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Exploring the Efficacy of Organic Citrus Formulations for Salinity Amelioration in Contrasting Agro Climatic Regions

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The world's food supply is currently under threat from saline soils, an issue that is exacerbated by climate change and insufficient rainfall. This study was to find out if introducing an amendment made from citrus peels may lower the salinity of the soil and promote plant development in two distinct agro climatic zones in India. The chosen regions, Zone 13 (which covered the Gujarat Plains and Hills Region) and Zone 1 (which represented the Western Himalayan Region), had varying soil quality and weather. It has been found that the amendment works well in neutral and salted soils to lower soil salinity. In neutral soil (Zone 1), the amendment greatly decreased salinity by 50%, and in saline soil (Zone 13), by 75%. The acidic nature of the amendment effectively neutralized soil salts, hence enhancing the conditions for enhanced nutrient uptake by plant roots. Furthermore, the soil properties were significantly improved by the addition of kitchen garbage. It is expected that increased plant growth and higher agricultural production will result from this improvement in soil quality. Both soil types had reduced soil organic carbon (SOC) concentrations, the study also revealed. Overall, the study suggests that adding citrus peels to soil can be a long-term solution to problems with salt. To evaluate the scalability and practical application of this organic amendment for soil development, more investigation and field testing are necessary. Citrus peel amendment has the ability to alleviate salt problems in soil across a range of agro climatic zones. In addition to improving agricultural output, this strategy supports food security and sustainable farming methods.

Keywords: Agriculture; Agro-climatic regions; Citrus peel; Organic amendments; Soil salinity; Sustainable.

Saline soils, while being a vital natural asset, are facing an escalating global predicament due to climate change and insufficient rainfall. This surge in deteriorating saline soils poses a grave risk to worldwide food security[1]. Among the primary impediments to crop cultivation, soil salinization stands out, causing hindered crop growth and diminished agricultural output. The Food and Agriculture Organization's report[2] reveals that 19.5% of irrigated land and 2.1% of arid farmlands contend with soil saltiness. The adverse repercussions of saline and sodic soils encompass decreased productivity, heightened demand for water, fertilizers, and quality seeds, as well as a restricted array of viable crops. Due to the negative impacts on cereal grain germination

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and emergence, poor plant growth is a common tendency in fields with high soil salinity. Farmers are therefore forced to grow crops that can withstand salt, even if they may not always generate significant financial gains. Approximately 6.74 million acres of land in the country currently struggle with soil salinity. An estimated 10% extra land per year succumbs to salinization, and by 2050, over half of the world's arable land may be contaminated by salt. In this context, saline soils affect around 44% of the land in 12 states and a Union Territory, whereas sodic soils have an impact on approximately 47% of the land in 11 states [3]. Over time, the extensive consumption of traditional soil additives typically worsens soil stress and reduces nutrient accessibility. Because of this, choosing fertilizers wisely becomes crucial in these areas to effectively combat soil erosion.

According to different weather patterns and rainfall amounts, our nation has been divided into 15 agro- climate regions. Because of this, there exist variations in the soil properties that each sustain diverse plant and animal life. This division supports farmers in maximizing yields and using available resources. Numerous crops may grow in various soil types and climates found in various geographical areas. Depending on the kind of soil, different soil additives have different efficacies.

Salinity is a limiting issue for successful agriculture in varied parts of the country as saline and salty sodic soils with salt content predominate[4]. The use of soil supplements, such as poultry manure [1](Diacono & Montemurro, 2015,), crop straws, farmyard manure, sewage sludge, and biochar (Seenivasan et al., 2016; Singh et al., 2019), continues to be recognized as a method to enhance the physical and chemical qualities of the soil while reducing salinity problems. It's vital to keep in mind, meanwhile, because organic amendments typically contain levels with slower release rates. As a result, using both chemical fertilizers and amendments together is a growing trend [8].

In order to explore the impact of adding kitchen waste amendment to saline soil we conducted a study, in two agro climatic regions from northern and westerns parts of the country. In the study we examined the efficacy of these amendments to support plant growth, in both types of soil.

MATERIALS AND METHODS

Site selection and soil sample collection

According to the country's agro-climatic zoning, soil samples for the pot experiment were taken from two different regions: Zone 1, which represents the Western Himalayan Region, and Zone 13, which includes the Gujarat Plains and Hills Region. The northern region's climate was categorized as temperate, with an annual rainfall average of 80 cm. The region had temperatures ranging from 0.4°C to 16°C, with an average of 9°C. Inceptisols are the most common type of soil in this area.

The western part of the country experienced a semi-arid climate with annual rainfall averages of about 20 cm. Average temperature fluctuation was 28.1°C, with lows of 23.8°C and highs of 38°C. This region's soils are considered to be aridisols. In all areas, soil samples were taken at depths of roughly 12 to 15 centimeters using a V-shaped technique. These samples were then exposed to the sun for around 48 hours to dry. A 2 mm sieve was used to homogenize the soil and ensure consistency by removing stones, roots, and other debris. The samples were then kept in order to conduct a physicochemical examination. Table 1 lists the specific soil components in detail.

Preparation of amendment

Citrus peels were used as the source of the study's amendment, which was then fermented. Peels from citrus fruits were carefully separated from kitchen trash and washed. These peels were sun-dried for 48 hours before being crushed into little pieces. The fermentation procedure used to create the final orange peel powder was started by putting it in a shaded, enclosed area with a carbohydrate source for 30 days. A little yeast was added to hasten the fermentation process. The created mixture was filtered and placed to prepared soil pots after the 30-day period. The color and pH of the amendment were recorded. According to the Days after Sowing (DAS) schedule, this formulation was used in a 1:2 ratios (formulation to water) and applied during the first planting as well as every 10 days following that. The stages of methodology involved in creating the formulation are shown in Figure 1 in graphic form.

Pot experiment design

Soils were transferred into 12-15 cm pots. Four to five mung bean (*Vigna radiata* L.) seeds were sown in each pot. The citrus formulation was added to the soil in the pots to improve it, and tap water was used for irrigation according to the needs. Every ten days, a 1:2 dilution of the citrus amendment in water was given. The soils from the pots were examined three times throughout the experiment: before planting, in the middle of growth, and after harvest. Whole experiment was conducted in 3 replicates. The purpose of this investigation was to evaluate the impact of the citrus amendment on soil salt levels as well as plant growth.

Physicochemical characterization

In the pre-amendment phase, soils were homogenized and then tested for pH, EC, salinity, water holding capacity, texture, and SOC (soil organic carbon). Following that, an amendment was added every 10 DAS, and in the post-harvest period, soil samples from the pots were tested for the same parameters. With the help of the OAKTON multi-parameter PCSTestrTM 35, pH, EC, and salinity were measured. Using the Walkely and Black Rapid Titration Method, soil organic carbon was calculated both before and after harvest (Gupta, 2009).

Statistical analysis

Statistical analysis of the collected data was done through software IBM SPSS 26.

DISCUSSION

A mixture made from organic kitchen waste was found in the study to be beneficial in reducing soil salinity. This effectiveness was seen in soils from agro climatic Zone 1 (inceptisols) and Zone 13 (aridisols), respectively.

Characterization of the amendment

A strongly acidic character was revealed by the developed amendment's pH value of 2.03. After 30 days, the light brown tint of the amendment turned light brown and began to smell fruity.

Physico-chemical characterization of soils

Physico-chemical characterization of both the soils was done in three phases which were 1) pre amendment phase (P 0), 2) Mid phase (P 1), and 3) Post-harvest phase (P 2). Organic carbon was analyzed in pre amendment and post-harvest phases. Table 2 shows the overall physico-chemical

Table 1. Composition of soil from both regions

Soil type	Soil order	Soil depth (cm)	Mechanical composition Sand%	Silt%	Clay%	SOC (%)	pH
Soil 1 Zone 13	Aridisols	0-15	41	49	10	2.050	7.49
Soil 2 Zone 1	Inceptisols	0-15	29	64	7	1.250	6.58

*SOC-soil organic carbon

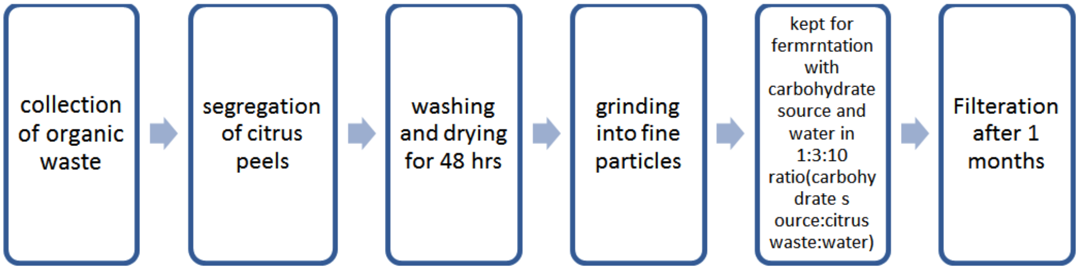

Fig. 1. Overall formulation preparation process.

Table 2. Phase and treatment wise descriptive statistical analysis of soil samples

Sample ID	Parameter	Minimum	Maximum	Mean	S.E.	Std. Deviation
a. soil = 1,	pH	7.48000	7.49000	7.48667	0.00333	0.00577
Control,	EC (mS/m)	467.00000	471.00000	469.00000	1.154701	2.00000
phase = .00	Salinity(‰)	0.56500	0.57000	0.56733	0.001453	0.00252
	*WHC(%)	36.00000	36.00000	36.00000	0.000000	0.00000
	*SOC(%)	1.950	2.070	2.02333	0.037118	0.064291
	*SOM(%)	3.362	3.569	3.48823	0.063992	0.110838
a. soil = 1,	pH	7.47000	7.49000	7.47667	0.00667	0.01155
Control,	EC (mS/m)	1836.00000	1837.00000	1836.33333	0.333333	0.57735
phase = 1.00	Salinity(‰)	0.85400	0.86400	0.85900	0.002887	0.00500
	*WHC(%)	37.02300	37.02900	37.02667	0.001856	0.00321
	*SOC(%)	-	-	-		-
	*SOM(%)	-	-	-		-
a. soil = 1,	pH	7.45000	7.48000	7.46667	0.00882	0.01528
Control,	EC (mS/m)	642.00000	650.00000	647.00000	2.516611	4.35890
phase = 2.00	Salinity(‰)	0.24100	0.29500	0.26800	0.015588	0.02700
	*WHC(%)	37.78000	37.80000	37.79000	0.005774	0.01000
	*SOC(%)	0.721	0.8	0.76833	0.024113	0.041765
	*SOM(%)	1.243	1.379	1.32467	0.041571	0.072002
a. soil = 1,	pH	7.47000	7.48000	7.47667	0.00333	0.00577
treatment = 2.00,	EC (mS/m)	467.00000	472.00000	469.66667	1.452966	2.51661
phase = .00	Salinity(‰)	0.56500	0.56900	0.56700	0.001155	0.00200
	*WHC(%)	36.00000	36.00000	36.00000	0.000000	0.00000
	*SOC(%)	1.790	1.890	1.84333	0.029059	0.050332
	*SOM(%)	3.086	3.258	3.17791	0.050098	0.086773
a. soil = 1,	pH	7.44000	7.48000	7.45667	0.01202	0.02082
treatment = 2.00,	EC (mS/m)	1250.00000	1288.00000	1268.66667	10.974718	19.00877
phase = 1.00	Salinity(‰)	0.60200	0.72300	0.67867	0.038490	0.06667
	*WHC(%)	37.12000	37.13000	37.12667	0.003333	0.00577
	*SOC(%)	-	-	-		-
	*SOM(%)	-	-	-		-
a. soil = 1,	pH	6.72000	6.79000	6.76333	0.02186	0.03786
treatment = 2.00,	EC (mS/m)	283.00000	365.00000	331.33333	24.781265	42.92241
phase = 2.00	Salinity(‰)	0.12900	0.16200	0.14567	0.009528	0.01650
	*WHC(%)	37.79000	37.82000	37.80667	0.008819	0.01528
	*SOC(%)	0.420	0.490	0.45833	0.020480	0.035473
	*SOM(%)	0.724	0.845	0.79017	0.035308	0.061155
a. soil = 2,	pH	6.53000	6.58000	6.55333	0.01453	0.02517
Control,	EC (mS/m)	113.00000	116.00000	114.66667	0.881917	1.52753
phase = .00	Salinity(‰)	0.20300	0.20500	0.20433	0.000667	0.00115
	WHC(%)	60.00000	60.00000	60.00000	0.000000	0.00000
	SOC(%)	1.150	1.250	1.20000	0.028868	0.050000
	SOM(%)	1.983	2.155	2.06880	0.049768	0.086200
a. soil = 2,	pH	6.95000	6.97000	6.96000	0.00577	0.01000
Control,	EC (mS/m)	427.00000	430.00000	428.33333	0.881917	1.52753
phase = 1.00	Salinity(‰)	0.18900	0.19500	0.19167	0.001764	0.00306
	WHC(%)	60.01000	60.01000	60.01000	0.000000	0.00000
	SOC(%)	-	-	-		-
	SOM(%)	-	-	-		-
a. soil = 2,	pH	6.70000	6.75000	6.72333	0.01453	0.02517
Control,	EC (mS/m)	168.00000	172.00000	170.00000	1.154701	2.00000
phase = 2.00	Salinity(‰)	0.05000	0.10000	0.07667	0.014530	0.02517

	*WHC(%)	60.03000	60.03000	60.03000	0.000000	0.00000
	*SOC(%)	1.028	1.040	1.03433	0.003480	0.006028
	*SOM(%)	1.772	1.793	1.78319	0.006000	0.010392
a. soil = 2,	pH	6.56000	6.58000	6.57000	0.00577	0.01000
treatment = 2.00,	EC (mS/m)	116.00000	121.00000	118.66667	1.452966	2.51661
phase = .00	Salinity(‰)	0.20500	0.20700	0.20600	0.000577	0.00100
	WHC(%)	60.00000	60.00000	60.00000	0.000000	0.00000
	SOC(%)	2.740	2.890	2.81000	0.043589	0.075498
	*SOM(%)	4.724	4.982	4.84444	0.075147	0.130159
a. soil = 2,	pH	6.74000	6.77000	6.75667	0.00882	0.01528
treatment = 2.00,	EC (mS/m)	495.00000	530.00000	516.33333	10.806377	18.71719
phase = 1.00	Salinity(‰)	0.22300	0.24000	0.23267	0.005044	0.00874
	*WHC(%)	60.01200	60.01700	60.01467	0.001453	0.00252
	*SOC(%)	-	-	-		-
	*SOM(%)	-	-	-		-
a. soil = 2,	pH	6.39000	6.49000	6.42667	0.03180	0.05508
treatment = 2.00,	EC (mS/m)	219.00000	262.00000	236.33333	13.093680	22.67892
phase = 2.00	Salinity(‰)	0.10200	0.12000	0.10900	0.005568	0.00964
	*WHC(%)	60.10000	60.15000	60.12000	0.015275	0.02646
	*SOC(%)	0.298	0.315	0.30833	0.005239	0.009074
	*SOM(%)	0.514	0.543	0.53157	0.009032	0.015643

*SOM-soil organic matter
*SOC-soil organic carbon
*WHC-water holding capacity

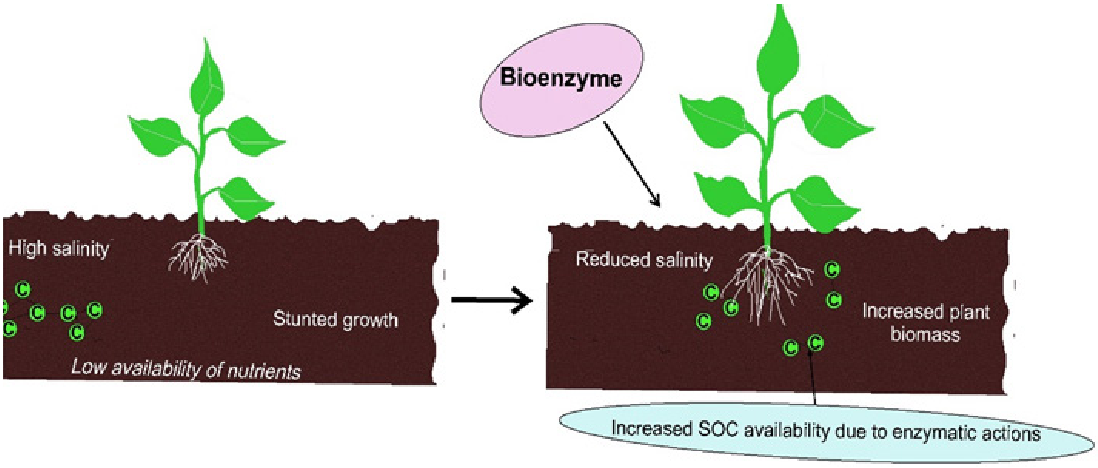

Fig. 2. Comprehensive illustration of the organic amendment impact on soils

characterization of the control and treated soils in pre, mid and post-harvest phases. The data clearly showed a declining trend in pH and conductivity values of soil 1 from zone 13. This is in concurrence with studies by Mao et al., 2022. Overall decline in pH in treated saline soil from zone 13 was 9.77% and in post-harvest phase. But it was reduced by only 0.40% in the control soil in post-harvest phase. The amendment reduced pH value in the soil 2 from zone 1 by 1.98%. However, the pH in untreated soil was increased by 2.59% in post-harvest phase. Electrical conductivity in untreated soil 1 was increased in post-harvest phase by 37.95%. This was observed due to partial alkaline nature of the irrigation water. But the amendment declined the conductivity value by 29.4% in the soil. EC value in soil 2 from zone 1 was almost doubled in post-harvest phase with respect to control which was 48.5% increase. The amendment increased the water holding capacity of soil 1 in treated

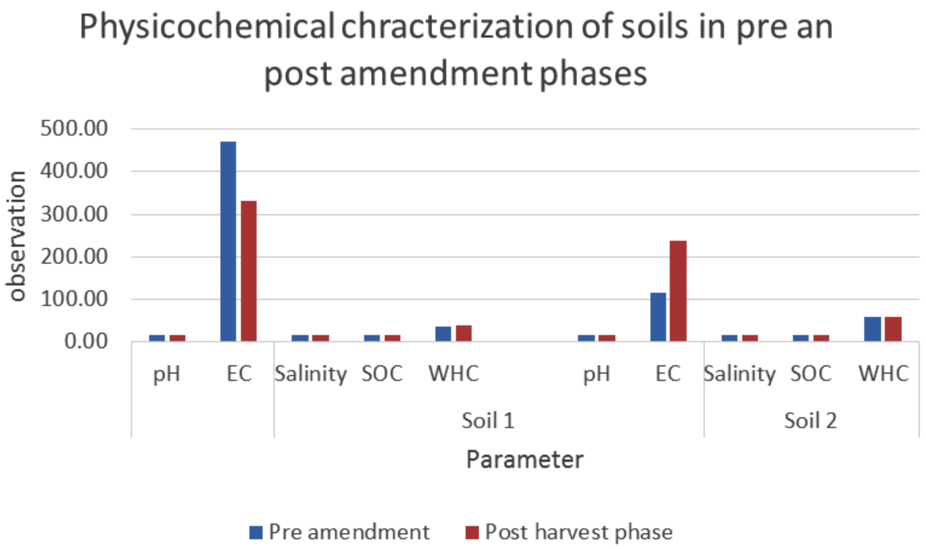

Fig. 3. Physicochemical characterization of soils in pre and post amendment phases

and untreated soil by 4.97% and 5% respectively. Similarly, it showed significant increase in soil 2 by 0.05% and 0.2% in untreated and treated soils respectively.

Impact analysis of organic formulation on soil salinity and SOC

Soil salinity represents the saltiness of the soil which occurs due to the presence of water soluble ions. Soil salinization occurs due to processes like mineral weathering and withdrawal of ocean water (Bello et al., 2021). The amendment reduced the soil salinity saline soil 1 by 53.57% and 75% in untreated and treated soils respectively. However, the amendment showed lower efficacy in salinity reduction in treated (50%) neutral soil 2 from zone 1 with respect to control (65%).

Moreover, a decrease in soil organic carbon (SOC) content was evident in both soil types. The amendment led to a reduction in SOC in saline soil 1 of 77.72% and 62% for treated and untreated soils, respectively. In neutral soil 2, corresponding reductions were 75% and 14.16% for treated and untreated soils, respectively. Notably, soil organic carbon serves as a significant nutrient within the soil matrix. The presence of soil salts typically creates an obstacle for nutrient absorption by plant roots. The acidic nature of the formulation effectively neutralized the existing soil salts, thereby fostering a favorable environment for enhanced root nutrient uptake. Furthermore, the enzymes within the amendment, generated through the fermentation process, facilitated the breakdown of larger molecules into smaller components. Figure 2 illustrates the comprehensive impact of the amendment on both soil types. Fig. 3 indicates the trend of salinity reduction in pre and post-harvest phases. This enzymatic action contributed to greater soil availability of these compounds, rendering them more accessible for plant uptake. Table.2 shows the trend of physicochemical characterization in both soils.

CONCLUSION

In conclusion, the study that was undertaken to analyze the impact of adding kitchen waste amendment to saline soils in two unique agro-climatic areas revealed useful insights into alleviating soil salinity concerns and increasing plant development. The kitchen waste amendment, made from fermented citrus peels, reduced soil salinity in both saline soil (Zone 13) and neutral soil (Zone 1). It increased soil parameters such as pH, electrical conductivity (EC), and water holding capacity (WHC) substantially. The amendment significantly decreased soil salinity, notably in saline soil, where it lowered salinity by 75%. The decrease was 50% in neutral soil. This decrease in soil salinity is crucial for improved plant development and nutrient uptake. The presence of salts in the soil caused a drop in SOC content in both soil types, according to the study. The acidic nature of the amendment, on the other hand, successfully neutralized the soil salts, generating a more conducive environment for improved root uptake of nutrients. While the study focused mostly on soil features, the reduction in soil salinity and increase in soil qualities are likely to benefit plant development. Better crop yields are predicted as a result of greater fertilizer availability and reduced salt stress.

In summary, the usage of kitchen waste amendment produced from citrus peels shows potential as a long-term solution to soil salinity concerns in a variety of agro-climatic areas. This strategy has the potential to increase agricultural output while also contributing to food security and sustainable farming practices by enhancing soil characteristics and reducing salinity. Further research and field trials may provide valuable insights into the practical application and scalability of this organic amendment for soil improvement.

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Conflict of interest

The authors declare no conflict of interest.

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Ethics approval statement

This research project does not involve any experimentation on human subjects or animals.

Data availability statement

The data has been made available in the aforementioned manuscript.

Authors contribution

The authors confirm contribution to the paper as follows: Study conceptualization: KDV and SBS. Sampling of soils: AS, KDV SBS and MBS. Data analysis: AS, SBS and KDV. Data interpretation: KDV and SBS. Figures and diagrams: KDV. Draft manuscript preparation: KDV and SBS. All authors reviewed the results and approved the final version of the manuscript.

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