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# Salinity study of the soils of Fadama farms, Sokoto, Nigeria

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**ABSTRACT**

The wetland farms in the Wammakko region of Sokoto, Nigeria have been experiencing an increase in stunted growth of plants, reduced yield, burnt leaf tips and visible accumulation of whitish residues on the topsoil, all of which are pointers to a salt problem. This study was conducted during the dry season of August 2018 in the wetland Fadama farms, Nigeria to determine the salinity status of the soil. The experiment was conducted by dividing the chosen study area into 3 sites (based on topography, upper, middle and lower for sites A, B and C, respectively), from each site soil samples were collected at the depths of 0-15 and 15-30 cm. The collected samples were air-dried, crushed and sieved. The soil was then analyzed for particle size distribution, pH, organic carbon, total nitrogen, available phosphorous, exchangeable cations, soluble ions, cation exchange capacity (CEC), electrical conductivity (EC) at 25°C, Exchangeable sodium percentage (ESP) and sodium adsorption ratio (SAR) to aid in the salinity assessment. The analytical result revealed that the soil was predominantly silt loam with a pH range between slightly acidic to neutral. The organic carbon, total nitrogen and available phosphorous were low. The EC (25°C) was not >4, SAR was <13, ESP was >15 at 0-15 cm soil depth across sites. The soil was saline-sodic and $Mg(HCO_3)_2$ and $CaCl_2$ were identified as major contributors to the absolute salt concentration in the study area.

**Key Words :** Adsorption ratio, electrical conductivity, exchangeable sodium percentage, saline, salinity, sodic

## INTRODUCTION

Environmental stresses such as high winds, extreme temperatures, soil salinity, drought and flood have affected the production and cultivation of agricultural crops, among these, soil salinity is one of the most devastating environmental stresses, which causes major reductions in cultivated land area, crop productivity and quality (Yamaguchi and Blumwald, 2005; Shahbaz and Ashraf, 2013). A soil that contains excess salts that impair its productivity is referred to as a salt-affected soil. Salt in the soil can influence soil processes through the salt concentration in the soil solution (salinity) which determines the osmotic potential and the concentration of sodium on the exchange complex of the soil.

Saline soils have an electrical conductivity (EC) greater than 4 dS/m, exchangeable sodium percentage (ESP) less than 15% or salt absorption ratio (SAR) less than 13 and pH less than 8.5. Salinity is often associated with prolonged wetness and lack of surface cover and therefore increases the vulnerability of soils to erosion.

Salinity problems have been identified in irrigated fields lying in the same ecological zone of the study area (Jibrin *et al.*, 2008; Alhassan *et al.,* 2018), but continuous research in relation to salinity management is lacking or rather scanty for the wetland farm lands in Sokoto. The need for this cannot be over-emphasized especially when viewed against the realization that such information forms the background to an efficient and holistic use of soil and water resources (Anita *et al.*, 2020). It was also reported that information about the land base of Nigeria is required for land use and land management decisions at several levels of natural resources development (Orimoloye *et al.*, 2019; Fasino *et al.*, 2021). The

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foregoing therefore highlights the need to generate recent information on soil salinity levels of the wetland farm land with a view to foster correct management. This research was, therefore, developed to investigate the existence or not of salinity in the study area, to assess the extent of salinity (saline, saline-sodic or sodic), and to determine some physical and chemical properties of the soil.

## MATERIALS AND METHODS

The research was conducted during 2018 dry season at the Sokoto Fadama wetland farms, behind, Nigeria. Sokoto lies on latitude $13^0$ 03' 5" N: longitude $5^0$ 13' 55" E and altitude of 350m above sea level in the Sudan savanna agro-ecological zone of Nigeria (Kowal and Knabe, 1972). The climate has a mean annual rainfall of 659mm. The relative humidity ranges from 10-25% in the dry season but much higher in the rainy season (51-79%), with temperature range of 19-40$^0$C.

Three sampling sites were chosen across the cultivated field (according to topography, upper, middle and lower for sites A, B and C, respectively) from which representative soil samples were taken. From each site, 9 augering points were randomly selected and samples were collected using auger at 0-15 cm and 15-30 cm depths and composited to homogenize it. The composited soil samples were labeled as soil zone $A_1$ (0-15) and $A_2$ (15-30) for site 1; zone $B_1$ (0-15) and $B_2$ (15-30) for site 2and zone $C_1$ (0-15) and $C_2$ (15-30) for site 3.

Particle size analysis was determined using the Boyoucos hydrometer method. Soil pH was determined using a 1:1 soil-water ratio with glass electrode pH meter (Bates, 1954). Organic carbon and total nitrogen were analyzed using Walkley Black and micro-Kjeldahl Method respectively. Available phosphorus was determined using the Bray-1 method (Bray and Kurtz, 1945). Exchangeable bases were determined as follows; flame photometer was used to determine the concentration of Na and K while Ethylene diamine tetra-acetic acid (EDTA) method (titration) was used to determine Ca and Mg (Sharu *et al.*, 1982). $SO_4$ by calorimeter and chloride (Cl) by titration. $CO_3$ and $HCO_3$ were determined by potentiometer titration of saturated extract with HCl to pH 7 and 4 respectively (USSLS, 1954). The cation exchange capacity (CEC) was determined using ammonium acetate extraction method (Mustapha *et al.*, 2020). Electrical conductivity ($EC_{25}$) was determined with conductivity cell by measuring electrical resistance of a 1:2 soil: water suspension.

## RESULTS AND DISCUSSION

### Textural Properties of Soils in the Study Area

Table 1 presented results of the textural properties of soils in the study area. From the result, proportion of silt is greater than clay, with sand occupying the least proportion. The higher silt content observed in the subsurface layers of many soils may be attributed to illuviation process (Sharu *et al.*, 2013) The result indicated that soils in the area are within the silt clay loam to silt loam textural range.

### Selected Chemical Properties of Soils in the Study Area

Table 2 presented result of some chemical properties of soils in the study area, the result revealed that both organic carbon and organic matter throughout the study area

**Table 1.** Textural properties of soils in the study area

| Site | Code | Depth (cm) | Sand (%) | Silt (%) | Clay (%) | Texture Class |
|---|---|---|---|---|---|---|
| A | $A_1$ | 0-15 | 15.88 | 48.83 | 35.29 | Silt clay loam |
| | $A_2$ | 15-30 | 8.24 | 68.82 | 22.94 | Silt loam |
| | Mean | - | 12.06 | 58.83 | 29.12 | |
| B | $B_1$ | 0-15 | 23.53 | 58.82 | 17.65 | Silt loam |
| | $B_2$ | 15.30 | 38.82 | 34.71 | 26.47 | Loam |
| | Mean | - | 31.18 | 46.77 | 22.06 | |
| C | $C_1$ | 0-15 | 8.24 | 47.64 | 44.12 | Silty clay |
| | $C_2$ | 15-30 | 12.94 | 54.71 | 32.37 | Silty clay loam |
| | Mean | - | 10.59 | 51.18 | 38.25 | |

**Table 2.** Selected chemical properties of soils in the study area

| Site | Code | Depth (cm) | Total nitrogen (%) | Organic carbon (%) | Organic Matter (%) | Available phosphorus (mg/kg) |
|---|---|---|---|---|---|---|
| A | $A_1$ | 0-15 | 0.077 | 1.10 | 1.892 | 1.32 |
| | $A_2$ | 15-30 | 0.056 | 1.10 | 1.892 | 1.36 |
| | | Mean | 0.067 | 1.10 | 1.892 | 1.34 |
| B | $B_1$ | 0-15 | 0.039 | 1.12 | 1.926 | 1.36 |
| | $B_2$ | 15-30 | 0.035 | 0.58 | 0.998 | 1.28 |
| | | Mean | 0.037 | 0.85 | 1.462 | 1.32 |
| C | $C_1$ | 0-15 | 0.046 | 1.62 | 2.786 | 1.23 |
| | $C_2$ | 15-30 | 0.035 | 1.96 | 3.371 | 1.22 |
| | | Mean | 0.041 | 1.77 | 3.086 | 1.23 |

were low. Organic carbon less than 4% was considered very low in soils of the region (Chude *et al.*, 2012; Chaudhari *et al.*, 2018). The low organic matter content of the soils in Sokoto State has been attributed to factors such as continuous cultivation, frequent burning of farm residues commonly carried out by farmers in the area which tends to destroy much of the organic materials that could have been added to the soil (Aliyu *et al.*, 2020). Furthermore, Low organic matter content in soils of Sokoto area could be due to rapid decomposition and mineralization of organic materials contributed by sparse vegetation in the hot semi-arid climate as promoted by radiation (Agbu and Ojanuga, 1989). Low amounts of organic carbon in arid and semi-arid regions also appear to promote clay dispersion (Basga *et al.*, 2018). The low organic carbon values indicate poor fertility status of the soils.

The results of total nitrogen for all the sites are presented in Table 2, with values ranging from 0.077% to 0.056%; 0.039% to 0.035% and 0.046% to 0.035% for sites A, B and C respectively. These values show that the nitrogen levels of the study area were very low. Soil nitrogen content in Nigeria less than 0.5% is low (Chude *et al.*, 2012). Tropical soils are intrinsically low in N and these low N values may be due to low organic matter content of the soils since inorganic nitrogen contribute to only a small portion of total nitrogen in savannah soils (Mustafa and Nnalee, 2007; Bensemann *et al.*, 2018).

The values of Available phosphorus ranged from 1.32 to 1.36 mg/kg; 1.36 to 1.28 mg/kg and 1.23 to 1.22 mg/kg for sites A, B and C, respectively (Esu, 1991). Soils with available P level of <10 mg/kg is rated low. Therefore, this qualifies the soils of the study sites to be within the low range of available P.

## The EC, SAR, ESP and pH Values of the Study Area

### Soils from Site A

The values of the electrical conductivity at $25^0$C ($EC_{25}$) were 1.67 dS/m and 0.85 dS/m at depth $A_1$ and $A_2$ with a mean of 1.27 dS/m were less than 4 dS/m (Table 3) which indicates small amounts of soluble salts in the soil solution. This mean value places the soil as a saline-sodic soil (Gonzalez *et al.*, 2004). The mean value of the pH of both depths was 6.6 and therefore, neutral (Chude *et al.*, 2012). Since it is less than 8.5 which satisfies the criteria for classification of the soil as a saline-sodic soil (Sajal and Nasrin, 2020).

**Table 3.** The EC, SAR, ESP and pH values of the study area

| Site | Code | Depth (cm) | $EC_{25}$ (dS/m) | SAR | ESP (%) | pH |
|---|---|---|---|---|---|---|
| A | $A_1$ | 0-15 | 1.67 | 0.91 | 19.39 | 6.3 |
| | $A_2$ | 15-30 | 0.86 | 0.37 | 8.83 | 6.8 |
| | Mean | - | 1.27 | 0.64 | 14.11 | 6.6 |
| B | $B_1$ | 0-15 | 2.36 | 1.35 | 25.64 | 6.4 |
| | $B_2$ | 15-30 | 1.45 | 0.70 | 17.86 | 6.8 |
| | Mean | - | 1.19 | 1.02 | 21.75 | 6.6 |
| C | $C_1$ | 0-15 | 2.06 | 1.00 | 27.18 | 7.1 |
| | $C_2$ | 15-30 | 0.93 | 0.46 | 9.06 | 7.4 |
| | Mean | - | 1.5 | 0.73 | 18.12 | 7.2 |

EC= Electrical conductivity, SAR= Sodium adsorption ratio, ESP= Exchangeable sodium percentage.

The soil (soil A) has the sodium adsorption ratio (SAR) mean of 0.67, which was less than 13 and that indicates the concentration of sodium in the soil is much lower than the concentration of calcium and magnesium. The value is a threshold to define saline soils. The soil has a mean value of exchangeable sodium percentage (ESP) less than 15%, and therefore, the sodicity level is slight to moderate. This indicates the presence of less exchangeable sodium percentage relative to total exchangeable cations in $A_1$ which shows that precipitation have drawn sodium or magnesium ions to the soil surface. The obtained value is a threshold to define saline soils, low SAR values of the saturated extract are associated with low ESP values and vice versa.

Therefore, based on the examined parameters above and the attendant reasons and explanations, the soils of site A falls into the category of saline-sodic soils.

**Soils from Site B**

The soil has a mean value of 1.91 dS/m, which is below the 4 dS/m threshold and was characterizes as sodic soil. The pH values for both depths $B_1$ and $B_2$ were 6.4 and 6.8 respectively with a mean of 6.6 (slightly acidic to neutral) were less than 8.5 and this indicates the soil as saline-sodic and saline. The pH value of saline and saline-sodic soils is seldom higher than 8.5 due to high exchangeable Mg, Na and, or carbonate ions (Sajal and Nasrin, 2020). When an exchangeable magnesium or carbonate ion reacts with water, they produce hydroxides ions ($OH^-$) via the following reactions:

$$\rightarrow \text{Na-clay} + H_2O \quad \rightarrow \text{H-clay} + Na^+ + OH^-$$
$$\rightarrow CO3^{2-} + H_2O \quad \rightarrow HCO_3^- + OH^-$$

The resulting increase in amounts of OH- raises the pH. Soils collected from site B has minimal exchangeable sodium, magnesium and carbonate ions and this could be a reason for the slightly acidic to neutral nature of the soil. The SAR values of site B were 1.36 and 0.70 for $B_1$ and $B_2$ respectively, with a mean value of 1.02 (Table 3). This mean is less than 13 which indicates minimal levels of sodium concentration which is lower than the concentrations of calcium and magnesium. This is a threshold to categorize the soil as saline. The ESP values of $B_1$ and $B_2$ were 25.64% and 17.86% with a mean of 21.75%. these values are greater than 15% and it is a threshold to define sodic and saline-sodic soils.

Therefore, based on the examined parameters above and the attendant reasons and explanations, the soils of site B falls into the category of saline-sodic soils.

**Soils from Site C**

The $EC_{25}$ values of 2.06 and 0.93 for sites $C_1$ and $C_2$ respectively with a mean of 1.5 dS/m threshold which classifies the soil as a sodic soil because the values are below 4 dS/m. The pH values were 7.06 for site $C_1$ which is neutral and 7.35 for site $C_2$ which is slightly alkaline, both values place the soil as a saline soil. The SAR values were 1.00 for $C_1$ and 0.46 for $C_2$ with a mean of 0.73 which is less than 13 and it is a threshold to classify saline soils. The ESP value for $C_1$ is 27.18 which is very much higher that $C_2$ with a value of 9.06, this sharp contrast in exchangeable sodium percentage could be due to presence of zeolite minerals in the surface horizon the study areas (Gupta *et al.*, 1981). The mean ESP value was 18.12% and this is greater than 15% and therefore can be categorized as a saline-sodic soil (Gonzalez *et al.*, 2004). Based on the above EC, SAR, ESP and pH values, the soils of site C is saline-sodic.

**Type of Salt Formed in The Study Area**

The type of salts analyzed in the soil of the study area were carbonates, bicarbonates, chlorides, nitrates and sulphates (Table 4). Of these five salt types, bicarbonates were the most abundant in site A followed by nitrates, chlorides, carbonates with the least being sulphate. In site B, chlorides were the most abundant salt in the soils followed by nitrates, bicarbonates, carbonates and sulphates being the least. In site C, chlorides occupied the highest range with bicarbonates taking second

**Table 4.** Soluble ions of soils in the study area

| Site | Code | Depth (cm) | $CO_3^{2-}$ | $HCO_3^-$ | $Cl^-$ | $NO_3^-$ | $SO_4^{2-}$ |
|---|---|---|---|---|---|---|---|
| A | $A_1$ | 0-15 | 1.50 | 4.00 | 4.00 | 4.80 | 0.45 |
| | $A_2$ | 15-30 | 1.50 | 5.00 | 2.80 | 3.20 | 0.58 |
| | Mean | - | 1.50 | 4.50 | 3.40 | 4.00 | 0.52 |
| B | $B_1$ | 0-15 | 1.00 | Nil | 4.20 | 2.00 | 0.20 |
| | $B_2$ | 15-30 | 1.00 | 2.50 | 3.80 | 4.00 | 0.25 |
| | Mean | - | 1.00 | 2.50 | 4.00 | 3.00 | 0.25 |
| C | $C_1$ | 0-15 | 1.00 | 1.00 | 3.40 | 2.40 | 0.45 |
| | $C_2$ | 15-30 | 1.50 | 6.00 | 4.80 | 3.60 | 0.29 |
| | Mean | - | 1.25 | 3.50 | 4.10 | 3.00 | 0.37 |

place followed by nitrates, carbonates and finally sulphates. Sulphates and carbonates concentrations were generally found to be very low compared to the other analyzed salts. The high concentrations of nitrate could be due to excessive inorganic nitrogen fertilizer application and, or due to biological activity. These nitrates could be easily leached from the soil due to excessive irrigation, therefore it may not reflect future conditions. Mostly sulfates and/or chlorides salts are found in saline soil (Reich *et al, 2017)*, which indicates that this soil type has a saline character. However, there is more bicarbonate salt in soil from all the sites followed by chloride, mostly the presence of bicarbonate salt is a character of sodic soils (Qadir and Schubert, 2002), which indicated that these three soil sites had more saline-sodic character than either saline or sodic.

The dominant salt type in the three sites was different because the concentration of ions (cations and anions) which was involved in salt formation was different in each type of soils. The more dominant anions in soil from the three sites were $HCO_3$, Cl, $CO_3$ in decreasing order and from the cation (Table 4), there was more concentration of Ca, Mg, Na followed by K, in decreasing order (Table 5). By taking both the anion and cation concentration, it was possible to say there were more $Mg(HCO_3)_2$ (magnesium bicarbonate) and $CaCl_2$ (calcium chloride). The least expected salt type in soil from the three sites would be $Na_2SO_4$ (sodium sulfate).

## Similarities and Differences Among Soils of the Study Area

Salinity status of the three locations were saline-sodic, the only disparity is the seriousness of the salt problem. Using the four parameters of $EC_{25}$, SAR, ESP and pH, soils from site A has highest saline character given that its ESP is lower than sites B and C. SAR and ESP values are a direct indication of sodicity character (Keshavarzi *et al.*, 2016), which indicates that soils from site B has a higher sodicity character than soils of site C. $EC_{25}$ directly references salinity character (Bado *et al.,* 2016), therefore, soils from site C has a high salinity character than site B.

The lowest proportion of the exchangeable bases was occupied by potassium followed closely by sodium. Calcium has the highest proportion of the exchangeable bases. The exchangeable bases of the soils are generally low. Similar results were reported, Calcium and magnesium are the predominant basic cations in the soils (Obi *et al.*, 2011).

Magnesium almost equals the amount of calcium and this high concentration of calcium is not good for optimum soil properties. Abundance of $Mg^{2+}$ alone or in association with excess exchangeable sodium may behave like $Na^+$ in soil degradation (Qadir and Schubert, 2002). Mixed $Mg^{2+}$-$Na^+$ soils develop hydraulic conductivity that is lower than soils under similar environmental conditions. This is because hydrated $Ca^{2+}$ is lesser in size than hydrated $Mg^{2+}$. Therefore, water is accumulated in the soil surface than when exchangeable $Ca^{2+}$ is present, resulting in weakened soil binders.

Calcium to magnesium ratio determines how tight or loose a soil is. The more calcium a soil has, the looser it is, and the more magnesium, the tighter the pore spaces are, making the soil to drain more slowly and organic matter will break down poorly.

Cation Exchange Capacity of the soils

**Table 5.** Exchangeable bases (cmol/kg of soil), effective cation exchange capacity and percentage base saturation of soils of the study area

| Site | Code | Depth (cm) | Na | K | Ca | Mg | PBS (%) | Effective CEC (cmol/kg) |
|---|---|---|---|---|---|---|---|---|
| | | | ---(cmol/kg)--- | | | | | |
| A | $A_1$ | 0 -15 | 1.44 | 0.18 | 2.65 | 2.35 | 89.40 | 7.40 |
| | $A_2$ | 15 -30 | 0.56 | 0.12 | 2.4 | 2.25 | 83.50 | 6.40 |
| | Mean | - | 1.00 | 0.15 | 2.53 | 2.30 | 86.46 | 6.90 |
| B | $B_1$ | 0 -15 | 2.00 | 0.18 | 2.55 | 1.85 | 84.30 | 7.80 |
| | $B_2$ | 15 -30 | 1.00 | 0.12 | 1.95 | 2.15 | 93.40 | 5.60 |
| . | Mean | - | 1.50 | 0.15 | 2.25 | 2.00 | 88.85 | 6.70 |
| C | $C_1$ | 0 - 15 | 1.52 | 0.13 | 2.35 | 2.30 | 82.90 | 7.60 |
| | $C_2$ | 15 -30 | 0.65 | 0.13 | 1.60 | 2.15 | 87.10 | 5.20 |
| | Mean | - | 1.09 | 0.13 | 1.98 | 2.23 | 85.00 | 6.40s |

is medium in $A_1$, $A_2$, $B_1$ and $C_1$ and low in $B_2$ $C_2$ (Esu, 1991). The medium to low CEC of the soils could be attributed to the nature of clay minerals (Hassan *et al.*, 2011).

The range of the percentage base saturation (PBS) of the study area was 89.40 to 83.50% ; 84.30 to 93.40% and 82.90 to 87.10% for sites A, B and C, respectively. Anni *et al.* (2018) reported that soils with base saturation of >50% are regarded as fertile soils while soils with less than 50% were regarded as not fertile soils. Based on this, the soils are generally fertile.

## CONCLUSION

The results showed that the texture of the soils was predominantly silt loam and soil pH was slightly acidic to neutral. The organic carbon, total nitrogen and available phosphorous were found low. The soil of the area was saline-sodic but there were differences in the absolute salt concentration within the area. Bicarbonate, chloride and nitrate were the dominant salt forming anions in the area. It is recommended that there should be addition of calcium source (calcium sulfate), planting of salt tolerant crops and keeping the soil continually wet by mulching.

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