Combating Soil Salinity in Sugarcane Farming: IntegratedApproaches and Bio-Saline Agriculture Innovations

ABSTRACT

Sugarcane, a vital commercial crop globally, faces significant challenges due to soil salinity, particularly in India where regions such as Gujarat, Uttar Pradesh, Maharashtra, West Bengal, and Rajasthan are notably affected. Salinity impairs sugarcane growth through reduced water uptake, ion toxicity, nutrient imbalance, stunted growth and soil structure degradation. To combat these issues, various strategies have been proposed, including improving drainage, leaching, selecting salt-tolerant varieties, optimizing irrigation, and using soil amendments. Bio-saline agriculture, incorporating plant growth-promoting rhizobacteria (PGPR) and salt-tolerant plants, offers an innovative approach by enhancing soil fertility and crop resilience under saline conditions. Additionally, research indicates that long-term irrigation practices can exacerbate soil salinity, altering key soil parameters such as pH, electrical conductivity and sodium levels. Studies on spent wash application show variable impacts on sugarcane yield and quality, with optimal results observed at moderate application rates. Effective management of soil salinity through these combined approaches can mitigate adverse effects and improve sugarcane productivity and sustainability.

Keywords: [Soil Salinity, Sugarcane Cultivation, Saline-Sodic Soils, Soil Amendments, Bio-Saline Agriculture, Spent Wash]

1. INTRODUCTION

Sugarcane is one of the most important commercial crops cultivated worldwide, with its raw materials playing a crucial role in the industrial sector. These materials include molasses, bagasse, press mud, sugarcane wax and sugarcane juice. Globally, India ranks as the second-largest producer of centrifugal sugarcane after Brazil, with a total production of 34.5 million metric tons. (Pant *et al.* 2019). Annually, the government of India announce prices for various crops based on recommendations from the commission for agricultural costs and prices (CACP), which are approved by the cabinet committee of economic affairs. For the year 2024, the fair and remunerative price (FRP) for sugarcane has been announced at Rs. 340 per quintal, with a sugar recovery rate of 10.25 per cent.

In India, Uttar Pradesh leads in both the area under cultivation and production of sugarcane, covering a total area of 25.28 lakh hectares and producing 2056.26 lakh tons. Tamil Nadu tops in productivity with an average yield of 107 tons per hectare. In Karnataka, Belagavi district leads in both the area under cultivation and production of sugarcane, covering a total area of 2.7 lakh hectares and producing 260.86 lakh tons. This high productivity can be attributed to several factors. Firstly, Mandya benefits from fertile soils, particularly alluvial and black soils, which are well-drained and rich in essential nutrients for sugarcane growth. Secondly, the district's agro-climatic conditions,characterizedbyasemi-aridtropicalclimatewithmoderaterainfalland ample sunshine, create favorable conditions for sugarcane cultivation. Lastly, efficient irrigationpractices, including the utilization of canal

water from the Krishna Raja Sagara Dam and otherreservoirs, ensure consistent water supply throughout the growing season, thereby promoting robustgrowthand high yields of sugarcanein Mandyadistrict (Indiastat, 2024).
Nearly 75% of salt-affected soils in the country exist in the states of Gujarat (2.23 million ha), Uttar Pradesh (1.37 million ha), Maharashtra (0.61 million ha), West Bengal (0.44 million ha) and Rajasthan (0.38 million ha) (Mandal *et al.,* 2018). The pot study on sugarcane exposed to varying soil salinity levels (0, 38, 75, 150, and 300 mm NaCl) found significant reductions in plant height and leaf photosynthetic rate with increasing salt concentration (Zhao *et al*., 2020). High salinity levels in soil adversely affect sugarcane cultivation, leading to delayed germination, leaf yellowing and burning, reduced tillering, stunted growth, poor field stand and decreased cane yields (Karthikeyan *et al*., 2023 and Alghobar*et al*., 2016).

2. Soil salinity

Refers to the presence of elevated levels of soluble salts in the soil. These salts, primarily sodium chloride (NaCl), calcium chloride ($CaCl_2$), and magnesium sulfate ($MgSO_4$) (Choudary and Kharche, 2018).

2.1 Types of salt-affected soils(Anonymous,2024)

a) **Saline Soils:** These soils contain soluble salts such as sodium chloride (NaCl), calcium chloride ($CaCl_2$), and magnesium chloride ($MgCl_2$). Saline soils typically have an electrical conductivity (EC) of the saturation extract (ECe) greater than 4 dS m^{-1} (De Sutter, 2008).
b) **Sodic Soils:** Sodic soils are characterized by high levels of sodium (Na^+) ions relative to other cations like calcium (Ca^{2+}) and magnesium (Mg^{2+}). The sodium percentage (ESP, exchangeable sodium percentage) is generally more than 15 per cent. These soils often have poor structure and permeability due to the dispersal of clay particles (Andrade Foronda and Colinet, 2023).
c) **Saline-Sodic Soils:** These soils exhibit characteristics of both saline and sodic soils, having high levels of both soluble salts and exchangeable sodium. They have an ECe greater than 4 dS m^{-1} and an ESP greater than 15 per cent (Kumar *et al*. 2013).
d) **Alkaline Soils:** Alkaline soils have a high pH (typically above 8.5) due to the presence of carbonates and bicarbonates of sodium and potassium. These soils can inhibit the uptake of certain nutrients by plants and may have poor physical properties (Zewd and Siban, 2021).
e) **Acidic Soils (Acid Sulfate Soils):** Acidic soils are characterized by low pH (below 5.5) due to the accumulation of sulfuric acid or other acids. These soils can be problematic for agriculture as they may have toxic levels of aluminium and manganese, and they can limit the availability of essential nutrients for plant growth (Prasittikhet and Gambrell, 1990).

2.2 Effects of soil salinity and its impact on crops (Rathod, 2023)

a) **Reduced Water Uptake:** High salt concentrations in the soil create an osmotic imbalance, making it difficult for plants to absorb water from the soil. This leads to water stress in plants, even if water is available in the soil (Yadav *et al.* 2011).
b) **Ion Toxicity:** Excess ions like sodium (Na^+) and chloride (Cl^-) can accumulate in plant tissues, disrupting cellular processes. This toxicity can cause leaf burn, chlorosis (yellowing of leaves), and ultimately reduce photosynthesis and growth (Yadav *et al.* 2011).
c) **Nutrient Imbalance:** Soil salinity interferes with the uptake of essential nutrients such

d) as potassium (K^+), calcium (Ca^{2+}), and magnesium (Mg^{2+}). This imbalance can lead to nutrient deficiencies, affecting overall plant health and yield (Yadav *et al.* 2011).

e) **Stunted Growth and Yield Reduction:** Prolonged exposure to saline conditions can severely stunt plant growth and reduce crop yields. In severe cases, it can lead to crop failure if crops are not tolerant to high salinity levels (Yadav *et al.* 2011).

f) **Soil Structure Degradation:** Salts can also affect soil structure by causing dispersion of soil particles, leading to the breakdown of soil aggregates and increased soil erosion risk (Yadav *et al.* 2011).

g) **Altered Microbial Activity:** Soil salinity can disrupt the balance of soil microbial communities. Many beneficial microorganisms crucial for nutrient cycling and plant health are sensitive to high salt levels, affecting soil fertility and overall ecosystem function (Yadav *et al.* 2011).

h) **Limited Crop Options:** High soil salinity restricts the range of crops that can be grown successfully. Only salt-tolerant crops or varieties can thrive in saline soils, limiting agricultural diversity and economic options for farmers (Yadav *et al.* 2011).

3. Measures to overcome soil salinity effect in sugarcane crop(Mallikarjuna, 2017)

3.1 Improving Drainage: Enhancing soil drainage can help reduce the accumulation of salts in the root zone. This can be achieved through land levelling, installation of subsurface drainage systems like tile drains, and ensuring proper slope gradients to facilitate runoff (Awaad, 2023).

3.2 Leaching: Leaching involves applying excess water to the soil to flush out accumulated salts beyond the root zone. This practice helps in reducing soil salinity levels temporarily and can be combined with proper drainage practices for better results (Awaad, 2023).

3.3 Selection of Salt-Tolerant Varieties: Planting sugarcane varieties that are more tolerant to salt stress can help mitigate the effects of soil salinity. These varieties are adapted to absorb and utilize water and nutrients efficiently under high salt conditions. Some salinity tolerant varieties like Co 775 and Co 1148 have shown better performance under saline conditions (Awaad, 2023).

3.4 Optimized Irrigation Management: Implementing efficient irrigation practices such as drip irrigation or sprinkler irrigation can minimize water use and reduce the risk of salt accumulation near the soil surface. Avoiding over-irrigation and scheduling irrigation based on soil moisture and crop needs are crucial (Awaad, 2023).

3.5 Soil Amendments: Adding soil amendments such as gypsum (calcium sulfate) can help in displacing sodium ions and improving soil structure. Gypsum application can aid in reducing soil sodicity and enhancing water infiltration rates (Venkataramana *et al.*,2020).

3.6 Balanced Fertilization: Properly balanced fertilization practices can help maintain optimal nutrient levels in the soil, which can mitigate nutrient imbalances caused by soil salinity (Awaad, 2023).

3.7 Monitoring and Management: Regular monitoring of soil salinity levels using soil testing and adopting integrated soil and water management practices are essential. This helps in timely adjustments and interventions to prevent or minimize the impact of soil salinity on sugarcane crops (Awaad, 2023).

4. Bio-saline Agriculture

One unique and effective method to reduce the impact of soil salinity on sugarcane crops is the use of bio-saline agriculture, which involves the application of plant growth-promoting rhizobacteria (PGPR) and halophytes (salt-tolerant plants). Bio saline agriculture in sugarcane involves cultivating salt-tolerant sugarcane varieties and employing biological agents like salt-tolerant microbes and mycorrhizal fungi to improve soil fertility and nutrient uptake under saline conditions. It emphasizes efficient water management through techniques like drip irrigation and utilizing brackish water sources to minimize soil salinity, (KiranYadavet al., 2023). Additionally, organic amendments and bio-fertilizers are used to enhance soil structure and support robust root growth, mitigating the adverse effects of salinity on sugarcane crops (Sharma and Singh, 2017).

Gundlur*et al*. (2018) surveyed soil in the Ghataprabha command area, finding that long-term irrigation (over 30 years) led to higher pH (mean 8.55), electrical conductivity (mean 1.31 dS m^{-1}), cation exchange capacity (mean 55.23 cmol kg^{-1}), and exchangeable sodium percentage (mean 12.46%) compared to unirrigated soils. Unirrigated soils had lower pH (mean 7.91), EC (mean 0.37 dS m^{-1}), CEC (mean 49.40 cmol kg^{-1}), and ESP (mean 6.82%), (Table.1).

Table 1. Effect of long-term years of irrigation on different soil parameters (Gundlur*et al*. 2018)

Sample No.	Unirrigated	Periods of irrigation (years)			
		10-15	15-20	20-30	>30
pH					
Range	7.29 – 8.75	7.55 – 8.92	7.46 – 8.66	7.83 – 8.85	7.79 – 9.08
Mean	7.91	8.20	8.47	8.47	8.55
SD	0.26	0.30	0.27	0.27	0.31
CEC (cmol kg^{-1})					
Range	44.39 – 57.60	45.7 – 61.48	42.80 – 59.20	46.64 – 63.46	48.98 – 60.29
Mean	49.40	52.04	52.64	54.32	55.23
SD	3.60	4.04	4.37	5.04	3.44
EC (dS m^{-1})					
Range	0.13 – 0.98	0.15 – 2.0	0.25 – 1.65	0.16 – 2.45	0.39 – 2.65
Mean	0.37	0.65	0.86	1.12	1.31
SD	0.25	0.50	0.38	0.68	0.49
SAR					
Range	4.79 – 9.77	6.02 – 9.12	5.69 – 11.1	6.88 – 10.89	8.56 – 13.2
Mean	6.20	7.38	7.97	9.04	11.61
SD	1.21	1.18	1.33	1.14	1.18
ESP (%)					
Range	3.37 – 12.52	4.59 – 12.69	3.50 – 13.84	5.14 – 14.17	8.52 – 14.94
Mean	6.82	8.66	9.55	10.64	12.46
SD	3.23	2.08	2.26	2.64	1.92

Kamble (2014) studied the effects of spent wash application on sugarcane yield and soil properties at Ugar Sugar Factory, using a randomized complete block design with five treatments and five replications. The results showed that sugarcane yield was highest with 5 to 10 years of spent wash application, but decreased with 15 to 20 years of application, due to increased soil salinity and salt accumulation. The quality parameters (brix, pol and purity) also peaked with 5 to 10 years of spent wash. Nitrogen and phosphorus uptake were optimal in this treatment but declined with longer spent wash application. Spent wash increased soil potassium and sodium levels, (Table.2).

Table 2. Effect of different periods of spentwash application on growth, yield, total dry matter yield and quality parameters of sugarcane at harvest. (Kamble, 2014)

Treatment	Millable cane height (cm)	Diameter of cane (cm)	No. of internodes (plant^{-1})	Internode length (cm)	No. of millable canes (1000 ha^{-1})	Cane yield (t ha^{-1})	Total dry matter (g plant^{-1})	Cane quality			
								Brix (%)	Pol (%)	Purity (%)	Juice Na (mmol L^{-1})
P_0	182.9	2.71	21.26	10.98	111.80	123.8	270.1	20.26	17.86	88.17	1.04
P_1	193.6	2.90	22.32	11.41	114.12	135.1	279.2	21.12	19.45	92.16	1.09
P_2	176.3	2.62	19.51	9.65	105.50	109.3	237.4	20.38	17.98	89.24	1.76
P_3	164.1	2.29	17.89	8.62	93.04	83.3	212.5	19.51	17.51	88.78	1.54
S.Em. ±	2.5	0.04	0.32	0.24	1.53	3.00	2.8	0.19	0.15	0.92	0.12
CD (P=0.05)	7.65	0.13	0.99	0.46	4.73	9.2	8.5	0.59	0.46	2.84	0.36

6. Conclusion

Soil salinity significantly impacts sugarcane production, causing reduced growth, yield, and quality due to impaired water uptake, ion toxicity, and nutrient imbalances. Effective measures to combat salinity include improving drainage, leaching, using salt-tolerant varieties, optimizing irrigation, applying soil amendments, and balanced fertilization. Bio-saline agriculture, leveraging salt-tolerant plants and microbes, offers a promising approach to mitigate these effects. Long-term irrigation and spent wash applications show varying impacts on soil parameters and sugarcane yield, highlighting the need for careful management to avoid negative consequences on soil health and crop productivity. Regular monitoring and adaptive strategies are crucial for sustainable cultivation.

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