Stimulating Tropical Soils with Na^{+} Cl^{-} Radicals and Reclamation of Na^{+} Cl^{-} Salinity Using Biochar and Hydro-Leaching Technology: A Sustainable Strategy for Management of Saline and Sodic Soils Under Climate Change

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Estimulación de suelos tropicales con iones Na^{+} Cl^{-} y recuperación de la salinidad Na^{+} Cl^{-} utilizando tecnología de biocarbón e hidrolixiviación: una estrategia sostenible para la gestión de suelos salinos y sódicos bajo el cambio climático

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Abstract: Humanity suffered far-more-than 80% increase in environmental-climatic-ecosystem-degradation. As a modality towards sustainable-solution to salt-soil toxicity with climate-change, and for the reclamation/management of global Salt Affected-Soils, this study investigated soil-salinity status with the objectives of x-raying sustainable approaches for the management and reclamation of salt-affected soils. Stimulations and laboratory studies were conducted to induce soil samples with 70g of $Na^{+}Cl^{-}$ radicals which follow a reclamation procedure with 70 g of biochar technology and leaching with one (1) liter of distilling water. Results indicated the two reclamation strategies were able to reclaim soils induced with $Na^{+}Cl^{-}$ radicals at a Coefficient of Variation value at (CV=62%) which indicated a high variability potential in the reclamation technology. Forecasting results indicated that the area could remain free of salt, but if unsustainable practices like the application of untreated wastewater for irrigation, then a percentage at a high dosage of salt (4.3 dS/m for $Na^{+}Cl^{-}$) could result as observed during the inducement stage of this experiment. Biotechnical tools like Biochar at 70g are recommended for reclamation at a pot stage of salinity influence, and at a larger dosage for larger fields, as this could drive sustainable soil-productivity.

Keywords: Salt-affected soil, Biotechnical Tools, Hydro-leachingTechnology, Biochar Technology, Clean Mechanism, Sodic-soil sequestration.

Resumen: La humanidad ha sufrido un aumento de más del 80% en la degradación del medio ambiente-climático-ecosistema. Como una modalidad hacia la solución sostenible de la toxicidad del suelo salino con el cambio climático, y para la recuperación/gestión de los suelos globales afectados por la sal, este estudio investigó el estado de la salinidad del suelo con los objetivos de radiografiar los enfoques sostenibles para la gestión y recuperación de los suelos afectados por la sal. Se realizaron estímulos y estudios de laboratorio para inducir muestras de suelo con 70 g de radicales Na^+Cl^- que siguen un procedimiento de recuperación con 70 g de tecnología de biochar y lixiviación con un (1) litro de agua de destilación. Los resultados indicaron que las dos estrategias de recuperación fueron capaces de recuperar los suelos inducidos con radicales Na^+Cl^- con un valor de Coeficiente de Variación de (CV=62%) que indicaba un alto potencial de variabilidad en la tecnología de recuperación. Los resultados del pronóstico indicaron que el área podría permanecer libre de sal, pero si las prácticas insostenibles como la aplicación de aguas residuales no tratadas para el riego, entonces un porcentaje a una alta dosis de sal (4,3 dS/m para Na^+Cl^-) podría resultar como se observó durante la etapa de inducción de este experimento. Se recomiendan herramientas biotécnicas como el biocarbón a 70g para la recuperación en una etapa de influencia de la salinidad, y a una dosis mayor para campos más grandes, ya que esto podría impulsar la productividad sostenible del suelo.

Palabras clave: Suelo afectado por la sal, Herramientas biotécnicas, Tecnología de hidrolixiviación, Tecnología del biocarbón, Mecanismo limpio, Secuestro del suelo sódico.

1. INTRODUCTION

It is a far cry that disease outbreak, death, malnutrition including high-flux of migration has been recorded in lands of the global community affected with salts. The continual pilled-up of these soluble salts has over the years been geared by unsustainable land management, unsustainable agriculture including the vagrancies in the earth climatic system, which has worsen the hardship faced in many lands of the earth. With the increasing frequency in salt pollution-climatic variability nexus, more than 75% possibility in a worst-case scenario been projected (FA0, 2020). Rapid increase in environmental degradation aligning with soil-salt toxification and deforestation at a rate of above 80% has occurred in Asia. Also, above 50% painful experience has been faced in Africa relating to salty-lands which has geared migration and intensify the already dry-nature of the African continent, thereby altering habitats, degrade and natively manipulate the ecosystem towards unsustainability, while impacting on the lives-nutrition-economic nexus of the region (Abel *et.al*., 2019; International Institute of Applied System Analysis, 2019). This list is inexhaustive and heart-broken, presenting a view that if sustainable remediation is not taken then we will have more malnourished and sick people in years to come, our environment will be more polluted and toxic, our water system will become more and more difficult to remediate, there could be increase in local, national and international conflict among other unforeseen unpleasant happenings.

Soil salinity has emerged as the most significant problem of present-day agriculture especially as scanty of rainfall coupled with high temperature driven by climatic change which over the years and more devasting now has cause huge down-turn on Agricultural production and on soil functionality and sustainability.

The salinization, or development of salt affected soils (saline and sodic), is a degradation process usually leading to desertification of lands. In general, in salt affected soils the water deficits make the survival of natural vegetation and crops difficult or impossible. These moisture deficits are due to the difficulties for

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the plants to use the water stored in the soil ("saline soils"), or to the difficulties for root development and for water infiltration into the soil ("sodic soils"). Although those processes may occur and have occurred under natural conditions, they become accelerated, leading to secondary salinization, when, mainly in arid and semiarid environments, the soil water regime is drastically changed with the introduction of irrigation and/or drainage.

In many countries, irrigation has become a very important component of food production, sometimes the most important. The areas with irrigation in the World has increased from 50 Mha in the year 1900 to 100 Mha in 1950, and to more than 250 Mha (Pla, 2007), over the recent years this phenomena have also contributed to the decrease of productivity and the increasing risks of dryland agricultural production on lands already affected by other degradation processes, mainly water erosion. The yearly loss of productivity, and desertification of irrigated lands, amounts to 1.5 Mha around the World, but the salinity problems, in different degrees, presently affect almost 50% of all the irrigated land (Pla, 2007). The social, economic, and environmental effects of salinization are of a high magnitude, with the consequence of high value placed on the maintenance of irrigated lands, and their coincidence with areas of large urban and industrial developments.

Salinity are predominant conditions in the plains, valleys, deltas and coastal plains of the world with the influx of sea, river and ocean salt water (Pla, 2007). In arid and semiarid climates, the scarcity and erraticity of rainfall, together with the high evapotranspiration rates, makes the water and salt balances favourable for the processes of soil salinization (Pla, 2007; Pannell and Ewing, 2006) The problems of secondary salinization are a consequence of non-adequate water management by irrigation and drainage, under a particular set of conditions, including: -Climate, Crops, Soils, Fertilization, Groundwater depth, Water quality, Irrigation system.

Soil salinity is the presence of soluble salts in the soil solution. Excess soluble salts in the root zone reduce plant growth, through either, osmotic stress or specific ion toxicities (Vijayvargiya and Kumar, 2011). Salinity generally occurs in arid and semi-arid regions, where leaching of the profile is restricted (Bernstein, 1975; Yuan *et al.* 2007). Soil salinity is one of the important soil properties that significantly affect agricultural production and environmental quality especially in the semiarid regions of the world and conventional chemical indicators of soil salinity include; electrical conductivity (EC), total dissolved solids (TDS) – refers to the total amount of soluble salts in a soil-saturated paste extract expressed in parts per million or milligrams per liter (ppm or mg/L), and exchangeable sodium percentage (ESP) is the sodium adsorbed on soil particles as a percentage of the Cation Exchange Capacity (CEC), while electrolyte stability index (ESI) gives a good indication of soil dispersion, although the threshold ESI value below which effective structural breakdown might occur is 0.025, which is twice as small as the expected 0.05 (Lin and Bañuelos, 2015; Odeh and Onus, 2008). Against these soil degrading factor, this study objectives include:

i. Present the result output of field investigating of salinity status of soils in University of Abuja

ii. Evaluate and present sustainable approaches for management and reclamation of salt affected soils of the study area

iii. Indicate Earth-system properties variability with soil salinity of the study area

iv. Forecast three (3) years interval in the salinity of the area with the present empirical data

2. MATERIALS AND METHODS

2.1. Location of the Study Area

The study was conducted during the dry season of late 2020 within the landmass of University of Abuja the Federal Capital Territory (FCT) of Nigeria as in Fig. 1.

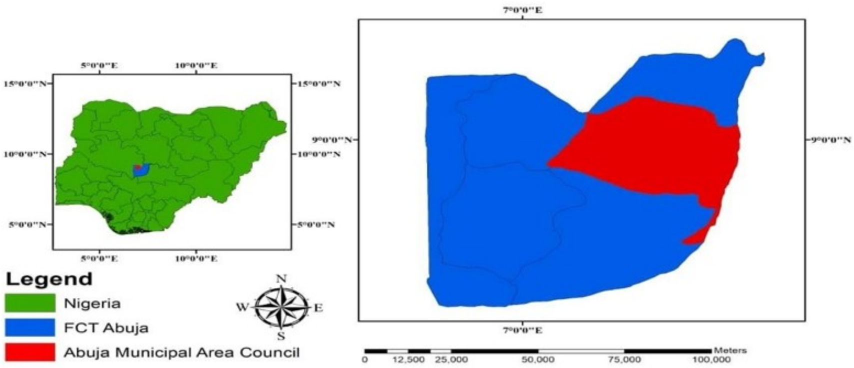

FIG. 1.
Location of the study area
Oku *et al.* (2020)

2.2 Background of the Study Area

The Federal Capital Territory of Nigeria falls within the Southern Guinean Savanna zone of the West Africa (Oku *et al*., 2020). The soils of Abuja are classified as Alfisols and sub order of Ustalfs with Ustic moisture regime. The area has a characteristics of the sub humid climate regime (Oku *et al*., 2020). There is a dominant occurrence of plinthite layers or continuous concretionary layers precisely within 24 cm and 39 cm and at times 150 cm depth (Oku *et al*., 2020). At the great-order group of Plinthustalfs, another sub-group as Typic Plinthustalfs exist (Lawal *et. al.*, 2012; Oku *et al.*, 2020).

2.3 Characteristics of the Soils of the Study Area

The soils of Abuja are underlain predominantly by basement complex rocks dominated by granites, gneisses, migmatites, quartzites and schist (Bennett *et. al.*, 1979; Oku *et al.*, 2020). The upland soils of the area which exist under the basement complex formation are generally deep, weakly to moderately structured and has sand to sandy clay in it texture with gravel and concretionary layers in the upper or beneath the surface layers (Ojanuga, 2006;Oku *et al.*, 2020). Quartz is observed to be the prominent mineral constituents of the soils with high kaolinite clay content which is responsible for the relatively low plasticity of the soils (Alhassan *et. al.*, 2012; Oku et. al., 2020).

2.4 Geographic information of the Study Area

Although officially in Abuja Municipal Council Area, the University of Abuja landmass falls within Gwagwalada. Gwagwalada is a suburb of the Federal Capital Territory, Nigeria. It is situated along Abuja-Lokoja road at about 55 kilometers away from FCT main town and centrally located between latitudes 8.55' N - 9. 00'N and longitudes 7. 00' E - 7. 04' E (Ishaya, 2013). With a population of about 157,770 at the 2006 census, the region covers a total landmass of about 65 km^2. out of the 8,000 km^2 of the total FCT land mass and located at the center of very fertile area with abundance of grasses (Ishaya, 2013). The area is bordered by Kuje Area council to the East, Abaji area council to the West, Kwali area council to the south and Abuja Municipal Area Council to the Northeast and to the North by Suleja Local Government Area of Niger State (Balogun, 2001).

2.5 Climatic and Geo-characteristics of the Study Area

The area is characterized by warm, humid, rainy season and a scorching dry season. Research report of Oku *et. al.* (2020) has indicated that the highest annual rainfall within the Territory is about 1632 mm. The area has been reported to have recorded a 20 % in its relative humidity. The area has recorded a 30% in it elevation with high values at the extreme south of the area.

2.6 Field Survey and Earth-system Property Data Collection

The University of Abuja landmass was stratified into four (4) stratum according to the catena that exist in the area. Twenty (20) experimental stations where five (5) random samples were taken and bulk together at each of the stratified points sampled to investigate the salinity variability that exist in the earth-system properties of the area.

2.7 Geographic studies and Data collection:

Field data were collected for geographic studies where each experimental stations in the three strata were georeferenced and mapped.

2.8 Soil Sampling and Data generation

Soil sampling was done with soil auger at a depth of 0-60cm at each location of the twenty (20) experimental points. Sampling methodology was stratified random sampling technique done in accordance with the four (4) catena used for the studies.

2.9 Pre-laboratory Investigation and Analysis

1. Particle size analysis distribution of (Afisols (Typic Plinthustalf)) the Area

Particle size distribution analysis (PSA) was done using the hydrometer method (Gee and Bauder, 1986).

2. Bulk density

Bulk density was determined by the core method (Burke *et. al.*, 1986).

3. Porosity

Porosity was calculated as the function of total volume not occupied by soil solids, assuming a particle density of 2.65 Mg m^{-3}(Danielson and Sutherland, 1986).

4. *Organic Carbon Determination*:

Soil organic matter content of the soil was estimated from the soil organic carbon content present in the soil. This procedure was done following the equation (equation 1) as presented by van Bemmelen, and used by Adiaha *et. a*l., (2020 c) which presented a value of 0.58, as a standard for converting SOC to SOM.

$$\text{OrganicMatter(OM)}\,\% = \text{OrganicCarbon(OC)}\,\% \times 0.58 - - -- - - 1 \qquad \text{[Ec 1]}$$

5. Soil organic carbon

Soil organic carbon was determined by the wet oxidation method (Nelson and Sommers, 1982). Percentage (%) SOM = % organic carbon×1.724 (Walkley, 1934).

6. Soil salinity

Soil salinity was measured by passing an electric current between two electrodes of a salinity meter in a sample of soil solution, as described by Government of New South Wales Department of Agriculture, NSW Agriculture (2003).

2.10.1 Laboratory Simulations and Soil Salinity Inducement and Treatment

i. Soil samples were induced with 70g of Na^{+} Cl^{-}. radical and kept in a control room temperature, this was done following the procedure outline by Todman1 *et. al.* (2018)

ii. Induced soil samples were treated with 70g of Biochar at one week after inducement (WAI) with Na^{+}. Cl^{-}. radical, this was done following the protocol outline by Todman1 *et. al.* (2018). The biochar was produced through thermal decomposition of biomass in an oxygen-limited environment.

iii. At 2WAI the sample was leached with one (1) liter of distilled water per can of the twenty (20) induced soil sample setup. This procedure was done following the direction prescribed by FAO (2017)

Post-laboratory Analysis

Particle size analysis, bulk density, porosity, Organic carbon, Soil Organic Matter including Soil salinity was determined one day after leaching (DAL) using the same procedure in the pre-analysis. This was done to determine the impact of the reclamation procedure on the status of the soil physical and chemical properties. The procedure was done following the description as prescribed by FAO (2017).

Laboratory Simulation Modelling

Result obtained from the % sand and % clay fraction of the experimental soil particle size analysis was fitted into the soil-water characteristics model. The use of the soil-water characteristics model was prescribed by NRCS (2015) and emphasized by USDA (2013) and has been utilized widely for Earth-system properties studies: modelling and forecast.

Earth-system properties including Wilting point, Field Capacity, Saturation, Matric Bulk Density, Available water, Matric Potential, Moisture Content and Matric Osmotic count were simulated by fitting particle size analysis result, Organic matter content including soil salinity analysis result into the soil-water characteristics model and modelled following the description by NRCS as prescribed (NRCS, 2015; USDA, 2013 and FAO, 2016, this simulation procedure has yield wide experimental result and has been validated in research report presented by FAO (2016) including the work of Adiaha *et. al.*, (2020 c).

2.12 Data Processing and Analysis

i) Descriptive statistics: CV, % analysis, Mean, STD, SE including the chi-square statistics was applied in the study

ii) Correlation test of the Principal Component Analysis (PCA) of the exploratory statistics was applied to draw up relationship and evaluate the loss due to the impact of salinization in the experiment.

iii) In other to find the interaction that exit between the parameters, the Pearson Product Correlation (PPMC) analysis was utilized, where the coefficient of determination (R) and correlation coefficient (r) was utilized to establish the relationship. Simple Linear Regression model: $Y = a + b*X$ was utilized to present the relating influence among the various parameters.

iv) The chi-square statistics was applied to predict the influence of the interacting parameters and test its significant at 0.05% probability level.

v) A modelling and statistical tool: Statgraphics Centurion “version 19” was utilized to run data analysis and modelling and for production of the graphics.

vi) QGIS and ArcGIS was used for geographic mapping and modelling

2.13 Standardization of Laboratory Experimentation and Analysis

All parameters determined in the study were compared with standardized ratings for tropical soils presented in Table 1, 2 and in Table 3.

TABLE 1
Ratings for interpreting selected Earth System properties for tropical soils

Parameter	Range / Rating		Source
	Low	< 2	Udo et al., (2009)
Organic matter (%)	Moderate	2 - 3	
	High	> 3	
	Very High	> 6	
	Poor agricultural soils	< 40	Kachinskii, (1970)
Porosity (%)	Satisfactory agricultural soil	41 - 45	
	Good agricultural soils	46 - 50	
	Best agricultural soils	> 50	
Coefficient of variability (%)	Low	< 15	Wildings, (1985)
	Moderate	16 - 35	
	High	> 35	
	0.8	Very slow	
	0.8 - 2	Slow	
Saturated hydraulic conductivity (cm/hr)	2.1 - 6.00	Moderately slow	FAO, (1963)
	6.1 - 8.00	Moderately rapid	
	8.1 - 12.50	Rapid	
	> 12.50	Very rapid	
	< 1	Low	
Organic carbon (%)	1 - 1.5	Moderate	Udo et al., 2009
	> 1.5	High	

Source: Adiaha *et. al.* (2021)

TABLE 2
Ratings and classifications for interpreting saline soils

Soil salinity class	EC (dS/m)	Effects on crop plants
Non-saline	0 - 2	Salinity effects negligible
Slightly saline	2 - 4	Yields of sensitive crops may be restricted
Moderately saline	4 - 8	Yields of many crops are restricted
Strongly saline	8 - 16	Only tolerant crops yield satisfactorily
Very strongly saline	> 16	Only very tolerant crops yield satisfactorily

Source: Jeffrey (2013); Adiaha *et. al.* (2021)

TABLE 3
General Porosity Ranking

Soil porosity status indicator	Rating (%)
Soil very compact	<5%
Soil compact	5-10%
Soil moderately porous	10-25%
Soil highly porous	25-40%
Soil extremely porous	>40%

Source: Pagliai (1988); Adiaha *et. al.* (2021)

3.0 RESULT AND DISCUSSION

3.1 Result output of field investigation of salinity variability status of soils at University of Abuja

The result of earth-system properties with salinity variability as presented in Table 4 indicated that the distribution of salinity is uneven in the area. The laboratory output indicated that soils at station 1 holds salinity value of 1.3 dS/m. At Station 2, the salinity value of the area was observed at 2.4 dS/m. Salinity value of 3.1 dS/m was observed for Station 3. It could be stated that the value at Station produced higher salinity value that stands over Station 4 (2.9 dS/m), Station 5 (2.0 dS/m) and all other stations in Strata 1 of the study area. It could be stated that the soils at location with Stata 1 of the study area ranges between electrical conductivity class of non-saline and slightly saline soils (1.3-.1 dS/m). A Coefficient of Variation at (CV= 28%) which indicated a moderate variability in the salinity of soils at this strata.

At Strata 2, as presented in (Table 5), a CV= 11% which is low variability in the salinity of the soils of the strata was observed. The salinity status at Station 6 indicated the site Electrical Conductivity (EC) flux at 2.5 dS/m presenting a view that soils of the site is slightly saline in nature. At Stata 7 an EC measure indicated 2.3 dS/m as salinity status of the area. At Strata 8 a salinity value of 2.5 was obtained which also indicated that the site is slightly saline. Station 9 presented a salinity value at 2.0 and Strata 10 EC salinity class was also observed at 2.0 and 1.8 respectively, this indicated that two stations are non-saline.

The behavior observed for Strata 3 in Table 6 presented that the strata is low variability class (CV= 9%) in its salinity status. It could be stated that all the stations in this strata holds a non-saline status in it EC with salinity values at (EC= 2.1, 2.0, 1.9, 1.6, 1.8 for Station 11, 12, 13, 14, and 15 respectively).

A similar variability class of CV= 3% as indicated in Table 7 was observed at soils that exist in Strata 4, where Station 16 produce a salinity value of 2.0 dS/m, Station 17 gave at salinity value at 1.9 dS/m, while Station 18, Station 19 and Station 20 produced a salinity class value at 1.8, 1.9 and 1.9 dS/m for the respective stations.

Result output and views presented in this study agrees with the research of FAO (2016) including the study of Oku *et. al.* (2020) which indicated variation in soil physical and chemical constituents due to variability that exist in the soil system and environmental influence.

TABLE 4
EarthSystem Properties Variability with Salinity flux in Soils for Strata 1

Strata 1

Lat	Long	Elevation (m)		Wilting point (% Vol)	Field Capacity (% Vol)	Saturation (% Vol)	Available water (cm/cm)	Saturated Hydraulic conductivity (cm/hr)	Matric Bulk Density (g/cm3)	Organic Matter (% Wt)	Organic Carbon (%)	Moisture Content (% Vol)	Matric Potential (kPa)	Matric Osmotic count (kPa)	Salinity (dS/m)
8.983139	7.180917	284	Station 1	3.3	10.3	47	0.07	12.848	1.4	14	8	13.8	126	126	1.3
8.981389	7.177806	264	Station 2	3.4	11.4	46.8	0.08	11.917	1.41	13	8	13.9	31	31	2.4
8.979833	7.176528	261	Station 3	4	12.2	46.5	0.08	10.704	1.42	12	7	14.8	32	32	3.1
8.981889	7.174444	260	Station 4	6.4	17.4	45.6	0.11	6.053	1.44	13	8	13.8	81	81	2.9
8.975417	7.168	256	Station 5	6.5	19.8	45.9	0.13	5.07	1.43	16	9	15	115	115	2
Mean				4.72	14.22	46.36	0.09	9.32	1.42	13.60	7.89	14.26	77.00	77.00	2.34
STD				1.43	3.71	0.53	0.02	3.16	0.01	1.36	0.79	0.53	40.00	40.00	0.65
CV %				30	26	1	24	34	1	10	10	4	52	52	28
SE				0.64	1.66	0.24	0.01	1.41	0.00	0.61	0.35	0.24	17.89	17.89	0.29

TABLE 5:
Earth-System Properties Variability with Variability with Salinity flux in Soils for Strata 2

Strata 2

Lat	Long	Elevation (m)		Wilting point (% Vol)	Field Capacity (% Vol)	Saturation (% Vol)	Available water (cm/cm)	Saturated Hydraulic conductivity (cm/hr)	Matric Bulk Density (g/cm3)	Organic Matter (% Wt)	Organic Carbon (%)	Moisture Content (% Vol)	Matric Potential (kPa)	Matric Osmotic count (kPa)	Salinity (dS/m)
8.975778	7.1685	252	Station 6	4.6	14.1	46.2	0.09	8.904	1.43	14	8	14.9	36	36	2.5
8.976694	7.169278	269	Station 7	5.2	14.5	45.9	0.09	8.17	1.43	11	6	28.1	41	41	2.3
8.971639	7.174667	275	Station 8	3.4	11.7	46.8	0.08	11.733	1.41	15	9	89.3	31	31	2.5
8.971028	7.175556	278	Station 9	7.2	18.8	45.8	0.12	5.453	1.44	18	10	79.3	101	340	2
8.973778	7.187639	289	Station 10	5.9	15.3	45.9	0.09	7.778	1.43	12	7	83.2	48	263	1.8
Mean				5.26	14.88	46.12	0.094	8.4076	1.428	14	8.12	58.96	51.4	142.2	2.22
STD				1.16	2.10	0.33	0.01	1.85	0.01	2.24	1.30	28.33	23.21	120.83	0.25
CV %				22	14	1	13	22	1	16	16	48	45	85	11
SE				0.52	0.94	0.15	0.00	0.83	0.00	1.00	0.58	12.67	10.38	54.04	0.11

TABLE 6
EarthSystem Properties Variability with Salinity flux in Soils for Strata 3

Strata 3

Lat	Long	Elevation (m)		Wilting point (% Vol)	Field Capacity (% Vol)	Saturation (% Vol)	Available water (cm/cm)	Saturated Hydraulic conductivity(cm/hr)	Matric Bulk Density (g/cm3)	Organic Matter (% Wt)	Organic Carbon (%)	Moisture Content (% Vol)	Matic Potential (kPa)	Matric Osmotic count (kPa)	Salinity (dS/m)
8.972861	7.188944	293	Station 11	4.7	10.3	46.7	0.06	12.06	1.41	16	9	84	30	286	2.1
8.976917	7.183	283	Station 12	4.3	11.7	46.7	0.07	11.733	1.41	11	6	67	31	276	2
8.976972	7.181639	275	Station 13	5.9	14.5	45.9	0.09	8.17	1.43	12	7	61	41	268	1.9
8.978722	7.184139	282	Station 14	5.2	13.8	46.2	0.09	9.05	1.43	10	6	52	34	226	1.6
8.981833	7.190139	288	Station 15	5.4	15	46.1	0.1	8.33	1.43	13	8	49	44	261	1.8
Mean				5.1	13.06	46.32	0.082	9.8686	1.422	12.4	7.192	62.6	36	263.4	1.88
STD				0.55	1.78	0.32	0.01	1.69	0.01	2.06	1.19	12.47	5.55	20.47	0.17
CV %				11	14	1	18	17	1	17	17	20	15	8	9
SE				0.25	0.80	0.14	0.00	0.76	0.00	0.92	0.53	5.58	2.48	9.15	0.08

TABLE 7:
Earth-System Properties Variability with Salinity flux in Soils for Strata 4

Strata 4															
Lat	Long	Elevation (m)		Wilting point (% Vol)	Field Capacity (% Vol)	Saturation (% Vol)	Available water (cm/cm)	Saturated Hydraulic conductivity (cm/hr)	Matric Bulk Density (g/cm3)	Organic Matter (% Wt)	Organic Carbon (%)	Moisture Content (% Vol)	Matic Potential (kPa)	Matric Osmotic count (kPa)	Salinity (dS/m)
8.981639	7.193583	284	Station 16	5.4	14.1	46.2	0.09	8.904	1.43	11	6	48	36	277	2
8.983722	7.177444	272	Station 17	4.7	11.7	46.6	0.07	11.038	1.42	13	8	42	31	262	1.9
8.985222	7.175778	277	Station 18	9.3	24	46.1	0.15	3.106	1.43	12	7	51	270	486	1.8
8.987972	7.175778	272	Station 19	5.5	15.5	46.1	0.1	8.05	1.43	10	6	71	48	277	1.9
8.986889	7.173361	252	Station 20	7	17.4	45.6	0.1	6.05	1.44	10	6	68	81	307	1.9
Mean				6.38	16.54	46.12	0.102	7.4296	1.43	11.2	6.496	56	93.2	321.8	1.9
STD				1.64	4.17	0.32	0.03	2.69	0.01	1.17	0.68	11.44	90.10	83.39	0.06
CV %				26	25	1	26	36	0	10	10	20	97	26	3
SE				0.73	1.86	0.14	0.01	1.20	0.00	0.52	0.30	5.12	40.29	37.29	0.03

Study Survey and point of study location Map Fig 2

FIG. 2:
Points of experimental stations investigated for the study

Organic Carbon Distribution in Soils of the Study Area Fig 3

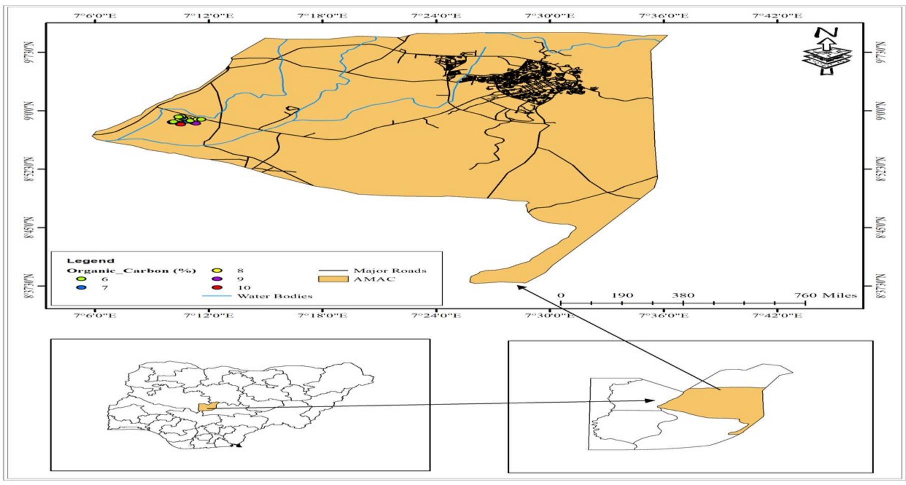

FIG. 3:
Organic carbon distribution in soils of University of Abuja, Nigeria

Strata variation that exist between Earth-System Properties and Salinity flux in Soils of the Area

The Strata influence that exist in the four stratum experimented as presented in Table 8 for this research indicated that there exist a variability in the salinity of the various soils that exist in the area, where the Strata 1 produced soils with mean salinity value at 2.34 dS/m of the Electrical Conductivity of the soil. Soils at Strata 2 produced soils with a mean value of EC = 2.22 dS/m, while Stata 3 soils recorded a value at 1.88 dS/m and Starla 4 = 1.90 dS/m respectively. It could be stated that data presented in Table 8 for the salinity variation in the four (4) Stratum investigated for this studies indicated that soil at Strata 1 has a Slightly saline potential at 2.34 dS/m > 2.22 dS/m for Strata 2 >1.90 dS/m for Strata 4 > 1.88 dS/m with ranking = non-saline at Strata 3.

TABLE 8

Strata variation that exist between EarthSystem Properties and Salinity flux in Soils of the Area

Mean Strata	Wilting point (% Vol)	Field Capacity (% Vol)	Saturation (% Vol)	Available water (cm/cm)	Saturated Hydraulic conductivity (cm/hr)	Matric Bulk Density (g/cm3)	Organic Matter (% Wt)	Organic Carbon (%)	Moisture Content (% Vol)	Matric Potential (kPa)	Matric Osmotic count (kPa)	Salinity (dS/m)
Strata 1	4.72	14.22	46.36	0.09	9.32	1.42	13.60	7.89	14.26	77.00	77.00	2.34
Strata 2	5.26	14.88	46.12	0.09	8.41	1.43	14.00	8.12	58.96	51.40	142.20	2.22
Strata 3	5.10	13.06	46.32	0.08	9.87	1.42	12.40	7.19	62.60	36.00	263.40	1.88
Strata 4	6.38	16.54	46.12	0.10	7.43	1.43	11.20	6.50	56.00	93.20	321.80	1.90
Mean	5.37	14.68	46.23	0.09	8.76	1.43	12.80	7.42	47.96	64.40	201.10	2.09
STD	0.55	1.13	0.10	0.01	0.83	0.00	0.98	0.57	17.53	19.82	86.39	0.18
SE	0.28	0.56	0.05	0.00	0.41	0.00	0.49	0.28	8.76	9.91	43.20	0.09
CV %	10	8	0	7	9	0	8	8	37	31	43	9

3.1.5 Particle Size Distribution (PSD) of Afisols (Typic Plinthustalf) of the Area

Result of particle size distribution of the area as presented in (Table 9) indicated that soils of the area are Loamy Sand, Sandy Loam and Loam soils, with variation impact at 15% for sand, which shows a low variability impact, 30% silt variation which contributed a high potential for the soil-physical quality potential and variation. However, the clay content variation influence of the soil was recorded at 53% which indicated a high contributory influence in the build-up of the few soil salinity observed in the strata one. At Strata 2, a 9% variation influence was observed to have been contributed by the sand content in soils of the area, which indicated a low contribution to the low soil carbon availability of the area. A 16% silt variation influence was observed to have added to the availability of the physical disability of the area. However, this contributory variation impact was moderate. A moderate contributory impact at a value of 31% was found for the clay content observed at Strata 2, indicating that clay particles of the soils at Strata 2 had more impact on the soil physical and chemical condition. Contributory impact on physical and chemical potential at the tone of CV = 9%, 24% and 27% for sand, silt and clay respectively was observed for the soils at Strata 3 indicating that sand particles in the soils had a low influence on the soil salinity flux of the area, while silt and clay content of the soil particles contributed towards the nature and EC of the soils. Sand and silt fraction of the soil particles at Strata 4 produce a moderate contributory effect on the soil functionality in the strata with a CV value recorded at 19% and 28% respectively.

It was observed that clay content at Strata 4 contributed the highest impact on the soil physical variability of the area with a variation contribution of 49% which stand above all other contributory impact in soils at Strata 1, 2, and 3 respectively. Results presented for the contribution of the Earth-System property of soil particle sizes indicated that the particles soils of the area has great potentials in the sustainability of the low to moderate salinity observed that exist in the soil system. Outcome of this finding agrees with the research of

Chude *et al.* (2020) which observed soil physical properties being a contributory factor to soil sustainability. This finding outcome also aligns with the work FAO (2020) which indicated the soils of physical and chemical properties being one of the major determinant of the soil functionality potential of an area. The research of Adiaha *et al*. (2020 c); Francious and Maas (1994); Hayward (1954) including Hernández *et. al.* (2020); Landeros-Sánchez *et. al*. (2016);Zuniga-Meza (2016); Úbeda Rivera and Dallatorre (2018); Catari et. al. (2022);Capetillo-Burela *et.al*. (2021);Colon-García *et. al*. (2021);Capetillo-Burela et. al. (2021); Catari *et. al.* (2022) also agrees with the outcome of this findings where the researchers reported the soils of the area contributing to bio-availability of soil organic carbon among other soil biophysical potential. Data presented in Table 10 indicated that the soils of the area ranges from compacted, moderately compact to been very compact, with CV = 60% which indicated a high variability in the soil pores system.

TABLE 9
Particle Size Distribution (PSD) of Typic Plinthustalf of University of Abuja, Nigeria

Experimental Station	Strata	Sand	Silt	Clay	USDA Textural Class
		g kg-1			
ST1		80.3	17.5	2.2	Loamy Sand
ST2		76	22.6	1.4	Loamy Sand
ST3		74.5	22.4	3.2	Loamy Sand
ST4		60.4	32.4	7.2	Sandy Loam
ST5	1	50.5	42.4	7.2	Loam
Mean		68	27	4	
STD		10	8	2	
CV %		15	30	53	
SE		4.5	3.6	0.9	
ST6		68.4	27.4	4.2	Sandy Loam
ST7		68.4	26.4	5.2	Sandy Loam
ST8		74.4	23.4	2.2	Loamy Sand
ST9		54.4	38.4	7.2	Sandy Loam
ST10	2	65.5	29.4	5.2	Sandy Loam
Mean		66	29	5	
STD		6	5	1	
CV %		9	16	31	
SE		2.7	2.2	0.4	
ST11		82.7	14	3.2	Loamy Sand
ST2		74.4	23.4	2.2	Loamy Sand
ST13		68.4	26.4	5.2	Sandy Loam
ST14		69.4	26.4	4.2	Sandy Loam
ST15	3	64.4	31.4	4.2	Sandy Loam
Mean		72	24	4	
STD		6	6	1	
CV %		9	24	27	
SE		2.7	2.7	0.4	
ST16		68.4	27.4	4.2	Sandy Loam
ST7		76.4	20.4	3.2	Loamy Sand
ST18		40.4	48.4	11.2	Loam
ST19		62.5	33.4	4.2	Sandy Loam
ST20	4	60.5	32.4	7.2	Sandy Loam
Mean		62	32	6	
STD		12	9	3	
CV %		19	28	49	
SE		5.4	4.0	1.3	

ST=Experimental station, SD = Standard deviation, CV = coefficient of variability, SE =Standard error

TABLE 10
Physical Properties Porosity of Soil of University of Abuja

Strata	Porosity (%)
Strata 1	
Station 1	21
Station 2	25
Station 3	17
Station 4	38
Station 5	38
Strata 2	
Station 6	14
Station 7	9
Station 8	18
Station 9	22
Station 10	15
Strata 3	
Station 11	35
Station 12	17
Station 13	1
Station 14	7
Station 15	41
Strata 4	
Station 16	18
Station 17	2
Station 18	13
Station 19	12
Station 20	14
X	18.85
STD	11.244
CV (%)	60
SE	2.51

X=mean, SD = Standard deviation, CV = coefficient of variability, SE = Standard error

Reclamation Programme Output

Strata 1

The strength of the reclamation strategies as presented in Table 11,Table 12,Figure 4, 5,6 and 7 indicated the influence of the reclamation strategy on the induced Na^+. Cl^-. radical. Data analysis and validation indicated a high significant influence at 5% probability level of the PPMC statistics and also at the chi-square statistics. Outcome of this findings confirms the research of FAO (2021) where her report indicated biological materials including gypsum and biochar including leaching being able to reclaim salt toxic soils.

TABLE 11
Salinization Reclamation Output at Strata 1

Strata 1								
				Pre-analysis	Post-analysis			
								Mean Reclamation
Geographic Properties				At existing point	Na+ Cl- Induce	Biochar Influence	Leaching Influence	Programme Influence % Influence
Lat	Long	Elevation (m)	Experimental Station Point	Salinity (dS/m)				
8.983139	7.180917	284	Station 1	1.3	4.3	0.8	0.5	0.65
8.981389	7.177806	264	Station 2	2.4	8.1	1.5	1	1.25
8.979833	7.176528	261	Station 3	3.1	9.1	0.8	0.3	0.55
8.981889	7.174444	260	Station 4	2.9	8.2	0.9	0.8	0.85
8.975417	7.168	256	Station 5	2	4.4	0.7	0.5	0.6
Mean				2.34	6.82	0.94	0.62	
STD				0.65	2.05	0.29	0.25	
CV %				28	30	31	40	
SE				0.29	0.92	0.13	0.11	

TABLE 12:
Influence of Biochar and leaching on Na+ Cl- Salinization at Strata 1

	Na+ Cl- Induce	Biochar Influence	Leaching Influence
Experimental Station Point	Salinity (dS/m)		
Station 1	4.3	0.8	0.5
Station 2	8.1	1.5	1
Station 3	9.1	0.8	0.3
Station 4	8.2	0.9	0.8
Station 5	4.4	0.7	0.5

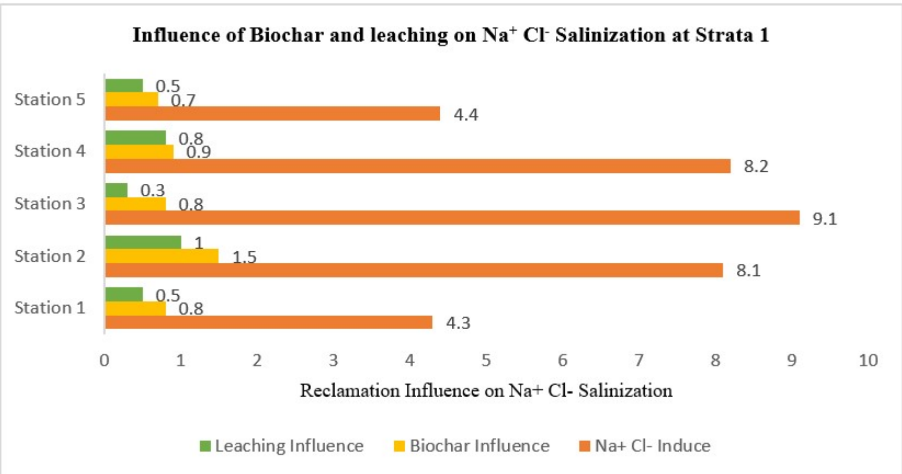

FIGURE 4:
Influence of Biochar and leaching on Na+ Cl- Salinization at Strata 1

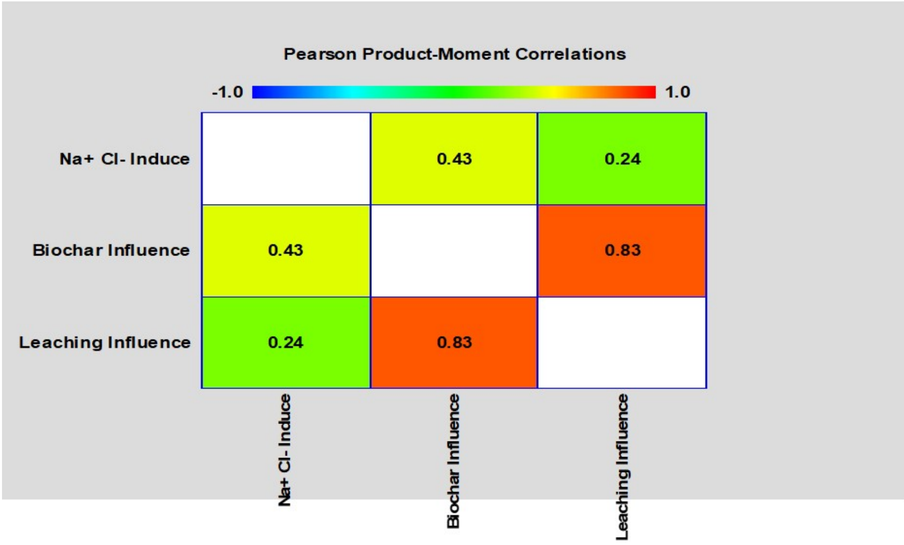

FIGURE 5
correlation influence of the programme for Strata 1

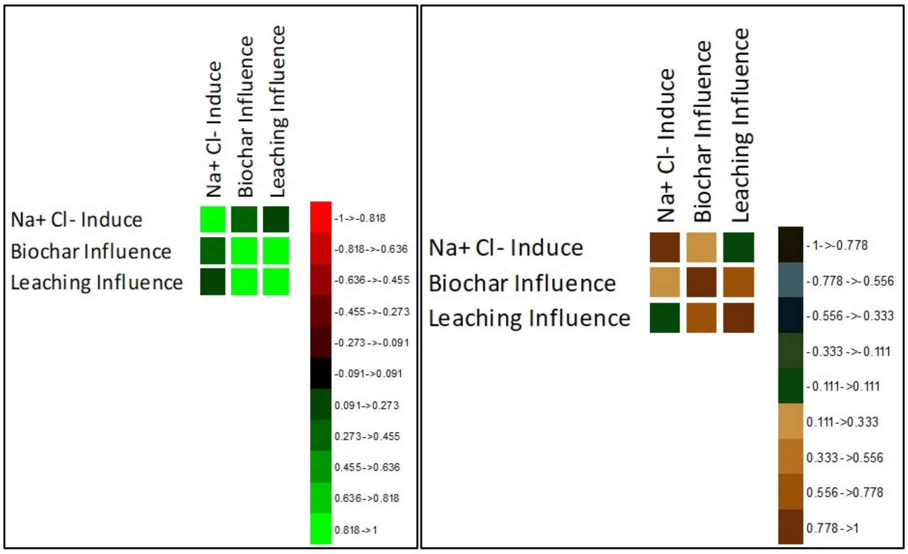

FIGURE 6
Image of the correlation matrix for reclamation Influence in Strata 1

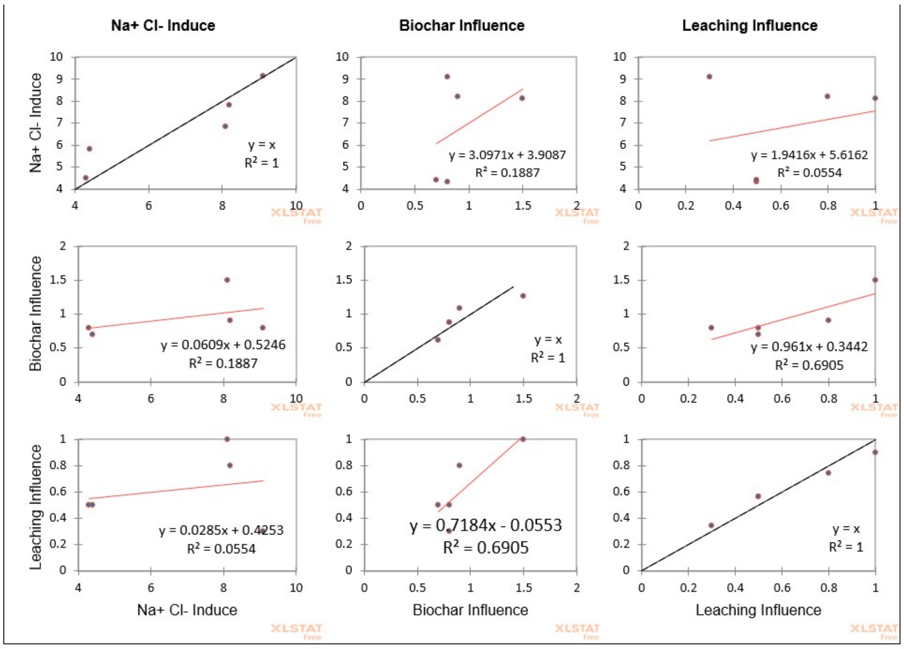

FIGURE 7:
Performance of the reclamation strategies

Forecasting three (3) years from today for STRATA 1

The result of the forecast indicated that the area will fluctuate in it salinity content in the raining season as presented in Figure 8a, 8b. The result also proof that there could be a build up of Na^+ Cl^- in the soils during the dry season as presented in Figure 9. Views presented in this findings is in accordance with the report presented by FAO (2021) which indicated climatic elements and environmental factors being among the driving forces for the buildup of soil salinity.

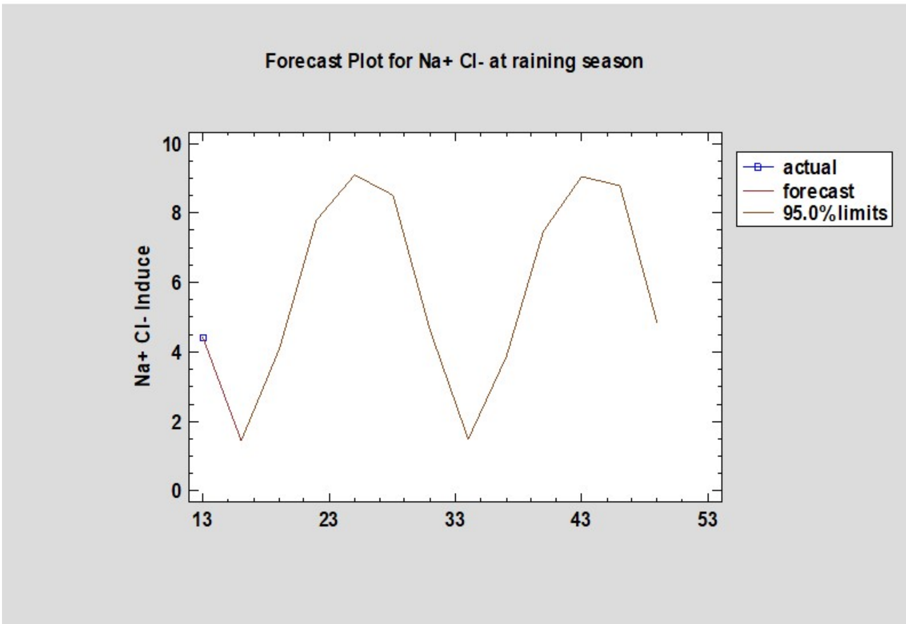

FIGURE 8A
Anticipated Salinity flux if the exist degradation of the event through Na+ Cl- build up from irrigation, climate change hazards including wrong chemical usage in the area

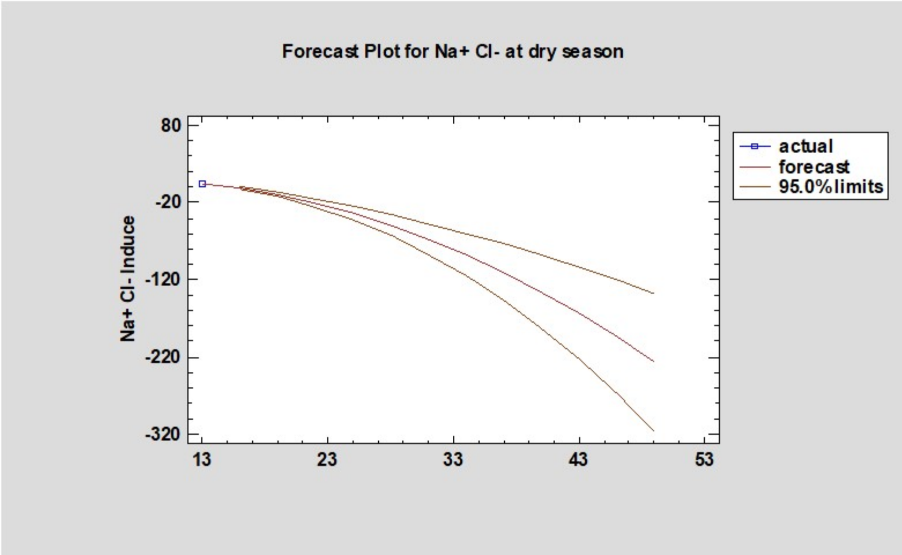

FIGURE 8B

Anticipated Salinity flux if the exist degradation of the event through Na^+Cl - build up from irrigation climate change hazards including wrong chemical usage in the area

Strata 2

The strength of the reclamation strategies as presented in Table 13, Table 14, Figure 9,10, 11 and 12 indicated that the reclamation programme yield productive output in the reduction of the induce salinity in the soil. Data analysis and validation indicated a significant influence at 5% probability level of the PPMC statistics and also at the chi-square statistics. Outcome of this findings confirms the research of FAO (2021) where her report indicated biological materials including gypsum and biochar including leaching being able to reclaim salt toxic soils. The result of the study is also in line with the views presented by Liang *et. al.* (2005) which indicated organic resources ability in the reduction of soil salinity.

TABLE 13

Salinization Reclamation Output at Strata 2

Strata 2								
				Pre-analysis	Post-analysis			
Geographic Properties				At existing point	Na Cl Induce	Biochar Influence	Leaching Influence	Mean Reclamation Programme Influence % Influence
Lat	Long	Elevation (m)	Experimental Station Point	Salinity (dS/m)				
8.975778	7.1685	252	Station 6	2.5	13.3	10.5	5.6	8.05
8.976694	7.169278	269	Station 7	2.3	9.1	7.4	4.3	5.85
8.971639	7.174667	275	Station 8	2.5	8.5	4.3	1.5	2.9
8.971028	7.175556	278	Station 9	2	7.3	4.5	2	3.25
8.973778	7.187639	289	Station 10	1.8	3.3	1.3	0.3	0.8
Mean				2.22	8.3	5.6	2.74	
STD				0.28	3.21	3.12	1.93	
CV %				13	39	56	70	
SE				0.13	1.44	1.40	0.86	

TABLE 14
Influence of Biochar and leaching on Na^{+} Cl^{-} Salinization at Strata 2

	Strata 2		
Experimental Station Point	Na+ Cl- Induce Salinity (dS/m)	Biochar Influence	Leaching Influence
Station 6	13.3	10.5	5.6
Station 7	9.1	7.4	4.3
Station 8	8.5	4.3	1.5
Station 9	7.3	4.5	2
Station 10	3.3	1.3	0.3

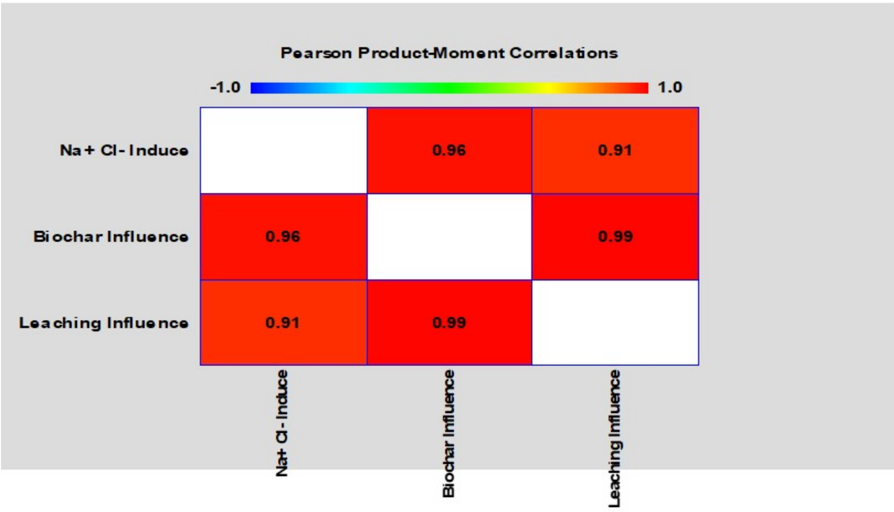

FIGURE 9
correlation influence of the programme for Strata 2

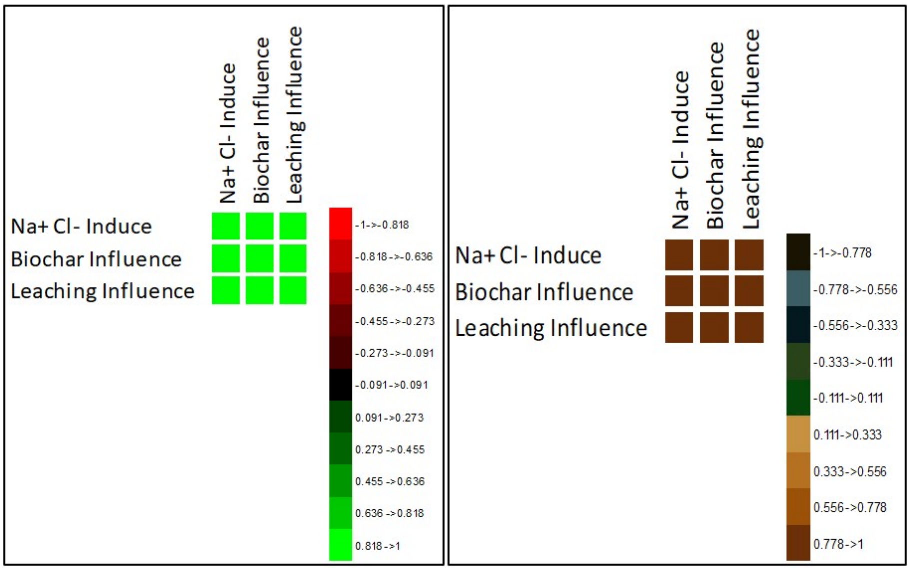

FIGURE 10
Image of the correlation matrix for reclamation Influence in Strata 2

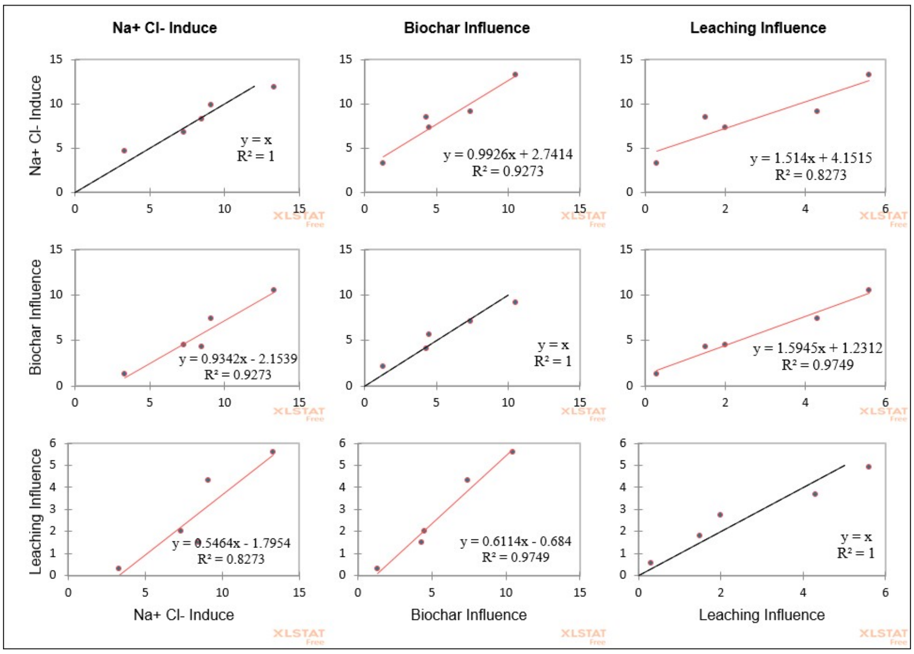

FIGURE 11
Performance of the reclamation strategies for Strata 4

Forecasting three (3) years from today for STRATA 2

Forecasting output for Strata 2 indicated also that the area will fluctuate in it salinity content in the raining season as presented in Figure 12. The result also indicated that there could be a build-up of $Na^{+.}$ Cl^{-}. in the soils during the dry season as presented in Figure 13. Views presented in this findings is in accordance with the report presented by FAO (2021) including the report of IPCC which indicated variation in soils and other component of the environment accounting for the variability that exist in the earth climatic system.

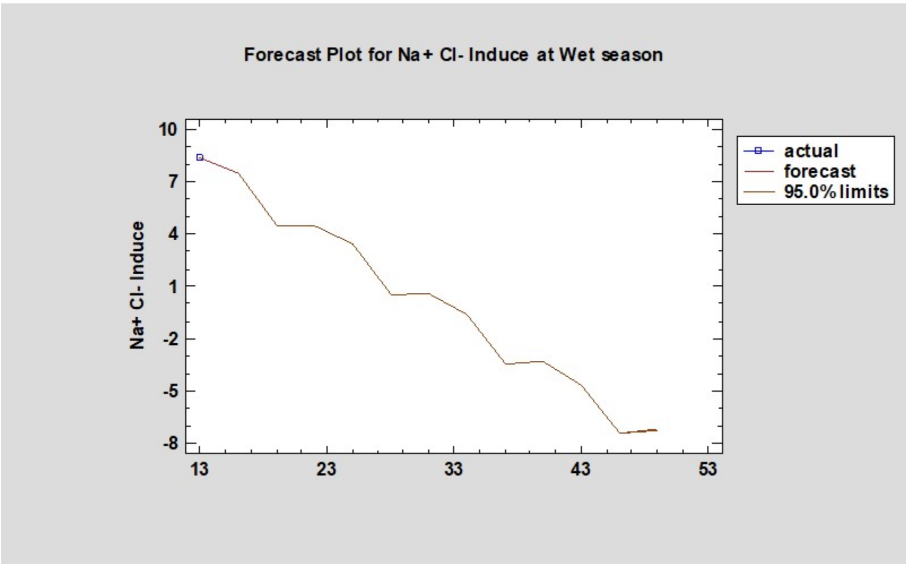

FIGURE 12
Anticipated Salinity flux if the exist degradation of the event through Na+ Cl- build up from irrigation, climate change hazards including wrong chemical usage in the area

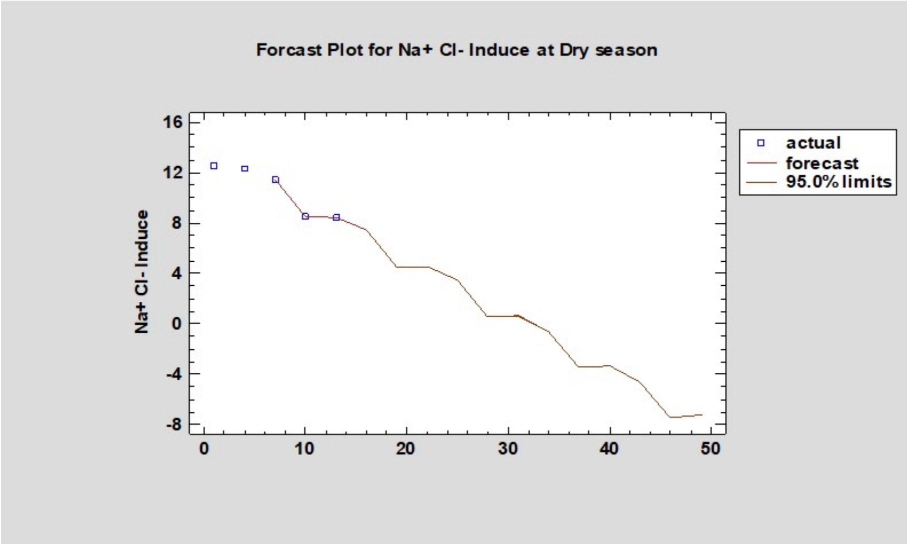

FIGURE 13
Anticipated Salinity flux if the exist degradation of the event through Na^+ Cl^- build up from irrigation, climate change hazards including wrong chemical usage in the area

Strata 3

At a 5% probability level of the PPMC statistics and also at the chi-square statistics as significant point was recorded for the strength of the reclamation strategies as presented in Table 15, Table 16, Figure 14, 15, 16 and 17 indicating that the influence of the reclamation strategy on the induced Na^+ Cl^- radical was positive and productive. Outcome of this findings confirms the research of FAO (2021) where her report indicated biological materials including gypsum and biochar being able to reclaim saline soils of the tropics.

TABLE 15
Salinization Reclamation Output at Strata 3

Strata 3								
				Pre-analysis	Post-analysis			
Geographic Properties				At existing point	Na+ Cl- Induce	Biochar Influence	Leaching Influence	Mean Reclamation Programme Influence % Influence
Lat	Long	Elevation (m)	Experimental Station Point	Salinity (dS/m)				
8.972861	7.188944	293	Station 11	2.1	10.5	6.3	4.2	5.25
8.976917	7.183	283	Station 12	2	7.3	4.5	1.2	2.85
8.976972	7.181639	275	Station 13	1.9	5.9	2.5	1.2	1.85
8.978722	7.184139	282	Station 14	1.6	8.1	5.9	3.2	4.55
8.981833	7.190139	288	Station 15	1.8	7.9	4.3	3.8	4.05
Mean				1.88	7.94	4.7	2.72	
STD				0.17	1.49	1.34	1.28	
CV %				9	19	29	47	
SE				0.08	0.67	0.60	0.57	

TABLE 16

Influence of Biochar and leaching on $Na^+ Cl^-$ Salinization at Strata 3

	Strata 3		
Experimental Station Point	Na+ Cl- Induce	Biochar Influence	Leaching Influence
Station 11	10.5	6.3	4.2
Station 12	7.3	4.5	1.2
Station 13	5.9	2.5	1.2
Station 14	8.1	5.9	3.2
Station 15	7.9	4.3	3.8

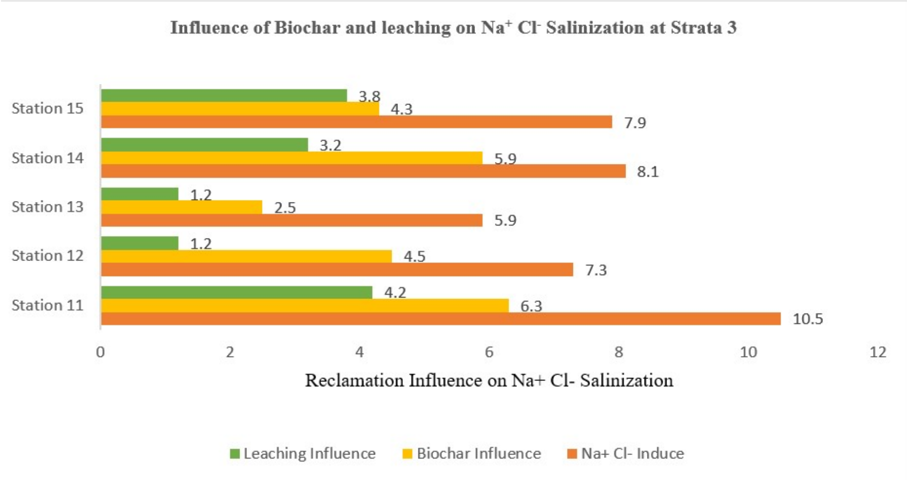

FIGURE 14

Influence of Biochar and leaching on Na+ Cl- Salinization at Strata 3

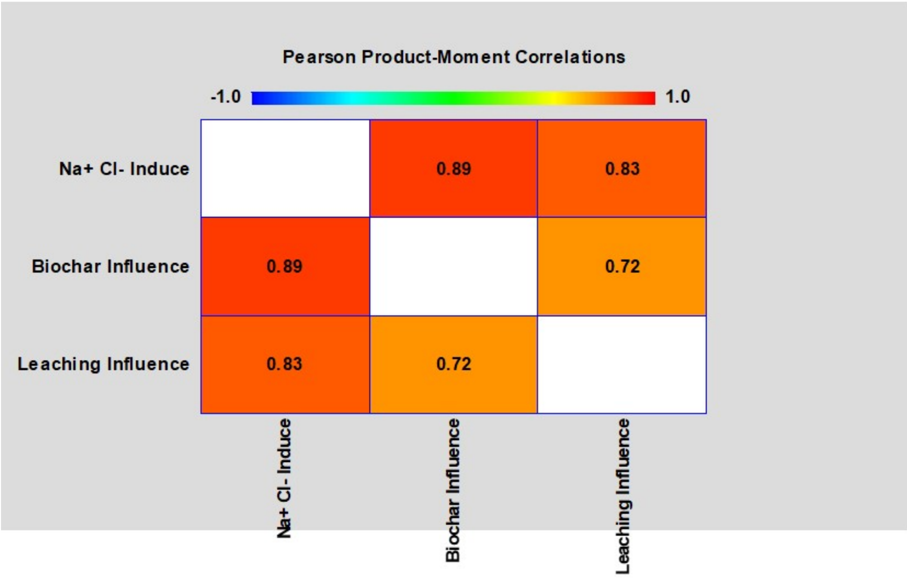

FIGURE 15

correlation influence of the programme for Strata 3

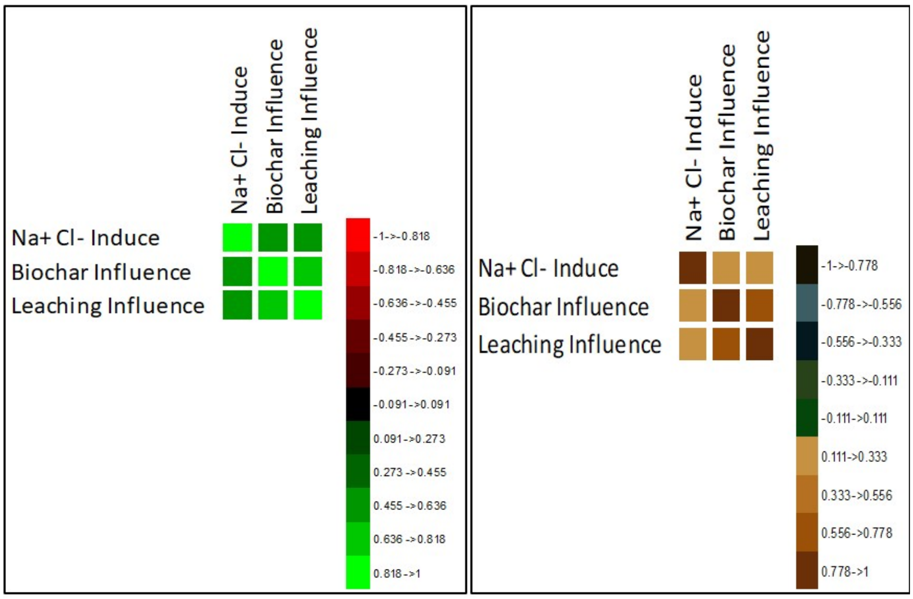

FIGURE 16
Image of the correlation matrix for reclamation Influence in Strata 3

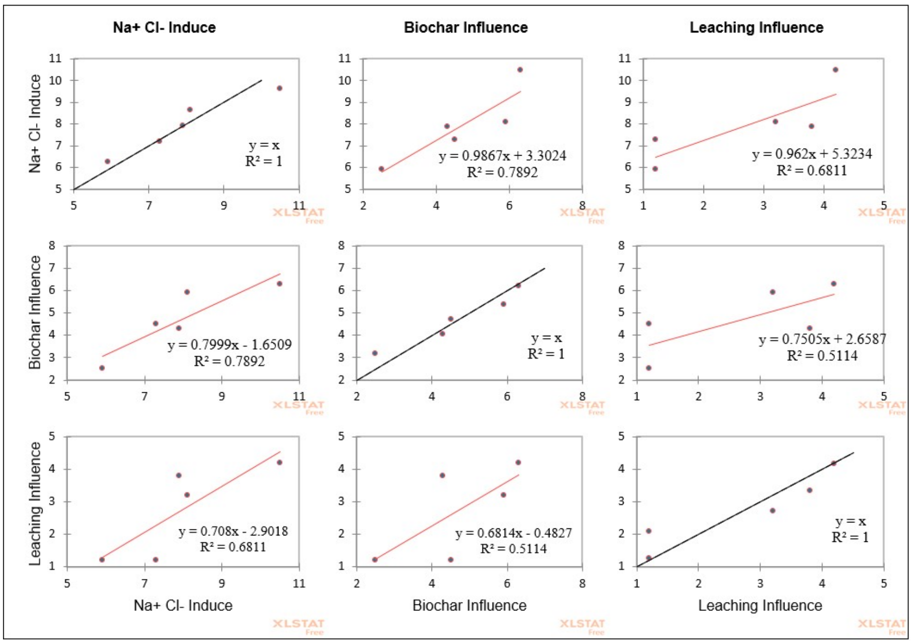

FIGURE 17
Performance of the reclamation strategies for Strata 3

Forecasting three (3) years from today for STRATA 3

Three years forecast output for Strata 3 has revealed that the area will fluctuate in it salinity class. This fluctuation will be climate controlled alongside other natural and anthropogenic factors. It could be stated that the raining season as presented in Figure 18 will be highly variable in its ability for the leaching of the area. The result indicated in Figure 19 for $Na^{+}.Cl^{-}$flux in three years time shows that the area could build-up salt during the dry period following anthropogenic and natural factors. Views explained in this findings is in accordance with the report presented by FAO (2021) including the report of Adiaha, *et. al.* (2022); IPCC (2020) which indicated variation in soils and other component of the environment with anthropogenic influence including the changes in the climate.

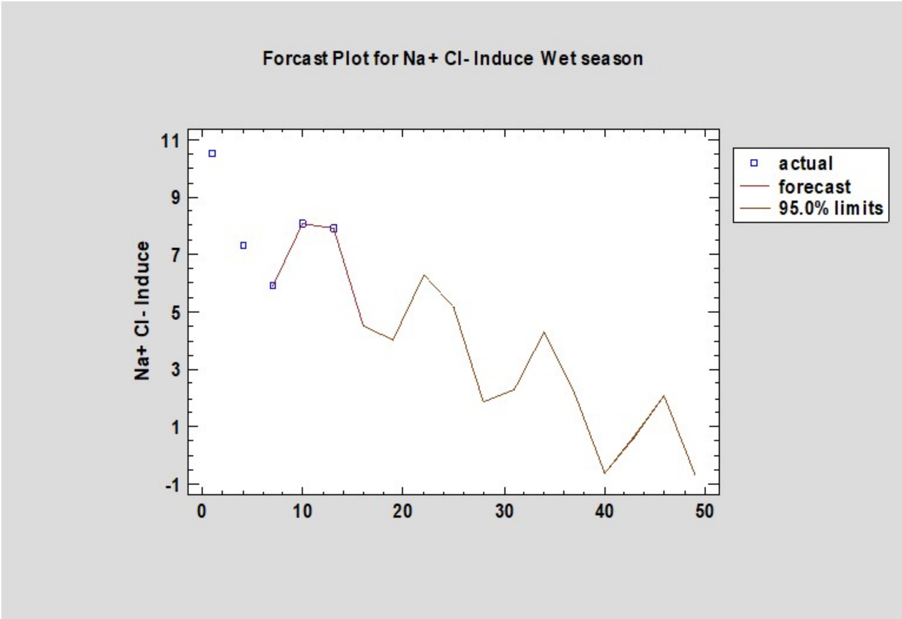

FIGURE 18
Anticipated Salinity flux if the exist degradation of the event through Na^{+} Cl^{-} build up from irrigation, climate change hazards including wrong chemical usage in the area

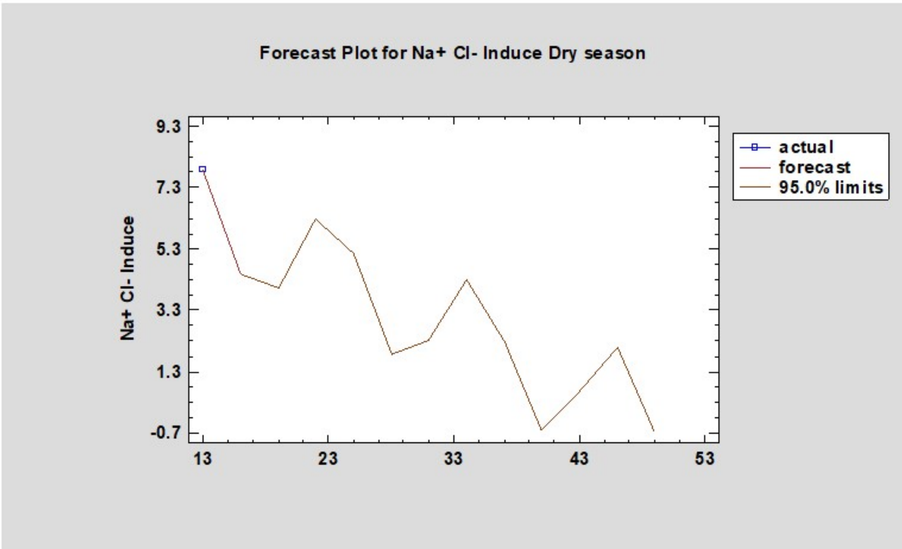

FIGURE 19
Anticipated Salinity flux if the exist degradation of the event through Na+ Cl- build up from irrigation, climate change hazards including wrong chemical usage in the area

Strata 4

The reclamation strategies as presented in Table 17 , Table 18, Figure 20, 21, 22 and 23 yield a significate influence in the reclamation process the induced Na^{+}. Cl^{-}. ions. Data analysis and validation indicated a high significant influence at 5% probability of level of the PPMC statistics and the chi-square statistics. Outcome of this findings confirms the research of FAO (2021) and the work of Liang *et. al.* (2005) where their report indicated biological materials having great influence in the reduction of soil salinity of an area.

TABLE 17
Salinization Reclamation Output at Strata 4

Strata 4								
				Pre-analysis	Post-analysis			
Geographic Properties				At existing point	Na Cl Induce	Biochar Influence	Leaching Influence	Mean Reclamation Programme Influence % Influence
Lat	Long	Elevation (m)	Experimental Station Point	Salinity (dS/m)				
8.981639	7.193583	284	Station 16	2	12.5	4.5	3.9	4.2
8.983722	7.177444	272	Station 17	1.9	12.3	10.2	18.5	14.35
8.985222	7.175778	277	Station 18	1.8	11.5	9.2	6.1	7.65
8.987972	7.175778	272	Station 19	1.9	8.5	4.4	3.1	3.75
8.986889	7.173361	252	Station 20	1.9	8.4	5.1	2.9	4
Mean				1.9	10.64	6.68	6.9	
STD				0.06	1.82	2.50	5.91	
CV %				3	17	37	86	
SE				0.03	0.81	1.12	2.64	

TABLE 18
Influence of Biochar and leaching on Na^+ Cl^- Salinization at Strata 4

	Strata 4		
Experimental Station Point	Na+ Cl- Induce	Biochar Influence	Leaching Influence
Station 16	12.5	4.5	3.9
Station 17	12.3	10.2	18.5
Station 18	11.5	9.2	6.1
Station 19	8.5	4.4	3.1
Station 20	8.4	5.1	2.9

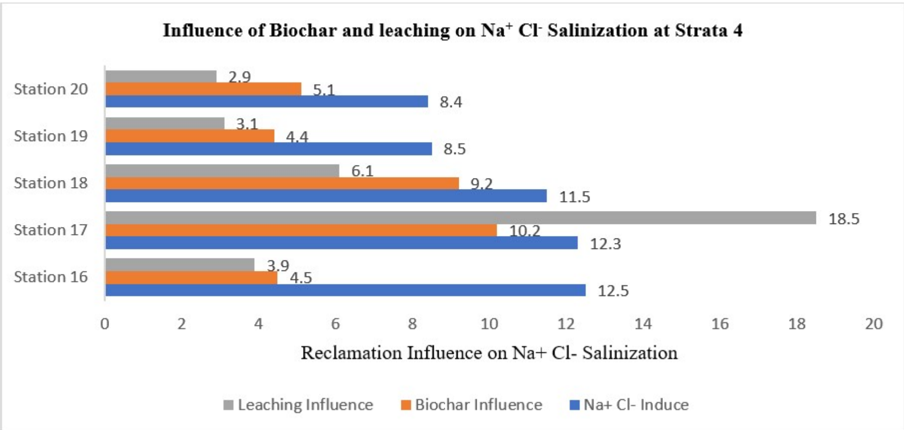

FIGURA 20
Influence of Biochar and leaching on Na^+ Cl^- Salinization at Strata 4

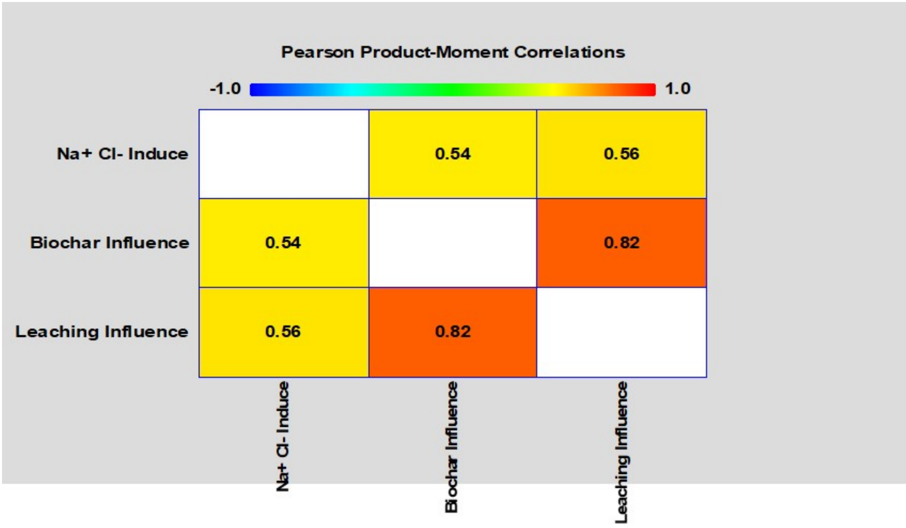

FIGURE 21
correlation influence of the programme for Strata 4

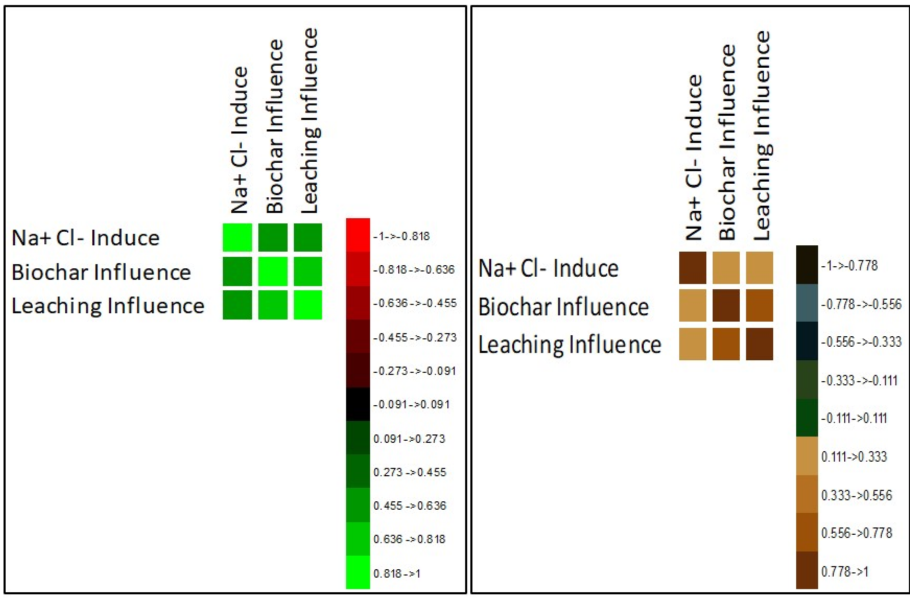

FIGURE 22
Image of the correlation matrix for reclamation Influence in Strata 4

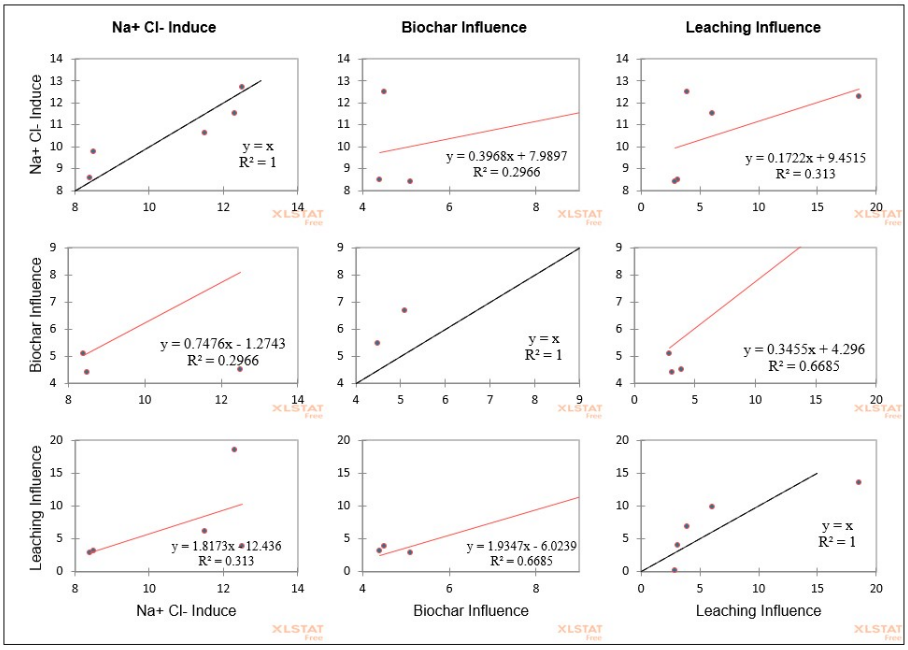

FIGURE 23
Performance of the reclamation strategies for Strata 4

Forecasting three (3) years from today for STRATA 4

Three years (3) interval forecasting output done for Strata 4 indicated also that the area will fluctuate in it salinity content in the raining season as presented in Figure 24. The result also indicated that there could be a build-up of Na+ Cl- in the soils during the dry period as presented in Figure 25. This findings is in accordance with the report presented by FAO (2021); IPCC (2016); Chude *et. al.* (2020) including the report of Oku *et. al.* (2020) which indicated variation in soil bio-physical and chemical functionality.

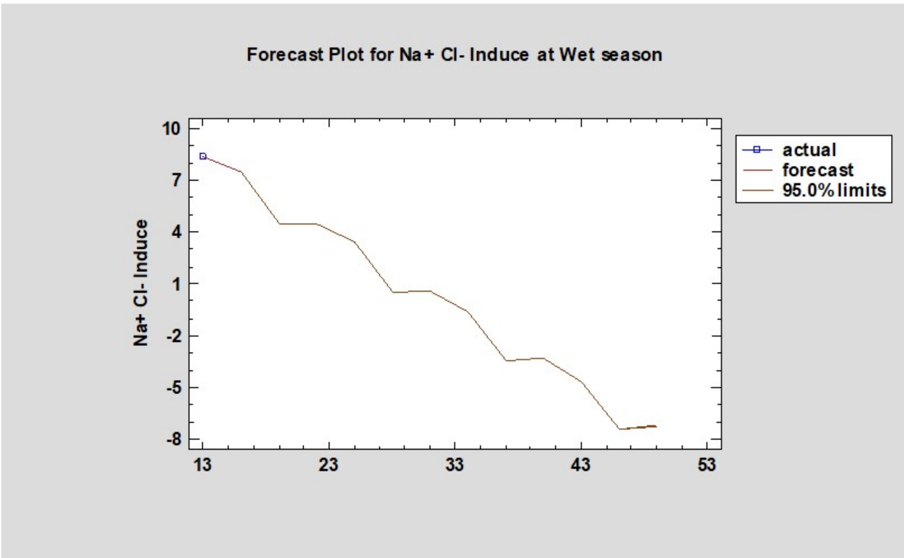

FIGURE 24
Anticipated Salinity flux if the exist degradation of the event through Na+ Cl- build up from irrigation, climate change hazards including wrong chemical usage in the area

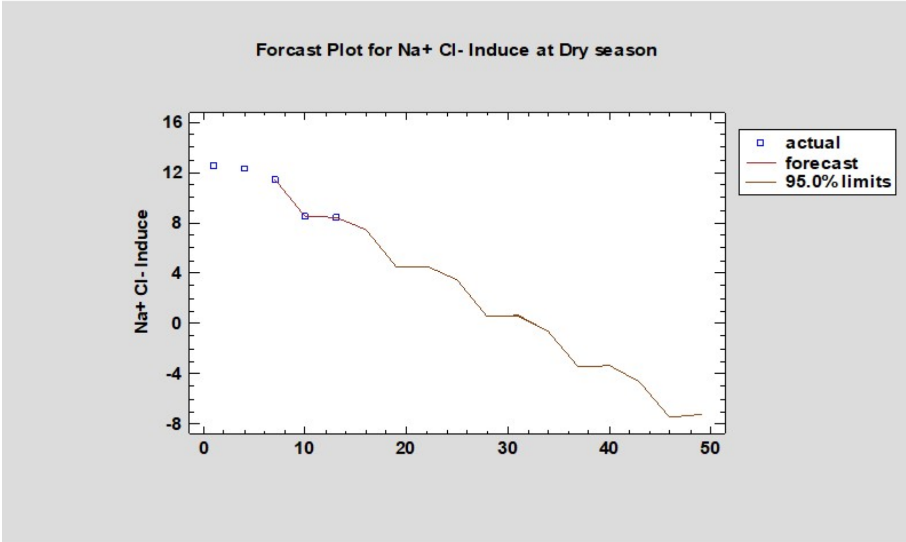

FIGURE 25
Anticipated Salinity flux if the exist degradation of the event through Na^{+} Cl^{-} build up from irrigation, climate change hazards including wrong chemical usage in the area

CONCLUSION

Outcome of this study indicated that Na^{+}. Cl^{-}. ions in salt affected soils can be effectively reclaimed with 70 g of biochar technology and leaching with distil water. The two reclamation strategies was able to reclaim soils induced with Na^{+}. Cl^{-}. radicals at a Coefficient of Variation value at (CV=62%) which indicated a high variability potential in the reclamation technology. Forecasting result indicated that the area could remain free of salt, but if unsustainable practices like application of untreated wastewater for irrigation occur, then a percentage at high dosage of salt (4.3 dS/m for Na^{+}. Cl^{-}) could result as observed during the inducement stage of this experiment. Hence biotechnical tools like Biochar at 70g is recommended for reclamation at a pot-stage of salinity influence reclamation, and at a larger dosage for larger fields, as this could drive sustainable soil productivity.

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