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Impact of Soil Amendments and Improved Alkaline Water on the Physico-Chemical Characteristics of the Soil, the Distribution of Salt in the Soil, the Growth, and the Yield of Hybrid Cotton Grown in Sodic Soil with Drip Irrigation

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The effects of ameliorated alkali water and soil amendments on the soil properties, growth, and yield of hybrid cotton in sodic soil under drip irrigation were investigated in this field experiment at Anbil Dharmalingam Agricultural College and Research Institute, Trichy, using cotton (RCH-20) as a test crop. The main-plot treatments included drip irrigation with gypsum treatment water and drip irrigation with spent wash treatment water; the sub-plot treatments included soil application of gypsum @ 50% GR (5.2 t ha^{-1}) and a one-time soil application of distillery spent wash at 5 lakh liters ha^{-1}. The treatment without amendments under main plot and sub-plots was used as a control. The experiment was designed in a strip-plot design with four replications. The application of additives through irrigation water or soil dramatically lowered the post-harvest soil's pH. Plots applied with wasted wash had the greatest pH reduction (M_1S_1) 7.81, followed by those applied with gypsum (M_2S_2) 7.90 and control (M_3S_3) 8.15. Because there was more soluble salt present in the spent wash treated plots, there was a little rise in EC. Drip irrigation with distillery spent wash (DSW) treated water and drip irrigation with gypsum treated water, respectively, resulted in ESP decreases of (M_2S_2) 0.97 and (M_1S_1) 0.61 over control. Similarly, ESP decreased by 2.63 and 1.31 when gypsum and DSW were applied to the soil, respectively, compared to the control. The organic carbon values ranged from (M_3S_3) 0.47 to (M_2S_2) 0.92 percent. In general, an increase in organic carbon content was observed in all the treatments that received amendments (Gypsum& DSW) compared to control. Salt distribution pattern conducted in treatment of distillery spent wash @ 5.0 lakh liters ha^{-1} significantly increased vertical depth of soil pH ranges (7.56,7.68,7.80,8.30) and decreased EC ranges (1.05,1.02,1.00,0.95) followed by horizontal line soil pH ranges (7.54,7.51,7.49,7.50) and EC ranges (1.04,1.02,1.00,1.02) at 120 DAS after application. In the experimental field recorded vertical depth of soil increased pH and decreased electrical conductivity compared to horizontal distances of soil pH and EC. The physico- chemical properties reduced in treatment one time application of DSW @ 5 lakh liters ha^{-1} recorded the highest physico-chemical properties followed by the treatment receiving irrigation with gypsum bed treated alkali water and lowest was recorded in the untreated alkali water irrigated through drip system in non- amended soil.

Keywords: Sodicity; gypsum; distillery spent wash; ameliorated alkali water; drip irrigation and salt distribution.

1. INTRODUCTION

"The lack of fresh productive land and worries about food security have brought productivity improvement of degraded lands back to the forefront of research and development. Approximately 9.38 million hectares of land in India are impacted by salt-affected soils (Suresh et al., 2023); of them, 5.50 million ha are saline soils, 3.77 million ha are alkali soils, and 3.5 lakh ha are sodic soils in Tamil Nadu (Selvamurugan et al., 2017). The major reason for the low productivity of crops grown in sodic soil is sodicity. A soil with pH more than 8.5. ESP of 15.0 or more and preponderance of CO_3 and HCO_3 of sodium is considered as alkali, where the EC is less than 4.0 dsm^{-1}" (Bhargava et al., 1981, Selvamurugan et al., 2024a). Recently, there has been increasing interest in flue gas desulfurization gypsum (FGDG) as an alternative to mined gypsum for amending sodic soils. FGDG is a by-product of the wet and semi-dry desulfurization processes used in coal-fired power plants, where limestone is employed to treat flue gas. This method produces a highly pure form of gypsum (over 99% purity). Both FGDG and mined gypsum serve as calcium sources that can replace sodium on soil and clay exchange sites (Clark et al., 2007). They also help enhance soil physical conditions by improving chemical properties such as electrical conductivity (EC), pH, and sodium adsorption ratio (SAR). Additionally, FGDG is typically more cost-effective than mined gypsum. However, the effectiveness of FGDG on various salt-affected soils must be assessed before it can be recommended to growers.

"Before plant response to salt stress is addressed, it is important to address the chemical and physical edaphology of the saline environment. Soils and irrigation water sources contain mineral salts, but the concentration and composition of the dissolved salts vary from one location to another" (Tanji and Wallender, 2012). "In solution, these salts dissolve and form positively charged cations and negatively charged anions. The most common cations are calcium (Ca^{2+}), magnesium (Mg^{2+}), and sodium (Na^{+}), whereas the most abundant anions are chloride (Cl^-), sulphate (SO_4^{-2}), and sodium bicarbonate ($NaHCO_3$). Sodic water is synonymous with 'soft' water. Sodicity can contribute to the deterioration of physical properties of the soil, which can indirectly affect plants resulting in surface crusting, reduced water infiltration, and reduced aeration causing anoxic or hypoxic conditions for roots. With shrinking agricultural land, reclamation and amelioration of sodic soils are important to maintain or increase the productivity of salt-affected soils" (Nelson and Ham, 2000).

2. MATERIALS AND METHODS

"The experiment was carried out in the Department of Soil Science and Agricultural Chemistry, Anbil Dharmalingam Agricultural College and Research Institute, in Tiruchirappalli, Tamil Nadu (10 45 5.465N, 78.36 1.227 E). The soil had a clay texture and was Typic Ustropept. Four replication and three mail plots, along with three subplots, were used to set up the field experiment**.** Treatment structure Main plots (Irrigation water treatment), M_1: Drip irrigation with gypsum treatment water, M_2: Drip irrigation with spent wash treatment water, M_3: Drip irrigation with untreated alkali, Subplots: Soil treatment, S_1: Soil application of gypsum @ 50% GR, S_2: One time application of DSW @5 lakh litter ha^{-1}, S_3: No treatments (control). A composite surface soil sample (0 -15 cm) representing the experimental site was collected before the layout of the field trial to assess the initial fertility status of experimental site. The collected soil samples were air dried, powdered with a wooden mallet, sieved through 2 mm sieve and stored in polyethylene bags for various physico-chemical analyses by following standard analytical procedures in Physico- Chemical parameters. Soil reaction (pH), and Soil water suspension 1:2 ratio using pH meter. Electrically conductivity and Soil water suspension 1:2 ratio using EC meter. Exchangeable sodium, and Flame photo meter. Organic carbon and Wet chromic acid digestion and Salt distribution pattern" [Jackson, 1973, Walkley and Black, 1934, Hanson et al., 1999).

3. RESULTS

3.1 Soil Reaction

The impact of improved alkali water and the application of gypsum and distillery spent wash on soil reaction is summarized in Table 1. Soil samples collected after crop harvest showed a slight decrease in pH, dropping from 8.82 to 7.45. The results indicated that irrigation with gypsum-treated alkali water, combined with a one-time application of distillery spent wash at a rate of 5 lakh liters per hectare, resulted in the lowest pH of 7.45. In contrast, the untreated alkali water used in a drip irrigation system on non-amended soil recorded the highest pH of 8.82.

3.2 Electrical Conductivity (EC)

The effect of ameliorated alkali water and soil application of gypsum and distillery spent wash on soil reaction given in Table 1. The analysis of soil sample taken after the harvest of crops indicates the slight decrease in soil pH from 1.09 to 0.23 was recorded. The results revealed that irrigation with gypsum bed treated alkali water with reclamation of soil through one time application of DSW @ 5 lakh liters ha^{-1}recorded the lowest 0.23 and the height 1.09 was recorded in the untreated alkali water irrigated through drip system in non -amended soil. (no amendment soil).

3.3 Exchangeable Sodium Percentage (ESP)

The exchangeable sodium percentage ranged from 11.82 to 23.50. The highest ESP level (23.50) was recorded treatment receiving untreated alkali water irrigated through drip system at non- amended soil and lowest level in alkali water through gypsum bed treatment receiving ESP level 11.8 percent and followed by irrigation with gypsum bed treated alkali water with reclamation of soil through one time application of DSW @ 5 lakh liters ha^{-1} recorded.

3.4 Organic Carbon (OC)

The organic carbon content is an important soil property, which determines the soil fertility cum productivity of the soil. The organic carbon values ranged from 0.50 to 0.92 per cent. In general, an increase in organic carbon content was observed in all the treatments that received amendments (Gypsum& DSW) compared to control.

3.5 Salt Distribution Pattern in Sodic Soil

Field experiment has conducted to study the effect of reclamation of sodic soil upon use of distillery spent wash and gypsum, Salt distribution pattern conducted in treatment of distillery spent wash @ 5.0 lakh liters ha^{-1} significantly increased vertical depth of soil pH

Table 1. Effect of drip irrigation using ameliorated alkali water and soil amendments on pH, EC, ESP and Organic carbon of post-harvest soil (Mean of four application)

	pH				EC (dSm^{-1})				ESP (%)				Organic carbon (%)			
Treatment	**S1**	**S2**	**S3**	**Mean**	**S1**	**S2**	**S3**	**Mean**	**S1**	**S2**	**S3**	**Mean**	**S1**	**S2**	**S3**	**Mean**
M1	7.76	7.5	8.75	8	0.6	1.04	0.48	0.7	14.8	12.7	23.2	16.9	0.62	0.9	0.42	0.64
M2	7.71	7.45	8.65	7.93	0.75	1.09	0.54	0.79	14.2	11.8	22.6	16.3	0.77	0.92	0.44	0.71
M3	7.85	7.62	8.8	8.08	0.5	0.98	0.45	0.64	15.5	13.3	23.5	17.4	0.54	0.86	0.39	0.59
Mean	7.77	7.51	8.73	8	0.61	1.03	0.23	0.71	14.8	12.6	23.2	16.8	0.64	0.78	0.41	0.64
	M	S	M at S	S at M	M	S	M at S	S at M	M	S	M at S	S at M	M	S	M at S	Sat M
CD(P=0.05)	0.34	0.23*	0.73	0.5	0.05*	0.06*	0.12	0.48	0.76	0.64*	1.66	1.42	0.04	0.05*	0.09	0.11

Table 2. Effect of drip irrigation using ameliorated alkali water and soil amendments on salt distribution pattern of post-harvest soil (Mean of four application)

S.NO	**Vertical depth**	**pH**	**EC (dSm^{-1})**	**Horizontal line**	**pH**	**EC (dSm^{-1})**
1	0- 5 cm	7.89	1.22	0- 5 cm	7.83	1.15
2	5-10 cm	7.92	1.15	5- 10 cm	7.86	1.17
3	10 -15 cm	7.95	1.02	10- 15 cm	7.96	1.1
4	15- 20 cm	8.6	0.98	15-20 cm	8.12	1.08

ranges (7.56,7.68,7.80,8.30) and decreased EC ranges (1.05,1.02,1.00,0.95) followed by horizontal line soil pH ranges (7.54,7.51,7.49,7.50) and EC ranges (1.04,1.02,1.00,1.02 dSm^{-1}) at 120 DAS after application. The physico- chemical properties reduced in treatment one time application of DSW @ 5 lakh liters ha^{-1} recorded the highest followed by the treatment receiving irrigation with gypsum bed treated alkali water and lowest was recorded in the untreated alkali water irrigated through drip system in non-amended soil.

4. DISCUSSION

The findings are in line with (Sharma et al., 1981) who reported that the soil pH reduced from 10.4 to 8.04 due to gypsum application. The reduction in soil pH was attributed to displacement of exchangeable Na by the calcium ion of gypsum and subsequent formation of sodium sulphate which get leached out of soil through drainage in the pots. Similar reduction in pH of sodic soil due to the application of gypsum was reported by Srinivasa, (1995), Ramappa, (1998) and Guruprasad, (2005). "The observed decline in soil pH suggested reduction in soil sodicity as a result of favourable effects of press mud (PM), FYM and gypsum. This may be due to the fact that the organic acids produced during the decomposition of organic amendments could have lowered the soil pH and also increased the solubility of gypsum resulting in removal of some of the Na^+ from the soil. High amount of soluble salts present in spent wash on direct application to soil at higher levels creates the problem of salinity" (Patil et al., 2004, Selvamurugan et al., 2024b). "Decrease in soil pH was attributed to acidic nature of raw spent wash (pH 4.1) which might have solubilized the native calcium carbonate and released free calcium ions and other calcium bearing minerals to the soil. In addition, the spent wash has calcium to an extent of 2600 mg L^{-1}. The decrease in soil pH was more pronounced in calcareous sodic soil compared to sodic soil. This was due to acidic nature of raw spent wash which might have solubilized the native free lime thus facilitating the release of Ca+Mg in free ionic forms and these ions have replaced the Na^+ on the exchange complex. Also, the substantial quantity of sulfur present in raw spent wash, might have solubilized the $CaCO_3$ thus decreasing the pH of soil. Results obtained in this study are in conformity with the findings of Mohammed Haroon and Subash" (Chandra et al., 2005). Chauhan and Tripathi (1983) reported that application of gypsum followed by leaching markedly reduced the electrical conductivity to normal levels in alkali soil. Similar results were also reported by Srinivasa, (1995) and Guruprasad, (2005). High amount of soluble salts present in spent wash on direct application to soil at higher levels creates the problem of salinity (Haroon and Bose, 2004).

Hence DSW @ (5.0 lakh liters ha^{-1}) treatment considered optimum for practical purpose for reducing the ESP to a desired level under field conditions. The results are in accordance with the findings of Rajkkannu et al., (1996), Valliappan, (1998), Sarwar et al., (2010) and Nehra and Hooda, (2002). With the increase in days after application of raw spent wash, there was gradual reduction in ESP. The decrease in soil ESP with addition of amendments (organic / inorganic) either alone or in combination may be attributed to increased Ca in soil solution as a result of addition of gypsum and organic sources which promoted Na displacement and its subsequent removal during irrigation to lower soil layers (Jamil et al., 2008).

Soil organic carbon is generally considered as the index of soil fertility and sustainability of any agricultural system. It decides the fate of soil structure, water holding capacity, infiltration rate, aeration and porosity and biological properties of soil. In the case of changes in organic carbon content, higher values were recorded in the treatments involving DSW than gypsum treatment combinations indicating the superior effect of an organic amendment. The usefulness of pressmud as a valuable organic manure on account of its high organic carbon content has been reported by several workers (Ramaswamy 1999, Patil et al., 2004, Singh et al., 1980). The increase in organic carbon content due to addition of organic manures either alone or in combination with gypsum corroborates the finding reported earlier by Dang and Verma (1996) and Singh et al., (2015). A negative relationship existed between the organic carbon and stage of crop which may be attributed to the decomposition of the organic amendments with time.

5. CONCLUSION

The one-time application of DSW at 5 lakh liters per hectare led to the most significant reduction in physico-chemical properties, followed by treatment with gypsum bed-treated alkali water.

The lowest reductions were observed in untreated alkali water irrigated through a drip system in non-amended soil. In the experimental field, vertical soil depth showed an increase in pH and a decrease in electrical conductivity (EC), contrasting with the horizontal distances where soil pH and EC were measured.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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