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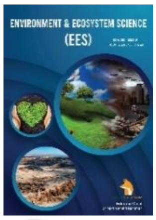

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RESEARCH ARTICLE

IMPACT OF SEASONAL FLOODING AND POST-FLOOD IRRIGATION ON SOIL FERTILITY AND SALINITY ALONG THE KAMANDA RIVER IN KIRU LGA, KANO STATE

Abdulkadir Aliyu[a*], Sani Ismail[a], Sani Sufiyanu[a], Muhammad Ibrahim[b], Zainab Yusuf Makarfi[c], Salisu Muazu[d]

[a] *Department of Soil Science, Faculty of Agriculture, Federal University Dutsin-Ma, Katsina State, Nigeria*
[b] *Department of Soil Science, Faculty of Agriculture Bayero University Kano, Kano State, Nigeria*
[c] *School of General and Applied Sciences, Shehu Idris College of Health Sciences and Technology Makarfi, Kaduna State, Nigeria*
[d] *Centre for Drylands Agriculture, Bayero University Kano, Kano State, Nigeria*
**Corresponding Author Email: aabdulkadir@fudutsinma.edu.ng*

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ABSTRACT

This study investigated the effects of flooding and post-flood irrigation on soil properties (soil fertility and salinity) along the Kamanda River in Kiru LGA Kano State, Nigeria. The region, characterized by a distinct wet and dry season, supports both rain-fed and irrigated agriculture, making it crucial to understand how flood-related processes influence soil quality. Soil samples were collected from four land-use categories (irrigated upland, irrigated lowland, unirrigated upland, and un irrigated lowland) at 0 to 30 cm depth. The results showed that all sampled sites had a sandy loam texture, with sand content ranging from 50.47% to 69.13%, silt content from 27.27% to 42.60%, and clay content from 3.61% to 7.60%. The soils had a slightly acidic to neutral pH (6.23-6.66) and moderate fertility, with organic carbon content ranging from 0.35% to 0.67%, total nitrogen from 0.14% to 0.18%, and available phosphorus from 11.29 mg/kg to 24.56 mg/kg. The cation exchange capacity (CEC) ranged from 3.79 cmol/kg to 6.38 cmol/kg, with exchangeable calcium, magnesium, potassium, and sodium varying across land uses. Salinity indicators, including electrical conductivity (0.011-0.022 dS/m), exchangeable sodium percentage (2.55-8.74%), and sodium adsorption ratio (<1), remained within acceptable limits. However, higher exchangeable sodium percentage values in irrigated lowlands suggest potential sodium accumulation. The study highlights the importance of sustainable land and water management practices to preserve soil quality and ensure long-term agricultural productivity in the region. The findings underscore the dual influence of flooding and irrigation on soil properties, suggesting the need for adaptive soil and water management practices to maintain long-term productivity in flood-prone agricultural landscapes.

KEYWORDS

Fertility, Flood, Irrigation, River and Salinity

1. INTRODUCTION

Soil is the most vital and precious natural resources that sustain life on earth. An understanding of good farming begins with the understanding of soil. The ability of soil to meet plant requirements differs widely and most of them have only moderate native ability but can be considerably or substantially improved by soil amendments. Soil that have natural fertility can produce substantially crop yield even without added fertilizer, but can produce even higher yield with an additional supply of the critical nutrients. (Fink, 2003). Optimum production of any crop depend on adequate supply of plant nutrient. When the soil does not supply sufficient nutrients for normal plant development and optimum productivity, application of supplemental nutrient is required (Forth and Ellis, 1997). For soil to be considered fertile, it should have adequate level of major nutrients (nitrogen, potassium, and phosphorus) and minor nutrients (manganese, chlorine, boron, molybdenum, copper, iron, cobalt and zinc as well as high organic matter and relatively moderate.

Soil salinity refers to the high concentration of soluble salt including Na+, Ca+ and Mg+, in soil having more than 4ds/m of soil electric conductivity to 0.2 mPa of osmotic potential produced by 40Mm sodium chloride (NaCl) in the solution. Saline soils are those soils which have an electrical conductivity of the saturation soil extract of 4ds/m at 25^{o}C.Rengasamy, 2002 and Richards, 1954). The major soluble cations are Na^+, Ca^{2+}, Mg^{2+}, K+ and the anions Cl^-, SO_4^{2-}, HCO^{3-}, CO^{3-}, and NO^{3-} (wong et al., 2004b). Saline soils have many physical changes in them as compared with normal healthy soil. They have nutrient deficiency and toxicities because of boron, carbonate and aluminum ion present. These soils are observed to have very low organic matter and biological activity (Rengasamy, 2002).

Seasonal flooding and post-flood irrigation have significant impacts on soil fertility and salinity in agricultural areas, particularly in regions prone to flooding. The Kamanda River in Kiru LGA, Kano State, likely experiences similar effects to those observed in other flood-prone areas worldwide.

Flooding events can have both positive and negative consequences for soil fertility and agricultural productivity. On one hand, floods can deposit nutrient-rich sediments, enhancing soil fertility (Zhang et al., 2020). For instance, in the Ili Valley of Xinjiang, China, proper flooding management increased soil organic carbon and total phosphorus content, leading to enhanced enzyme activity and improved soil fertility (Zhang et al., 2020). However, excessive flooding can also lead to soil saturation, which may negatively impact crop growth and soil microbial activity (Fournier et al., 2016; Zhang et al., 2020).

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Interestingly, the timing and duration of floods play crucial roles in determining their impact on agriculture. In Amazonian floodplains, the annual flood cycle is integral to rural livelihoods, affecting soil fertility and fish migrations. However, extreme floods can have devastating effects on riverine populations (Langill and Abizaid, 2019). Similarly, summer flooding in Eastern Europe has shown to increase nutrient mobilization, particularly phosphate, due to iron reduction in waterlogged soils (Banach et al., 2009).

Post-flood irrigation practices can further influence soil fertility and salinity. In coastal regions, saltwater intrusion during flooding events can lead to long-term soil salinization, significantly impacting agricultural productivity (Gould et al., 2020). Understanding the complex interactions between seasonal flooding, post-flood irrigation, and soil properties is crucial for developing effective agricultural management strategies in flood-prone areas like the Kamanda River region. Future research should focus on local hydrological conditions, soil characteristics, and land-use practices to better predict and mitigate the impacts of flooding on soil fertility and salinity.

This research was carried in order to determine the current fertility status of soils along Kamanda river, Kiru local government area and to determine the salinity status of soils along Kamanda river in Kiru local government area.

2. Material and Methods

2.1 Study area

Kiru local government is located on Lat. 11⁰42' N and Long. 8º13' E in south-western part of Kano state with an area of 927km^2 and population of 264,781 according to 2006 census. Similar to other rural areas, major activity in Kiru local government is agriculture with rain fed farming being dominant. The area witnesses two distinct season, which are the rainy and dry seasons. The area is characterized by a mean annual rainfall of about 950 mm per anum and the mean daily temperature range is 33 °C. The irrigated area is about 18,450 ha and comprising 4 main water sources of irrigation which are "Natare River" located in eastern side, "Kadando River" in southern, "Kamanda River" western and Rafin "Kiru River" located in the northern side. The total irrigated area of Kiru is served from these four rivers, sometimes boreholes and wells are used to compliment for irrigation.

2.2 Sample collection

Soil samples was collected along Kamanda River in Kiru local government area of Kano state. A total of 36 samples was collected, 9 samples from 4 different locations using stratified random sampling at the depth of 0-15 and 15-30cm using soil auger.

2.3 Sample Preparation

The samples were collected using stratified random sampling. The samples were air dried, crushed using porcelain mortar and pestle to breakdown the aggregate into smaller particles. Afterwards, the crushed samples were sieved using 2mm sieve to remove the large particles and stored in a clean close container for analyses.

2.4 Sample Analysis

Particle size distribution was determined using the principles of the Bouyoucos hydrometer as described by (Gee and 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 ECe by using the Slavich conversion factor (Slavich and Petterson, 1993). Neutrally buffered ammonium acetate was used in the extraction of exchangeable bases (Anderson and Ingram, 1993). Ca2+ and Mg2+ 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 and Ingram, 1993). Cation Exchange Capacity was determined by summation method as described by (Chapman, 1965).

2.5 Soil Salinity Assessment

For the salinity test exchangeable sodium, percentage was use to establish the salinity status of the study area.

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

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

3. Result and Discussion

3.1 Influence of Flooding and Post-Flood Irrigation on Particle Size Distribution

Table 1 presents the particle size distribution (sand, silt, and clay) and the resulting soil textural class across different land uses along the Kamanda River. All locations, regardless of irrigation or flooding history, were classified as sandy loam, indicating a dominance of sand across the sites. The sand content ranged from 50.47% in the unirrigated lowland to 69.13% in the irrigated lowland, suggesting that irrigation and topography have a measurable impact on sand deposition. The highest silt content was recorded in the unirrigated lowland (42.60%), and the lowest in the irrigated lowland (27.27%). Similarly, clay content varied slightly, from 3.61% (irrigated lowland) to 7.60% (irrigated upland).

The similarity in texture class across all land uses implies that the area is generally dominated by coarse-textured soils, which are well-drained and less prone to waterlogging but often poor in nutrient retention. The irrigated lowland soils, while having the highest sand content, also had the lowest clay and silt percentages, likely due to the leaching and sorting effects of repeated flooding and irrigation. Conversely, the unirrigated lowland, being more susceptible to sediment deposition during flood events, exhibited higher silt content. These variations suggest that flooding and irrigation practices influence the soil's physical structure, potentially affecting water retention, aeration, and nutrient dynamics. The results conforms with the findings who found dominance of sand contents in the Northern Nigerian savannah soils (Noma and Sani, 2008; Abdulkadir et al., 2022). Another possible reason that contribute to the similarity and dominance of sandy texture is sediment deposition and flooding in the area as sediments transported and deposited by floodwaters can have a uniform texture resulting in similar texture across the area (Brady and Weil, 2018)

The variation in sand, silt and clay contents may be due to irrigation practices and topography of the area as the higher sand content in the irrigated could be due to sorting effect of irrigation water which tend to deposit coarser particles like sand (Hillel, 2004). Leaching and erosion might be another reason for the variation in silt content especially in un irrigated lowland as repeated flooding and irrigation can lead to leaching and erosion of finer particles like clay and silt (Sani et al., 2023)

Table 1: Influence of flooding and post flood irrigation on particle size distribution along river Kamanda

	SAND	SILT	CLAY	TEXTURAL CLASS
		%		
Land Use				
irrigated upland	57.80	34.60	7.60	Sandy loam
irrigated lowland	69.13	27.27	3.61	Sandy loam
Unirrigated upland	61.80	32.60	5.60	Sandy loam
unirrigated lowland	50.47	42.60	6.93	Sandy loam
SED	8.8	7.5	1.7	

3.2 Influence of Flooding and Post-Flood Irrigation on Soil Chemical Properties

Table 2 assesses how flooding and post-flood irrigation affect key soil chemical properties including pH (in water and $CaCl_2$), organic carbon (OC), total nitrogen (TN), and available phosphorus (Av. P). Across the land uses, soil pH (H_2O) ranged from 6.230 in unirrigated lowlands to 6.657 in unirrigated uplands, indicating slightly acidic to neutral conditions. The pH($CaCl_2$) values followed a similar trend but were consistently lower, reflecting natural pH buffering due to exchangeable cations.

Organic carbon varied from 0.3525% in irrigated lowlands to 0.6650% in unirrigated lowlands which arees with the findings of (Aliyu et al., 2020; 2024). This suggests that unirrigated lands, particularly lowlands, may retain more organic matter, possibly due to less frequent tillage and organic matter decomposition. TN values were relatively low across all land uses, ranging from 0.1400 to 0.1773, which is typical for tropical soils but may limit crop productivity if not managed properly (Núñez and Schipanski, 2023).

Available phosphorus was highest in the unirrigated upland (24.56 mg/kg), possibly due to limited crop uptake or reduced leaching compared to irrigated areas. In contrast, irrigated uplands had the lowest Av. P (11.29 mg/kg) which agrees with the findings, potentially due to higher crop demand or phosphorus fixation (Dawaki et al., 2020).

The data indicate that both irrigation and flooding influence soil fertility parameters. While irrigation can enhance nutrient cycling, it may also contribute to nutrient losses, particularly phosphorus (Srivastava et al., 2024). Conversely, unirrigated lowlands, which likely receive flood-borne sediments, appear to benefit from higher organic carbon and phosphorus accumulation. These trends underscore the importance of tailored nutrient management based on land use and hydrological history to sustain soil fertility (Rupngam and Messiga, 2024).

Table 2: Influence of flooding and post flood irrigation on soil chemical properties along river Kamanda

	pH(H_2O)	pH($CaCl_2$)	O.C(%)	TN	Av. P
Land Use					
irrigated upland	6.413ab	5.543ab	0.5852	0.1773	11.29
irrigated lowland	6.607a	5.737a	0.3525	0.1587	15.21
Unirrigated upland	6.657a	5.787a	0.4921	0.1400	24.56
unirrigated lowland	6.230	5.393b	0.6650	0.1680	15.32
SED	0.130	0.124	0.1304	0.0373	11.908

Note: O.C =Organic carbon, TN = Total Nitrogen, Av. P = Available phosphorus

3.3 Influence on Soil Exchangeable Bases, Exchangeable Acidity, and CEC

This table evaluates the effect of flooding and irrigation on essential soil cations (Ca, Mg, K, Na), exchangeable acidity (EA), and cation exchange capacity (CEC). Soils from the unirrigated upland showed the lowest Ca (1.359 cmol/kg) and CEC (3.792 cmol/kg), indicating lower nutrient-holding capacity and possibly higher vulnerability to nutrient depletion. In contrast, the unirrigated lowland recorded the highest Mg (1.929 cmol/kg), K (0.215 cmol/kg), and CEC (6.384 cmol/kg), likely due to sediment deposition from seasonal flooding.

The irrigated upland had the highest Ca concentration (2.662 cmol/kg) and high CEC (5.980 cmol/kg), suggesting nutrient enrichment likely due to fertilizer application and organic amendments common in managed fields. The irrigated lowland had the lowest EA (0.334 cmol/kg), which may be due to cation accumulation from irrigation water reducing soil acidity.

Overall, the differences in base cation concentrations and CEC across land uses illustrate how flooding and irrigation modify soil fertility status (Ma et al., 2024). Irrigated areas generally had higher calcium, possibly due to liming or fertilizer inputs. In contrast, unirrigated lowlands appear to benefit from natural cation inputs via sedimentation during floods (Cox et al., 2018). The relatively higher EA in the unirrigated upland and irrigated upland could affect nutrient availability, particularly phosphorus, due to increased soil acidity. The trends show the significance of land use history and water management practices in shaping soil chemical properties and highlight the need for location-specific soil management strategies.

Table 3: Influence of flooding and post flood irrigation on soil chemical properties along river Kamanda

	Ca	Mg	K	Na	EA	CEC
Land Use						
irrigated upland	2.662a	1.496	0.126ab	0.1502	0.445ab	5.980a
irrigated lowland	1.995ab	1.095	0.124ab	0.4483	0.334b	5.097ab
Unirrigated upland	1.359b	0.740	0.082b	0.1213	0.390b	3.792b
unirrigated lowland	2.344a	1.929	0.215a	0.2390	0.557a	6.384a
SED	0.3461	0.5468	0.0405	0.1914	0.0682	0.7783

3.4 Influence on Soil Salinity Indicators

Table 4 presents salinity indicators such as electrical conductivity (EC), base saturation (%BS), exchangeable sodium percentage (ESP), sodium adsorption ratio (SAR), and magnesium hazard (MH) across different land uses. EC values, a measure of soluble salts, were generally low (0.011–0.022 dS/m), suggesting non-saline conditions across the sites which agrees with findings of (Abdulkadir et al., 2022). However, the irrigated lowland had the lowest EC (0.011 dS/m), potentially due to leaching from frequent irrigation, while the unirrigated upland showed the highest (0.022 dS/m) which agrees with the findings of (Sani et al., 2024).

Base saturation was highest in the irrigated upland (73.80%) and lowest in the unirrigated upland (60.74%), reflecting higher nutrient base cations in managed irrigated systems. ESP was notably higher in the irrigated lowland (8.743%), possibly due to accumulation of sodium from irrigation water. SAR values were generally low (<1), indicating a low risk of sodicity, though the irrigated lowland had a relatively elevated SAR (0.387) which agrees with the findings, which may warrant monitoring (Sani et al., 2024).

MH values were moderate across all sites, with the highest in the unirrigated lowland (43.55), suggesting some potential magnesium-related imbalance in that location. Despite the overall non-saline classification, variations in ESP and SAR indicate potential risks of soil structure degradation under continued irrigation without adequate drainage (Pessoa et al., 2022).

The salinity levels are currently low, there are emerging signs particularly in irrigated lowlands of sodium accumulation, which could pose risks over time. Continuous monitoring and implementing salt management practices such as leaching, proper drainage, and use of gypsum may be necessary to maintain long-term soil productivity (Silatsa and Kebede, 2023).

Table 4: Influence of flooding and post flood irrigation on soil salinity along river Kamanda					
	EC	%BS	ESP	SAR	MH
Land Use					
irrigated upland	0.021a	73.80a	2.553	0.105	34.01
irrigated lowland	0.011b	71.33a	8.743	0.387	35.79
Unirrigated upland	0.022a	60.74b	3.204	0.118	35.26
unirrigated lowland	0.018ab	73.25a	3.914	0.170	43.55
SED	0.0032	3.35	3.77	0.178	6.48
Note that electrical conductivity (EC), base saturation (%BS), exchangeable sodium percentage (ESP), sodium adsorption ratio (SAR), and magnesium hazard (MH)					

4. Conclusion

The study has revealed that seasonal flooding and post-flood irrigation exert notable influences on both the fertility and salinity characteristics of soils along the Kamanda River in Kiru LGA. The particle size analysis confirmed a general sandy loam texture across all sampled sites, though variability in sand, silt, and clay content was observed depending on irrigation status and topographic position. These differences highlight the role of water movement and sediment deposition in shaping soil structure, with unirrigated lowlands particularly benefiting from silt-rich sediments. Chemically, the soils demonstrated moderate fertility, with variations in pH, organic carbon, total nitrogen, and available phosphorus across different land uses. Notably, unirrigated lowland soils exhibited higher organic matter and cation exchange capacity, indicating enhanced nutrient-holding capacity, potentially due to the accumulation of organic-rich flood sediments. Irrigated uplands, while benefiting from agricultural inputs, showed signs of nutrient depletion and reduced phosphorus availability, likely linked to continuous cropping and nutrient leaching. Salinity indicators, including EC, ESP, and SAR, remained within acceptable agricultural limits, suggesting that current irrigation practices have not yet resulted in severe salinization. However, higher ESP values in irrigated lowlands indicate potential sodium accumulation, which could affect soil structure and permeability over time.

Finally, while flooding can enhance soil fertility through sediment deposition, unmanaged irrigation may gradually lead to salinity-related issues. Therefore, sustainable land and water management practices such as controlled irrigation, organic matter incorporation, and periodic soil monitoring are essential to preserve soil quality and ensure long-term agricultural productivity in the region.

Reference

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

Aliyu, A., Dawaki, M. U., and Sani, M., 2020. Effect of Organic Soil Amendments on Soil Chemical Properties in Sudan Savannah of Nigeria. Nigerian Journal of Soil Science, 30(2), Pp. 122–132. https://doi.org/https://doi.org/10.36265/njss.2020.300215

Aliyu, J., Jimoh, . I. A., Abdullahi, Y.M., Abdulkadir, A. and Sani, S., 2024. Assessment of Soil Variability Under Different Land Use in Northern Guinea Savannah Zone of Kaduna State, Nigeria. FUDMA Journal of Agriculture and Agricultural Techology. 10(2) Pp. 71-79. https://doi.org/10.33003/jaat.2024.1002.11

Banach, A. M., Roelofs, J. G. M., Smits, A. J. M., Banach, K., Stępniewska, Z., Lamers, L. P. M., and Visser, E. J. W., 2009. Effects of summer flooding on floodplain biogeochemistry in Poland; implications for increased flooding frequency. Biogeochemistry, 92(3), Pp. 247–262. https://doi.org/10.1007/s10533-009-9291-2

Brady, N.C and Weil, R.R., 1999. The Nature and properties of Soils. 12th edition, prentice hall publishers, London, 1-9pp

Cox, C., Jin, L., Ganjegunte, G., Borrok, D., Lougheed, V., and Ma, L., 2018. Soil quality changes due to flood irrigation in agricultural fields along the Rio Grande in western Texas. Applied Geochemistry, 90, Pp. 87–100. https://doi.org/10.1016/j.apgeochem.2017.12.019

Dawaki, M. U., Abdulkadir, A., and 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. Nigerian Journal of Soil Science, 29(2), Pp. 122–132. https://doi.org/https://doi.org/10.36265/njss.2020.290215

Estefan, G., Sommer, R., and Ryan, J., 2013. Methods of Soil, Plant, and Water Analysis: A manual for the West Asia and North, ICARDA: Bierut, Lebanon, pp. 65 - 67.

Fink, A., 2003. Fertilizer and their Effective Use; Introductory chapter of the IFA World Fertilizer Use Manual. Germany http://www.fertilizer.org.

Forth, H.D. and B.G. Ellis., 1997. SoilFertility, 2nd eds. Lewis CRC Press., USA.290p

Fournier, S., Vazquez-Cuervo, J., Reager, J. T., Lee, T., David, C. H., and Gierach, M. M., 2016. SMAP observes flooding from land to sea: The Texas event of 2015. Geophysical Research Letters, 43(19). https://doi.org/10.1002/2016gl070821

Gee, G.W. and Or, D., 2002. Particle size analysis. In: J.H. Dane and G.C. Topp (eds). Methods of soil analysis, part 4. physical methods. Soil Science Society of America. Book series. No. 5 America Society Agronomy and Soil Science Society of America Madison, W1. Page 255-293.

Gould, I. J., Bosworth, G., Ruto, E., Wright, I., Pearson, S., and Collison, M., 2020. The impact of coastal flooding on agriculture: A case-study of Lincolnshire, United Kingdom. Land Degradation andamp; Development, 31(12), Pp. 1545–1559. https://doi.org/10.1002/ldr.3551

Langill, J. C., and Abizaid, C., 2019. What is a bad flood? Local perspectives of extreme floods in the Peruvian Amazon. Ambio, 49(8), Pp. 1423–1436. https://doi.org/10.1007/s13280-019-01278-8

Ma, D., He, Z., Zhao, W., Li, R., Sun, W., Wang, W., Lin, P., Wei, L., and Ju, W., 2024. Long-term effects of conventional cultivation on soil cation exchange capacity and base saturation in an arid desert region. Science of The Total Environment, 949, 175075. https://doi.org/10.1016/j.scitotenv.2024.175075

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) Pp. 71-76

Núñez, A., and Schipanski, M., 2023. Changes in soil organic matter after conversion from irrigated to dryland cropping systems. Agriculture, Ecosystems andamp; Environment, 347, 108392. https://doi.org/10.1016/j.agee.2023.108392

Pessoa, L. G. M., Freire, M. B. G. dos S., Green, C. H. M., Miranda, M. F. A., Filho, J. C. de A., and Pessoa, W. R. L. S., 2022. Assessment of soil salinity status under different land-use conditions in the semiarid region of Northeastern Brazil. Ecological Indicators, 141, 109139. https://doi.org/10.1016/j.ecolind.2022.109139

Rengasamy, P., 2002. Transient salinity and subsoil constraint to dry land farming in Australian sodic soil. An overview. AustralianJournalofExperimentalAgriculture, 42(3), Pp. 351-361.

Richards, L.A., 1954. Diagnosis and improvement of saline alkali soil, Agriculture, 160. Handbook 60. US Department of agriculture, Washington DC. PP: 4-5 roots. Plant Physiol. 43: 527-30.

Rupngam, T., and Messiga, A. J., 2024. Unraveling the Interactions between Flooding Dynamics and Agricultural Productivity in a Changing Climate. Sustainability, 16(14), 6141.

https://doi.org/10.3390/su16146141

Sani, S., Abdulkadir, A., Hmad Pantami, S. A., Sani, M., Amin, A. M., and 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), Pp. 719–729. https://doi.org/10.24925/turjaf.v11i4.719-729.5733

Silatsa, F. B. T., and Kebede, F., 2023. A quarter century experience in soil salinity mapping and its contribution to sustainable soil management and food security in Morocco. Geoderma Regional, 34, e00695. https://doi.org/10.1016/j.geodrs.2023.e00695

Slavich, P. G., and Petterson, G. H. Estimating the electri-cal conductivity of saturated paste extracts from 1: 5 Soil: water suspensions and texture. Aust. J. Soil Res., 1993: Pp. 73 – 81.

Srivastava, R. K., Purohit, S., Alam, E., and Islam, M. K., 2024. Advancements in soil management: Optimizing crop production through interdisciplinary approaches. Journal of Agriculture and Food Research, 18, 101528. https://doi.org/10.1016/j.jafr.2024.101528

Sufiyanu Sani, Aliyu Abdulkadir, Musa Muhammad, Musab Ibrahim, AbdulsalamSani Nababa, Ahmad Ubaidullah and Aliyu Suleiman., 2024. Assessment of Soil Salinity and Sodicity Status at Jibia Irrigation Project, Katsina State, Nigeria. Life Sciences: an International Journal (LSIJ) Vol.1, No.1

US Salinity Laboratory Staff, 1954. Diagnosis and improvement of saline and alkali soils. USDA Agricultural Handbook No. 60. U.S. Government Printing Office. Washington, DC.

Wong, V. N. L., Greene, R. S. B., Murphy., B. W., Dalal, R. and Mann, S. 2004b.carbon dynamics in salt affected soil. InRoach I.C ed.Regolith2004.CRC Leme,pp.407-410.

Zhang, Y., Cui, D., Yang, H., and Kasim, N., 2020. Differences of soil enzyme activities and its influencing factors under different flooding conditions in Ili Valley, Xinjiang. PeerJ, 8(7), e8531. https://doi.org/10.7717/peerj.8531