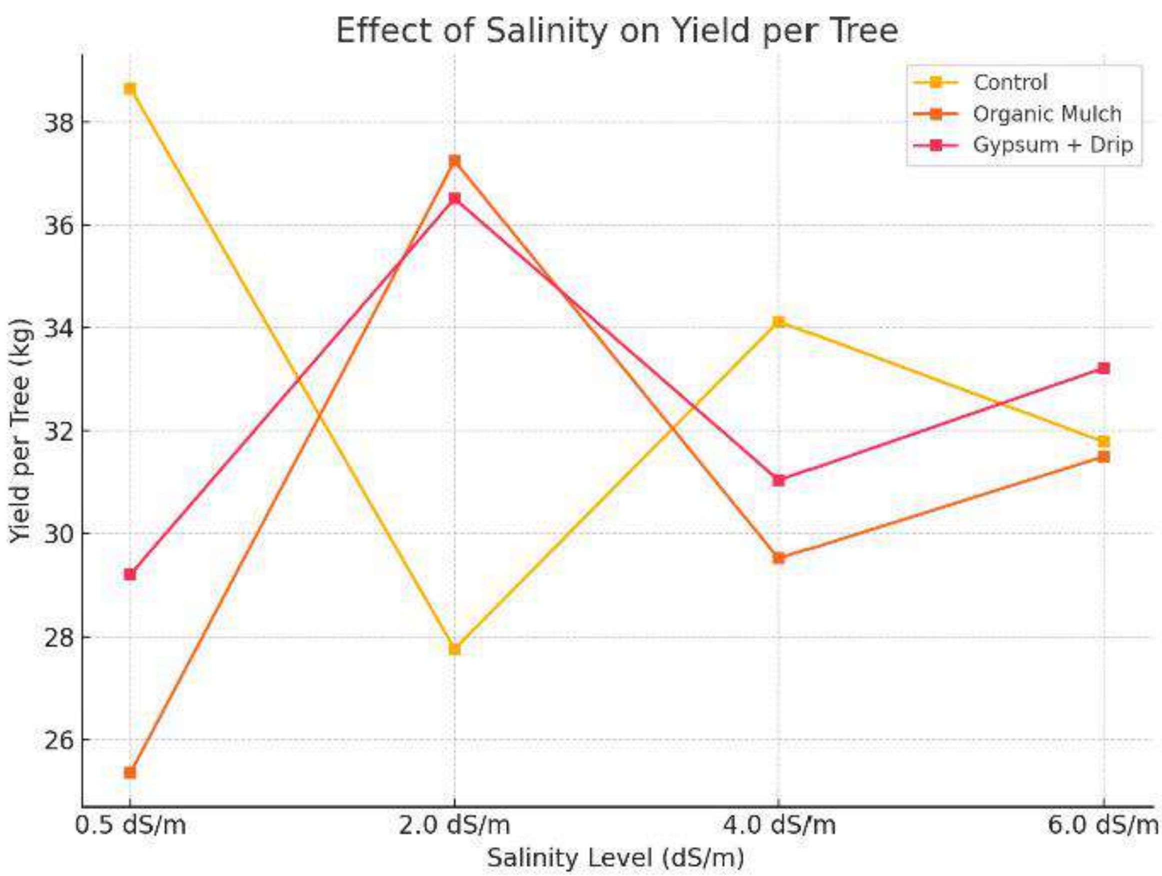

Figure 2. Effect of salinity and soil management on the yield per tree of ber

Interpretation:

Fruit yield declined with increased salinity. The best yield (42.5 kg/tree) was observed in 2.0 dS/m + Organic mulch, while the lowest (25.1 kg/tree) was recorded under 6.0 dS/m + Control. Singh and Dagar (2018) reported similar findings that mulching can reduce evaporative salt concentration and improve fruit yield in saline environments.

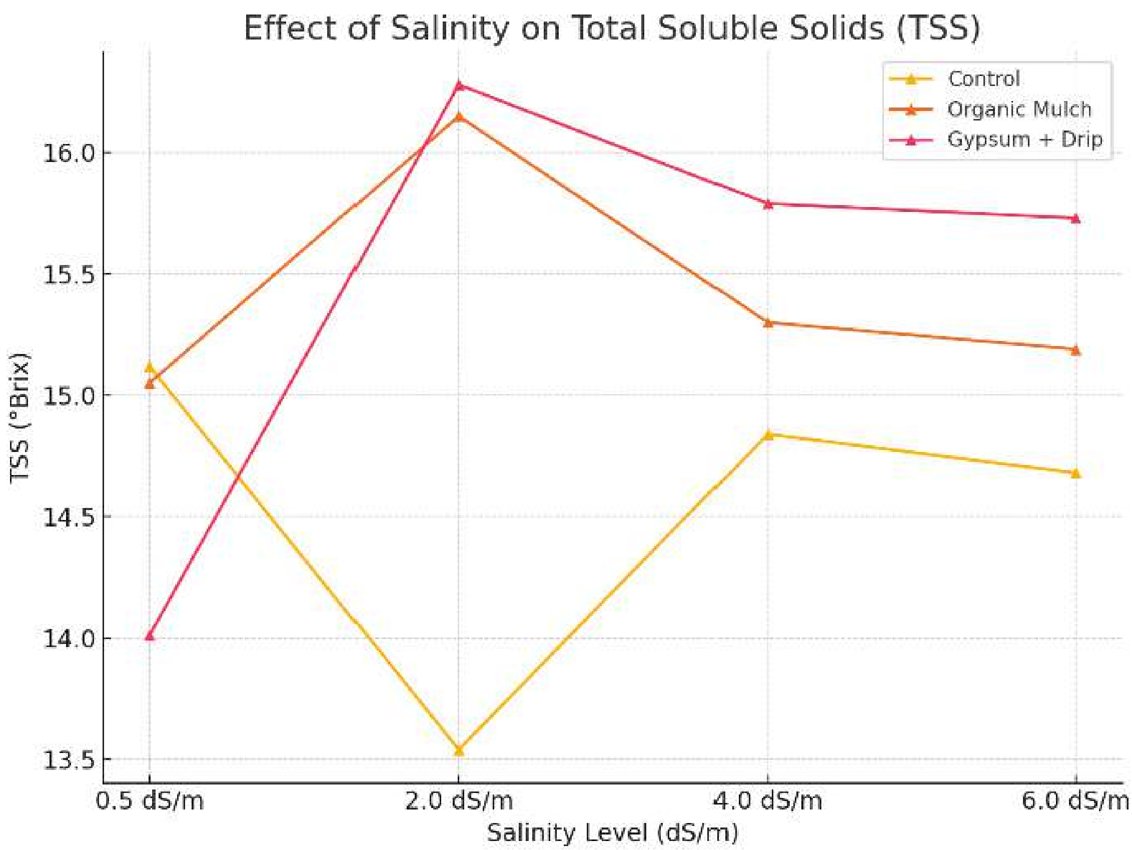

Figure 3. Effect of salinity and soil treatment on
otal Soluble Solids (TSS)

Interpretation:

TSS and total sugars declined under higher salinity, while acidity increased. The **highest TSS (17.2°Brix)** and **ascorbic acid (105.1 mg/100g)** were found under **2.0 dS/m + Organic mulch**, showing improved fruit palatability and nutritional quality.

Summary of Treatment Response

- **Best-performing treatment:**
  2.0 dS/m + Organic mulch gave the highest yield and best fruit quality, making it the most suitable strategy under moderate salinity.
- **Worst-performing treatment:**
  6.0 dS/m + Control, where yield and quality deteriorated sharply, indicating salinity stress without mitigation is detrimental to ber.

Conclusion

Summary of Major Findings

The present study demonstrated that salinity levels in irrigation water significantly affect the growth, yield, and fruit quality of ber (*Ziziphus mauritiana* cv. Umran). The impact was found to intensify with increasing salinity levels, particularly beyond 4.0 dS/m.

Key observations from the study include:

- Vegetative growth parameters such as plant height, canopy volume, and number of new shoots declined progressively with increasing salinity. However, the use of **gypsum with drip irrigation** and **organic mulch** effectively mitigated the negative effects of salt stress, especially at moderate salinity (2.0 dS/m).

- Fruit yield per tree was highest under **2.0 dS/m + organic mulch** (42.5 kg/tree) and lowest under **6.0 dS/m + control** (25.1 kg/tree). Yield losses beyond 4.0 dS/m were substantial, indicating that high salinity imposes direct limitations on productivity.
- Fruit quality traits such as TSS, total sugars, and ascorbic acid were also adversely impacted by increased salinity. The **best quality fruits** were obtained under **2.0 dS/m + organic mulch**, suggesting that mild salinity combined with proper soil amendments may even enhance certain quality parameters.
- Overall, the study established that **ber can tolerate irrigation water salinity up to 2.0 dS/m without major reductions in yield or quality**, provided appropriate soil management practices are in place.

Practical Recommendations

Based on the findings, the following recommendations are proposed for ber cultivation under saline irrigation conditions:

1. **Salinity Threshold:**

   Irrigation water with EC up to **2.0 dS/m** can be safely used for ber cultivation when combined with soil amelioration measures.

2. **Soil Management:**
   - **Organic mulching** (using 5 cm farmyard compost) helps improve moisture

retention and reduces salt accumulation.

- **Gypsum application (2 t/ha)** with **drip irrigation** facilitates leaching of sodium ions and enhances plant resilience.

3. **Variety and Rootstock Selection:** Use of salt-tolerant rootstock like *Ziziphus rotundifolia* under hardy cultivars like 'Umran' offers a robust system for dry and saline regions.
4. **Irrigation Scheduling:** Salinity management must include **real-time monitoring of EC** in irrigation water and soil, to prevent long-term salt buildup in the root zone.

Suggestions for Future Research

To further build upon the present findings, future studies may focus on:

- Long-term impact of saline irrigation on **soil health**, **microbial diversity**, and **ber tree longevity**.
- Evaluation of other **ber cultivars and rootstock combinations** under salinity stress for varietal improvement.
- Development of **integrated salinity management packages**, including biochar, vermicompost, or beneficial microbes to enhance salt tolerance.
- Use of **remote sensing and sensor-based drip systems** to automate salinity adjustments in real-time and optimize irrigation efficiency.

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