ASSESSMENT OF SOIL SALINITY AND SODICITY STATUS AT JIBIA IRRIGATION PROJECT, KATSINA STATE, NIGERIA

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ABSTRACT

Soil salinization and sodification, is one of the major threats to the semiarid agroecosystems. It is imperative to investigate saline levels under irrigation fields to maintain the sustainability of agricultural production. The main objective of this study was toassess the salinity and sodicity status of soil at Sector F1 of the Jibia Irrigation Project, a semi- arid region in Katsina State, Nigeria. Grid sampling was used to obtain one hundred and forty-four (144) soil samples from 206 ha of land. The grids were drawn at intervals of 150 m x 150 musing Google Earth software. Surface (0 - 20 cm) soil samples were collected at grid intersection points with the help of a Global positioning system (GPS) device. Soil samples were air-dried, passed through a 2mm sieve, and analyzed using standard laboratory procedures. The findings reveal low salinity and sodicity levels, with notable variability and localized challenges. Key parameters analyzed include pH, EC, SAR, PSB, and ESP. The mean pH and Electrical conductivity values of 6.82 and 0.19 dS/m indicate slightly acidic to neutral soil conditions and low salinity status respectively. The SAR and ESP Mean values of 0.09 and 2.63 respectively, indicate low sodicity, though high variability points to localized issues.The soil is predominantly sandy, thus low water and nutrient retention capacity. Recommendations for regular and routine monitoring, specific soil amendments and tailored and customized *irrigation practices are made to ensure sustainable soil health and agricultural productivity.*

KEYWORDS

Soil salinity, sodicity, Irrigation , soil management

1. INTRODUCTION

Irrigation has been recognized as one of the most important single input for crop production (Michael et al., 2005). Presently, Irrigated Agriculture contributes about 40 percent of all global food production which comes from the total irrigated areas worldwide (320 million hectares). This amounts to around 20 percent of the agricultural land that supports 2.4 billion people through employment (World Bank, FAO, 2019). Globally, irrigation accounts for about 70% of rice production, 20% of wheat output, and 50% of vegetable production (FAO, 2019). The global irrigated area is projected to increase by about 19% to 380 million hectares by 2030 (FAO, 2020).

Irrigation contributes approximately 10% of Nigeria's total crop production, which accounts for 30% of rice production, 10% of wheat production, and 20% of vegetable production, respectively. Thishelps to meet the food needs of the growing population especially for developing nations like Nigeria as the yield of crops increased by almost 50% for rice, 20% for wheat, and 30% for vegetables (Federal Ministry of Agriculture and Rural Development FMARD, 2016) (FAOSTAT, 2020).Nigeria has an estimated 1.3 million hectares of irrigable land, but only one fifth of the total area is currently under irrigation (FMARD, 2019)

The development of soil salinity in irrigated areas especially in the Arid and semi-arid regions is mostly due to a rise in the groundwater table, where dissolved salt is brought to the surface. As a result of higher temperatures in the region, Soil moisture gets evaporated from the soil surface, and salt is left behind. This results in a gradual increase in salt concentration on the surface and within the root zone (Tanji, 1996). The concentration of these soluble salts, retard and hinder the growth and successful development of crops (Rhoades 1986).

Approximately 8.7% of the world's total land area amounting to 833 million hectares, are affected by salinity worldwide (FAO, 2021). According to the African Soil Science Society (2018), 70 million hectares of land in Africa are damaged by salinity, with Egypt, Sudan, and South Africa suffering the worst effects. About 1.5 million hectares of land in Nigeria are affected by salinity; these are mostly in the northern regions, with the Northwest accounting for 500,000 of the total (NBS, 2019; FAO, 2019). Therefore, if preventive and remedial actions are not taken, the areas impacted by salinity will keep growingand continue to increase as long as irrigation is done (Simon 1997).

Understanding salinity and sodicity status in the Sector F1 of Jibia irrigation fields is essential in order to formulate integrated management and reclamation strategies specific to the site for sustainability of crop production.

The main aim of this research is to assess the salinity level of soil in sector F1 of Jibia irrigation project, Katsina state, Nigeria for sustainability of food production.

2. MATERIALS AND METHODS

2.1. Location of the Study Area

Study Area

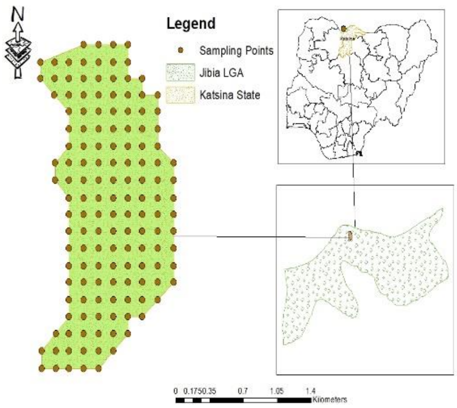

Figure 1: Map of Katsina state showing the study area with sampled points

The study was carried out in Sector F1 of the Jibia Irrigation Project (206 ha) located in Jibia Local Government Area, between latitudes $13^0$04'18"N and $13^0$10'27''N and longitudes $07^0$15'06"E and 07^0 18'.15''E (Figure 1). The landscape is nearly level to gently undulating with a 0–2% slope and averaging 442 meters above sea level (FDLAR, 1990), the study area falls within the semi-arid region of Nigeria, with a mean annual temperature of 35 °Cand precipitation of between 600–700 mm, respectively. The rainfall pattern is seasonal, with the peak rainfall occurring in the month of August. The dry season lasts between October and May (KTARDA, 2010). The geology of the location is the Chad Formation, which is made up of sedimentary rocks of Cretaceous origin (FDLAR, 1990).

According to SRRBDA (1991) Jibia Dam was constructed to boost agricultural production and supply portable drinking water. The project area covered a total of 3,472 ha. Which is divided into six parts (hydrological boundaries), based on six main canals (F1 to F6) that supply water to sub-canals and then to the irrigation plots. sector F1 occupies 206 ha and is gravity type

2.2. Soil Sampling

A reconnaissance survey was conducted in the study area to establish the location area and establish the sampling points (Figure 1). The grid sampling technique was used. Grids were drawn at 150-meter intervals, and a total of one hundred and forty-four (144) soil samples were collected at grid intersection points, which were identified with the help of a handheld GPS device (Figure 1). At each sampling point, soil samples were collected. The collected samples were air dried, crushed gently, and sieved through a 2 mm mesh size. The fine earth separates were properly labeled and stored for analysis in the laboratory.

2.3. Laboratory Soil Analysis

Particle size distribution was determined using the principles of the Bouyoucos hydrometer as described by Gee & Or (2002). The textural class of the studied soil was determined using the USDA textural triangle. The pH and EC of the soil were determined in soil: water ratio of 1:2.5 and 1:5 respectively, using glass electrode pH and EC meters as described in Estefan et al. (2013). EC values were then converted to EC_e by using the Slavich conversion factor (Slavich & Petterson, 1993).Neutrally buffered ammonium acetate was used in the extraction of exchangeable bases (Anderson & Ingram, 1993). Ca^{2+} and Mg^{2+} were read using Atomic Absorption Spectrophotometer (Buck Scientific Model 210 VGP), while Na^+ and K^+ were read using flame photometer (Jenway PFP 7). Exchangeable acidity was extracted using IM KCl solution and determined by titration with NaOH as described in Anderson & Ingram (1993). Cation Exchange Capacity was determined by summation method as described by (Chapman, 1965).Sodium Adsorption Ratio (SAR) was calculated using the relationship

$$SAR = \frac{\text{Na+}}{\sqrt{\frac{\sqrt{ca^{2+} + mg2+}}{2}}}$$

- Exchangeable sodium percentage was computed using the relationship

$$\text{ESP} = \frac{Na^+}{(CEC)} * 100$$

Where:
ESP= Exchangeable sodium percentage
Na^+ = Exchangeable sodium ion measured in $Cmol^-kg$

CEC= Cation exchange capacity measured in $Cmol^{-}kg$

- Percentage Base Saturation was computed using the relationship

$$PBS = \frac{ca^{2+} + mg^{2+} + K^{+} Na^{+}}{CEC}$$

2.4. Data Analysis

Descriptive statistical analysis was performed to assess the dispersion of the studied variables. Data variability was obtained according to the criteria proposed by Ogunkunle et al. (1993) – low (CV <15%), medium (15% ≤ CV ≤ 35%), and high (CV >35%)

3. RESULTS AND DISCUSSION

Table 1: Descriptive statistics of salinity parameters

	Mean	Minimum	Maximum	SD	CV (%)	Skewness	Kurtosis
pH	6.82	5.71	8.83	0.61	8.88	0.63	0.86
EC(dSm^{-1})	0.19	0.06	1.27	0.21	110.30	2.88	9.91
%Sand	82.79	34.00	98.00	13.01	15.72	-1.72	2.88
%Silt	11.21	0.56	41.28	8.31	74.10	1.51	2.21
%Clay	5.00	0.72	50.72	6.54	109.00	3.38	16.28
Acidity	0.37	0.17	0.83	0.16	41.46	0.79	0.64
Na($cmol^{-}kg$)	0.26	0.01	2.17	0.48	181.80	2.08	3.54
K($cmol^{-}kg$)	0.12	0.01	2.08	0.20	167.9	6.92	64.81
Ca($cmol^{-}kg$)	5.59	0.15	20.23	3.81	57.77	0.87	0.56
Mg($cmol^{-}kg$)	2.03	0.21	12.32	1.67	82.00	2.60	10.48
ECEC	9.38	1.23	25.91	5.06	53.91	0.93	0.65
% Base Saturation	28.85	8.65	60.91	9.78	33.90	0.96	0.92
SAR	0.09	0.002	0.98	0.18	188.9	2.36	5.56
ESP	2.63	0.06	27.44	5.04	191.30	2.53	6.41

ECEC= Effective Cation Exchange Capacity, PBS=Percentage Base Saturation., SAR= Sodium Adsorption Ratio, ESP= Exchangeable Sodium Percentag

Table 2: Correlation of soil properties

Soil parameters	PH	EC(ds/m	%SAND	%SILT	%CLAY	Na(Cmol/kg	K(Cmol/Kg)	ACIDITY	Ca(Cmol/kg)	Mgs(cmol/kg)	CEC(Cmol/kg	%BS	SAR	ESP
PH soil	1	.435**	-.060	.130	-.046	.067	-.032	-.237**	.185*	.065	.158	.035	.034	.010
EC (ds/m	.435**	1	-.306**	.321**	.201*	.046	.090	-.149	.402**	.350**	.421**	.305**	.005	-.016
%SAND	-.060	-.306**	1	-.905**	-.841**	.015	-.282**	.114	-.569**	-.640**	-.645**	-.474**	.076	.119
%SILT	.130	.321**	-.905**	1	.530**	-.054	.240**	-.165*	.485**	.574**	.554**	.452**	-.103	-.139
%CLAY	-.046	.201*	-.841**	.530**	1	.038	.256**	-.017	.517**	.543**	.581**	.368**	-.021	-.060
Nas(Cmol/kg)	.067	.046	.015	-.054	.038	1	-.025	.060	.234**	-.028	.263**	-.139	.963**	.904**
Ks(Cmol/Kg)	-.032	.090	-.282**	.240**	.256**	-.025	1	-.043	.298**	.317**	.365**	.205*	-.042	-.055
ACIDITY	-.237**	-.149	.114	-.165*	-.017	.060	-.043	1	.004	-.102	.005	-.192*	.037	.005
Ca(Cmol/kg)	.185*	.402**	-.569**	.485**	.517**	.234**	.298**	.004	1	.519**	.958**	.140	.101	.024
Mg(cmol/kg	.065	.350**	-.640**	.574**	.543**	-.028	.317**	-.102	.519**	1	.727**	.791**	-.068	-.106
CEC(Cmol/kg)	.158	.421**	-.645**	.554**	.581**	.263**	.365**	.005	.958**	.727**	1	.355**	.145	.067
%BS	.035	.305**	-.474**	.452**	.368**	-.139	.205*	-.192*	.140	.791**	.355**	1	-.145	-.159
SAR	.034	.005	.076	-.103	-.021	.963**	-.042	.037	.101	-.068	.145	-.145	1	.982**
ESP	.010	-.016	.119	-.139	-.060	.904**	-.055	.005	.024	-.106	.067	-.159	.982**	1

3.1. Soil Textural Properties

The soil in the Jibia Irrigation Project is predominantly sandy, with a mean sand percentage of 82.79%. The sand content ranges from 34.00% to 98.00%, showing moderate variability (SD: 13.01%, CV: 15.72%), as explained by Ogunkunle (1993). This high sand content suggests good drainage with low water and nutrient retention, as noted by Hillel (2004). The mean silt percentage is 11.21%, and the mean clay percentage is 5.00%, both showing significant variability. Low silt and clay content can lead to poor water retention, which aligns with findings by Brady and Weil (2008) that sandy soils require frequent irrigation and fertilization to maintain crop productivity. The sandy nature of the study area might be due to the nature of the parent materials which are mostly developed from sandstone and Aeolian deposits. Voncir *et.al.* (2008), Shehu *et. al.* (2015), and Sani *et al.* (2019, 2022, 2023) reported the dominance of sand contents in northern Nigerian soils. The variability in soil texture can impact water retention and root penetration, nutrient availability, and soil structure. High skewness and kurtosis in clay might suggest non-uniform soil composition, which can impact water infiltration and soil fertility (Dexter et al., 2022, Noma and Sani, 2008).

Sand content had a significant negative correlation with EC, K^+, Ca2+, $^{mg2+,}$ CEC, and PBS. This corroborates with the findings of Kaur *et. al. (2020)*, Abdulkadir et al., (2020), Ghafoor *et. al.* (2018), and Hussein et. al. (2019). Clay and silt contents were observed to have a positive correlation with the above-mentioned parameters. This observation agrees with the work of Liu *et. al.*, 2020; Zhang et al., 2020; and Gao *et al.*, 2020. There was no direct correlation between sand content and soil pH

Soil pH is an important soil parameter that affects a wide range of soil chemical and biological properties. The mean pH value is 6.82, indicating slightly acidic soil to neutral conditions. The pH ranges from 5.71 to 8.83. The coefficient of variation (CV) of 8.88% suggests relatively low variability in pH across samples. The slightly acidic to neutral condition of the soils in the study area is advantageous for crop health as reported by Havlin *et. al* (2005) that pH range of 6.5-7.5 is optimal for availability of nutrients in soils. Similarly, Singh *et. al* (2017) reported most crops are tolerant of pH range of 6.5-7.5. extreme pH values can impede nutrient uptake, thereby affecting nutrient availability, microbial activity, and overall soil productivity (Cai et al., 2020). The skewness and kurtosis values indicate that pH tends to be relatively normally distributed in the study area, which is typical in soil studies where pH can vary but often follows a general pattern.pH has a positive correlation with EC and a negative correlation with soil acidity.

Electrical Conductivity (EC) is a measure of the soil's salinity and ion concentration, influencing plant growth and soil health. The mean electrical conductivity (EC) in the study area is 0.19 dS/m, indicating low salinity. However, the range from 0.06 to 1.27 dS/m shows some areas with higher salinity levels. These EC range allows for optimal water uptake by crops (Maas et. al. 2017) and nutrient availability (Wang et. al., 2018). High skewness and kurtosis values suggest that EC values are not normally distributed and may be influenced by outliers or non-normal processes, such as specific land management practices or localized geological factors (Zhang et al., 2021). CV of 110.30% reflect significant variability. With a skewness of 2.88 and kurtosis of 9.91, the EC distribution is highly right-skewed and leptokurtic,this suggests that while most areas have low salinity, some areas may face salinity challenges with negative consequences for plant growth.

3.2. Exchangeable Bases

The mean concentration of sodium is modest at 0.26, there is a considerable range of variability from 0.01 to 2.17. This unpredictability is reflected in the high CV (181.80%). In a similar vein, potassium has a high CV (167.90%), a wide range (0.01 to 2.08), and a mean of 0.12. These trends imply that while potassium and sodium concentrations are generally low, there are certain places with abnormally high quantities, which could cause salinity problems.

Magnesium and calcium have moderate concentrations; their averages are 2.03 and 5.59, respectively. High variability is seen in both elements; magnesium has a range of 0.21 to 12.32 with a high CV of 82.00%, while calcium ranges from 0.15 to 20.23 with a high CV of 57.77%. The soil's fertility can be affected by the fluctuations in these nutrients, which are essential for plant growth. Plant development and nutrient availability are influenced by exchangeable cations in the soil. Skewness and kurtosis, two distributional features, can shed light on how fertilization and irrigation influence cation concentrations and distribution in the soil profile (Nadiri et al., 2023, Dawaki et al., 2019, Abdulkadir et al., 2022) and how other soil management techniques work.

The mean acidity level is 0.37, with values ranging from 0.17 to 0.83. The SD of 0.16 and CV of 41.46% reflect moderate variability. Skewness (0.79) and kurtosis (0.64) suggest a slightly right-skewed distribution with a relatively normal spread. These moderate acidity levels indicate potential issues with nutrient availability and microbial activity, which are essential for plant health. leaching is much less extensive in drier regions, allowing soils to retain enough nonacid $Ca2+$, $Mg2+$, $K+$, and $Na+$ to prevent a buildup of acid cations. Soils in semiarid and arid regions, therefore, tend to have alkalinepH levels (i.e., $pH > 7$),

3.3. Effective Cation Exchange Capacity (ECEC)

The mean ECEC is 9.38, with a range from 1.23 to 25.91, an SD of 5.06, and a CV of 53.91%, indicating high variability. The mean ECEC of 9.38(<10meq/100g) shows that the soil in the study area have limited capacity for cation, which can lead to deficiencies (Bingham, *et.al*. 2019; kiani*et. al.,* 2020 and Abdulkadir et al., 2022) the effective CEC increases as the pH level rises. CEC had significant positive correlation with EC, Exchangeable bases and percentage base saturation

3.4. Percentage Base Saturation

The mean percentage base saturation of 28.85% reflects the proportion of soil bases relative to acidic cations. Base saturation has a mean of 28.85%, ranging from 8.65% to 60.91%, with an SD of 9.78% and a CV of 33.90%. The skewness (0.96) and kurtosis (0.92) indicate a relatively normal distribution. These metrics are vital for assessing soil fertility and nutrient availability. Medium variability of base saturation suggests heterogeneous soil fertility, necessitating balanced fertilization and soil amendments, as recommended by Sanchez (2019) for improving soil fertility and supporting sustainable agriculture

The SAR has a low mean of 0.09, but the range (0.002 to 0.98) and high SD (0.18) and CV (188.90%) reflect significant variability. The skewness (2.36) and kurtosis (5.56) suggest a highly right-skewed distribution. ESP shows a mean of 2.63, with values ranging from 0.06 to 27.44. The high SD (5.04) and CV (191.30%) indicate considerable variability, with a highly right-skewed distribution (skewness: 2.53) and heavy tails (kurtosis: 6.41). High SAR and ESP values can indicate potential soil sodicity problems, affecting soil structure and permeability.SAR significantly correlates positively with Na^+ and ESP

SAR and ESP are critical for assessing soil salinity and sodicity, influencing soil structure and crop productivity. The skewness and kurtosis values highlight potential non-normality in their distribution, which may reflect specific soil management practices or environmental conditions affecting sodium accumulation and dispersion (Zhu et al., 2020).

3.5. Salinity Assessment

Salinity assessment is very important especially in irrigation projects, as excessive salt levels can significantly affect crop yield and soil health negatively. Electrical conductivity (EC) is a crucial parameter for determining the salinity status of soil. The mean EC value of 0.19 dS/m suggests low salinity levels. EC values below 0.2 dS/m indicate non-saline soils (Abdulkadir *et al.;* 2024,Abrol*et al*., 1988; Mass *et. al*, 201; Rhoades *et al*.1992). However, the observed range (0.06 to 1.27 dS/m) and high standard deviation (0.21) indicate high variability. This variability aligns with findings by Ayers and Westcot (1985), who reported that irrigation practices and soil management can lead to spatial variability in soil salinity. The high coefficient of variation (110.30%)) suggest that while most areas exhibit low salinity, certain spots might experience problematic salinity levels, potentially affecting sensitive crops. Regular monitoring and localized soil management practices, as recommended by Qadir et al. (2000), are necessary to address these issues.

3.6. Sodicity Assessment

Sodicity refers to the presence of high sodium levels in soil, adversely affecting soil structure, permeability, and plant growth. Key indicators of sodicity include the sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP).

3.6.1. Sodium Adsorption Ratio (SAR)

The mean SAR value of 0.09 indicates low sodium hazard, which is below the threshold of 13 suggested by the U.S. Salinity Laboratory Staff (1954) for sodic soils. The soils in the study area has low tendency to adsorb sodium ions which reduces dispersion and structural problems (Qadir and Schuberts, 2002) However, the range (0.002 to 0.98), high standard deviation (0.18), and coefficient of variation (188.90%) highlight significant variability. The highly right-skewed distribution (skewness: 2.36) and heavy tails (kurtosis: 5.56) imply that specific areas have elevated sodicity levels. This observation is consistent with Rengasamy and Olsson (1991), who noted that even low overall SAR values can mask localized sodicity issues that degrade soil structure. Implementing gypsum application, as suggested by Sumner (1993), could help mitigate sodicity in these areas.

3.6.2. Exchangeable Sodium Percentage (ESP)

The mean ESP of 2.63 is generally low (FAO, 2019), but the range (0.06 to 27.44), high standard deviation (5.04), and coefficient of variation (191.30%) indicate substantial variability. The right-skewed distribution (skewness: 2.53) and heavy tails (kurtosis: 6.41) show that while most areas have low ESP, some regions could face significant sodicity issues.High ESP values can lead to soil dispersion and reduced infiltration, which are critical issues in maintaining soil health and productivity(Oster and Jayawardane, 1998), Addressing high ESP through soil amendments and improved irrigation practices is essential for sustainable soil management.

4. CONCLUSION

The assessment of the Jibia Irrigation Project reveals low salinity and sodicity levels, with significant variability across different soil parameters. While overall conditions are favorable, localized areas with high EC, SAR, and ESP pose potential challenges. The sandy soil texture, combined with variable nutrient levels, underscores the need for tailored soil management practices. Regular monitoring and appropriate soil amendments are critical to maintaining soil health and optimizing agricultural productivity. The farmers are advised to implement a continuous soil monitoring program to detect and address salinity and sodicity issues promptly. They are also advised to use gypsum or organic amendments in areas with high SAR and ESP to improve soil structure and permeability. They also improve soil structure in sandy areas through organic matter additions to enhance water and nutrient retention.

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REFERENCES

[1] Abdulkadir Aliyu, Musa Muhammad and AbdulmalikDanjuma(2024). Productivity of tomato *(lycopersiconesculentum l*) as influenced by spacing and cow dung manure in the sudan savannah agro-ecological zone of Nigeria. Life Sciences: an International Journal (LSIJ) Vol.1, No.1, 2024

[2] Abdulkadir, A, Halilu, Y., & Sani, S. (2022). Evaluation of Physical and Chemical Properties of Soils at Bichi Local Government Area , Kano State , Nigeria. IREJournal, 5(9), 556–562.

[3] Abdulkadir, A., Dawaki, M. U., & Sani, M. (2019). Effect of Organic Soil Amendments on Soil Chemical Properties in Sudan Savannah of Nigeria Effect of Organic Soil Amendments on Soil Chemical Properties in Sudan Savannah of Nigeria. NJSS, 30(2), 122–132. https://doi.org/https://doi.org/10.36265/njss.2020.300215

[4] Abu, S., and Malgwi, W. (2011). Spatial Variability of Soil Physico-chemical Properties in Kadawa Irrigation Project in Sudan Savanna Agroecology of Nigeria. International Journal of Agricultural Research. Retrieved from http://docsdrive.com/pdfs/academicjournals/ijar /2011/714-735.pdf86–99.

[5] Biggar, J.W., Nielsen, D.R. (1976). Spatial variability of the leaching characteristics of a field soil.Water Resource. Res. 12, 78–84.

[6] Brady, N. C., & Weil, R. R. (2008). The Nature and Properties of Soils. 14th edition.

[7] Brady, N.C. and Weil, R.R. 1999. The nature and properties of soil. 12th edition. Prentice Hall, New Jersey, USA. 881 pp.

[8] Bronick et al. (2017). Soil Structure and Electrical Conductivity. Soil Science Society of America Journal, 81(4), 931-938.

[9] Cai, G., et al. (2020). Effects of soil pH on the availability and chemical speciation of heavy metals in coastal saline soil. *Environmental Pollution*, 264, 114783.

[10] Currie, D.R. 2006 Soil Physical Degradation due to Drip Irrigation in Vineyards: Evidence and Implications. Ph.D. thesis. The University of Adelaide.

[11] Dawaki, M. U., Abdulkadir, A., &Abdulrahman, B. L. (2020). Comparative Potential Effects of Biochar , Compost and Inorganic Fertilizer on Major Nutrient Ions Mobility and Stability in Screen - House Irrigated Maize in the Drier Savannas of Nigeria. NJSS, 29(2), 122–132. https://doi.org/https://doi.org/10.36265/njss.2020.290215

[12] Dexter, A.R., et al. (2022). The influence of soil texture on soil physical properties, crop performance and soil water dynamics: A review. *Soil and Tillage Research*, 224, 105016.

[13] FAO (2019). Management of Salt-Affected Soils. ESP values interpretation,

[14] FAO (2019). Soil Salinity and Irrigation.

[15] FAO, (2005). The importance of soil organic matter. FAO soils bulletin No. 80. Rome, Italy.

[16] Fasinmirin, J.T., Olorunfemi, I.E. (2012). Comparison of hydraulic conductivity of soils of the forest vegetative zone of Nigeria. Applied Tropical Agriculture 17(1): 64 – 77. FDALR(1990).The Reconnaissance soil survey of Nigeria (1:650,000) Soil Survey Report. Volume2. 316pp

[17] Federal Ministry of water resources (FMWR) (2017). Dams and Reservoirs operations. Federal ministry of water resources. Retrieved on June 10, 2018 fromhttp://www.waterresources.gov.ng/damsreservoir/

[18] Hamza, M.A., and W.K. Anderson. (2002). Improving soil physical fertility and crop yield on a clay soil in Western Australia. Australian Journal of Agriculture Research 53: 615–620.

[19] Hamza, M.A., and W.K. Anderson. (2005). Soil compaction in cropping systems. A review of the nature, causes and possible solutions. Soil and Tillage Research 82: 121-145.

[20] Haruna, S. and Nkongolo, N.V. (2013) Variability of Soil Physical Properties in a Clay-Loam Soil and Its Implication on Soil Management Practices. SoilScience Volume, Article ID 418586, 8 pp.

[21] Hillel, D. (1982). Introduction to soil physics. Academic Press, Inc. San Dieoga, California

[22] Hillel, D. 1998. Environmental soil physics: Fundamentals, applicationsan d environmental consideration. Academic Press, London, UK. 757pp

[23] Hopkins, B. (1966). Vegetation of the Olokkemeji Forest Reserve Nigeria.IV. The Litter and soil with special reference to their seasonal changes. Journal of Ecology, 54, 687–703.

[24] Horn, R. and Dexter, A. R. (1989). Dynamics of soil aggregation in a homogenized desert loess. Soil and Tillage Research, 13, 254–266.

[25] Ibrahim, M. H. (1991). Current water resources policies and the development of irrigation. In: National Agricultural Extension and Research Liaison Services Ahmadu Bello University Zaria (ed.) National Irrigation and Drainage Seminar . In Proceedings of the 11th National Irrigation and Drainage Seminar held at Concord Hotel Owerri, Nigeria 8th 13thDecember (pp. 6–9).

[26] Katsina State Agricultural and Rural Development Authority (KTARDA). (2010). Agricultural Based Data of Katsina State. 26pp
[27] Kavianpoor, H., EsmaliOuri, A., JafarianJeloudar, Z. and Kavian, A. (2012).Spatial variability of some chemical and physical soil properties in Nesho mountainous rangelands. American Journal of Environmental Engineering 2: 3444.
[28] Kay et al. (2018). Electrical Conductivity and Soil Water Infiltration. Journal of Soil and Water Conservation, 73(4), 251-258.
[29] Kay, B.D., Angers, D.A.(2002) . Soil structure. In: Warrick, A.W. (Ed.), Soil Physics Companion. CRC Press, Boca Raton, FL, pp. 249–295.
[30] Kemper, W.D. and Roseneau, R. . (1986). Aggregate stability and size distribution in Klute. A.(ed) methods of soil analysis part 1 physical and mineralogical methods 2nd edition. Agronomy Monograph Society of Agr/soil Science, 9, 425– 442.
[31] Kovda, V. A. (1973). Some effects of irrigation and drainage on soils, Irrigation, Drainage and Salinity. In FAO/UNESCO International source book (pp. 387–408).
[32] Lal, R. (1979). Physical Properties and moisture retention characteristics of some Nigerian soils. Geoderma, 21, 209–223.
[33] Li et al. (2020). Electrical Conductivity and Nutrient Uptake. Journal of Soil Science, 70(2), 241-252.
[34] Maas et al. (2017). Salinity and Crop Production. Journal of Agricultural Science, 155(3), 457-466.
[35] Murray, R. S., & Grant, C. D. (2007). The impact of irrigation on soil structure. Canberra: The National Program for Sustainable Irrigation (Land and Water Australia), 31.
[36] Nadiri, A., et al. (2023). Effects of soil properties and management practices on soil cation exchange capacity and nutrient availability: A review. *Geoderma*, 406, 115571.
[37] Nigeria National Committee on Irrigation and Drainage (NINCID) (2015).Country Profile Nigeria. Federal Ministry of Agriculture and water resources, Abuja, Nigeria. Retrieved June 12, 2018, from www.NINCID.org/cp_nigeria.html.
[38] Noma, S. S; and S. Sani. (2008) Estimation of Soil organic matter Content in soils of Sokoto Area: Comparing Walkley- Black and a proposed unconventional method. *Techno Science Africana Journal 2(1) 71-76*
[39] Oster, J. D., & Jayawardane, N. S. (2017). Soil Salinity and Sodicity: A Guide for Agriculture and Water Resources. FAO Irrigation and Drainage Paper 77.
[40] Qadir, M., & Schubert, S. (2002). Degradation Processes and Nutrient Constraints in Sodic Soils. Land Degradation & Development, 13(4), 275-294.
[41] Rengasamy, P. (2010). Soil Processes and Sodicity. Journal of Hydrology, 381(1-2), 1-9.
[42] Rhoades et al. (1992). Soil Salinity and Irrigation. Journal of Irrigation and Drainage Engineering, 118(5), 761-774.
[43] Richards, L. A. (1954). Diagnosis and Improvement of Saline and Alkali Soils. USDA Agricultural Handbook No. 60.
[44] Sani, S., Sani, M., Salihu, A. P., Aliyu, A., Yakubu, M., Garba, N. H., &Basiru, L. J. (2022). Spatial Variability of Soil Hydraulic Properties in Jibia Irrigation Project, Katsina State, Nigeria. Natural Resources and Sustainable Development, 12(2), 245–254. https://doi.org/10.31924/nrsd.v12i2.103
[45] Sani, S., Abdulkadir, A., HmadPantami, S. A., Sani, M., Amin, A. M., &Abdullahi, M. Y. (2023). Spatial Variability and Mapping of Selected Soil Physical Properties under Continuous Cultivation. Turkish Journal of Agriculture - Food Science and Technology, 11(4), 719–729. https://doi.org/10.24925/turjaf.v11i4.719-729.5733
[46] S. Sani, S. A. Pantami and M. Sani. (2019).Evaluation Of Soil Physical Properties At Jibia Irrigation Project, Katsina State, Nigeria. *Fudma Journal of Agriculture and Agricultural Techology*. 5(1) 231-243
[47] Tanji, K. K. 1996. Nature and extent of agricultural salinity. In *Agricultural Salinity Assessment and Management Manual*, K. K. Tanji (ed.). ACSE Manuals and Reports on Engineering Practice No. 71,New York, pp. 1–17.
[48] USDA (2019). Soil Quality Indicators: Sodium Adsorption Ratio.
[49] Wang et al. (2018). Electrical Conductivity and Nutrient Availability. Journal of Soil Science and Plant Nutrition, 18(2), 257-265.
[50] Wang et al. (2018). Electrical Conductivity and Nutrient Availability. Journal of Soil Science and Plant Nutrition, 18(2), 257-265.

[51] Zhang, Q., et al. (2021). Spatial variability and controlling factors of soil electrical conductivity and soil salinity in a coastal wetland. *Geoderma,* 384, 114824.

[52] Zhu, Y., et al. (2020). The influence of sodium adsorption ratio on soil physical and chemical properties in calcareous soil. *Scientific Reports,* 10(1), 1-11.