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EFFECT OF LONG-TERM TILLAGE PRACTICE AND CROPPING ON PHYSICOCHEMICAL PROPERTIES OF SOILS IN SOUTHERN GUINEA SAVANNAH AREA OF NIGERIA

Oguche Felix Michael*#, Musa John Jiya, Otuaro Ebierin Akpoebidimiyen***, Kuti Abayomi Ibrahimm**, Eze Peter Chukwu****, Umunnakwe Victor Chibuzor*****, Kutigi Ismila Baba****

*University of Debrecen, Faculty of Agricultural and Food Sciences and Environmental Management, Institute of Water and Environmental Management, 138, Boszormenyi St. 4032, Hungary
**Federal University of Technology, Department of Agricultural and Bioresources Engineering, P. M. B. 65, Minna, Nigeria
***Maritime University, Department of Civil Engineering, P. M. B. 1005, Okerenkoko, Nigeria
****Federal University of Technology, Department of Soil and Land Management, P. M. B. 65, Minna, Nigeria
*****International Skill Acquisition Centre and Farms, Km 10 Abuja-Keffi Road Gora, Nasarawa State, Nigeria

Abstract
Agriculture is the bravado of most developing countries like Nigeria; thus, it is the key point for the existence of those living in the country. This is study is aimed at the effect of long-term tillage practice and cropping on physicochemical properties of soils in Southern guinea savannah area of Nigeria. Soil samples were collected from a continuously cropped rice field using the random uniform grid method at depths between 0 - 15 cm, 15 – 25 cm, 25 - 50 cm and 50 – 75 cm. Samples were collected in five replicates, mixed and homogenized. Soil samples collected at the 0 - 15 cm, 25 - 50 cm depth were Sandy clay loam while those of 15 - 25 cm and 50 - 75 cm depths are sandy clay and sandy loam. The soil hydraulic conductivity for the zone of 25 to 50 cm had values ranging between 0.23 and 1.51 cm/hr. while the fourth zone considered had values ranging between 0.49 and 0.77 cm/hr. It was concluded that the farmers should conduct physical and chemical analysis of the soils they wish to carryout farming activities to decide the type of fertilizer to be used.

Key words: agriculture, cropping, chemical properties, land use, physical properties

INTRODUCTION

Agriculture is the nerve of most developing countries like Nigeria; thus, it is the focal point for the survival of those living in the country (Akanle and Omotayo, 2020). The effect of tillage practices on soils and the environment are not location specific, thus it cannot be generalised. It is believed that the depth of soil tillage decides the gravity of soil loosed from the clods which has effect on the quantity of water infiltrated into the root zones of crops (Renwick et al., 2021).

The long-term effect of soil tillage practice on farmlands differs with those of the short-term. Next to nothing has been done in long-term effect of tillage practice in the North Central part of Nigeria were agricultural activities predominant (Akinde et al., 2020).

Corresponding author

The most common tillage practice is manual in nature with little machinery activities. Thus, most soils degrade under prolonged intensive arable agriculture. In most cases, the physical degradation of soils on the farmland leads to crusts and compaction and would further lead to soil erosion (Cerda et al., 2018).

Ploughing of farmlands exposes the structural instability of the soils to the actions of raindrop effect, reduced infiltration, increased runoff and erosions, increased soil temperature, and evaporation which overall have a major effect on the crop yield from such areas (Kader et al., 2017). Mechanical soil tillage has been described to be beneficial most especially where soils are easily compacted and have the presence of mulchable materials.

Soil infiltration is related to the structural stability, bulk density and pore sizes (Ramezani et al., 2017; Minhas et al., 2021).

Long-term conventional tillage and no tillage systems can alter bulk density, aggregate stability, total porosity, and organic carbon content for soils operated upon with mechanical machines (Xu et al., 2018; Rincon-Florez et al., 2020).

The use of human power for soil cultivation overtime has been believed to be non-productive. Thus, the behavioral nature of the soil under various tillage conditions differ with respect to saturated hydraulic conductivity. Hence the effect of tillage depth and method on physical properties may explain the variability in crop growth, crop development, yield and quality (Liu et al., 2017; Çelik et al., 2020; Sokolowski et al., 2020).

Soil tillage practice is one of the most critical factors of agriculture that would affect soil physical and chemical properties. The various tillage practices used for most agricultural production influence the soil environment's physical, chemical, and biological properties. Soil tillage aims to create a conducive environment for plant growth. Soil tillage practices are defined as the physical, chemical, or biological soil manipulation to perfect the conditions for germination, seedling establishment and crop growth (Akpan and Udo, 2017).

Therefore, this study aims at studying the effect of long-term tillage practice and cropping on soil physicochemical properties in Nigeria's southern guinea savannah area.

MATERIAL AND METHOD

Study Area

Niger state lies in the Southern Guinea Savannah ecological zone of Nigeria between latitude 8˚ 10’ N and 11˚ 3’N and longitude 3˚ 20’E and 7˚ 30’E with Wushishi as one of the Local Government Areas within the State. Niger state has two distinct seasons: the rainy and dry seasons. The rainy season usually starts in the southern part of the state from early April and ends in late October, and in some rare cases, the first half of November. The dry season starts mostly from mid-November and ends in March of the following year. The average annual rainfall, temperature, and relative humidity of Niger state are 1,312 mm, 27.3 ˚C and 50.2 %, respectively (Ahaneku and Sadiq, 2014).

Wushishi Local Government of Wushishi is bordered by Gbako Local Government to the south, Rafi and Bosso Local Government Areas to the east, Mariga Local Government Area to the north; Mashegu and Lavun Local Government Areas to the west. Figure 1 shows the extracted map of Wushishi Local Government Area from the map of Niger State, showing the study location of Tungan Kawo Irrigation Scheme in red. The plot location for the experiment was latitude 9˚ 39’ 42” N 6˚ 5’ 56” E, 9˚ 41’ 22” N 6˚ 5’ 35” E, and longitude 9˚ 44’ 33” N 6˚ 5’ 25” E, respectively.

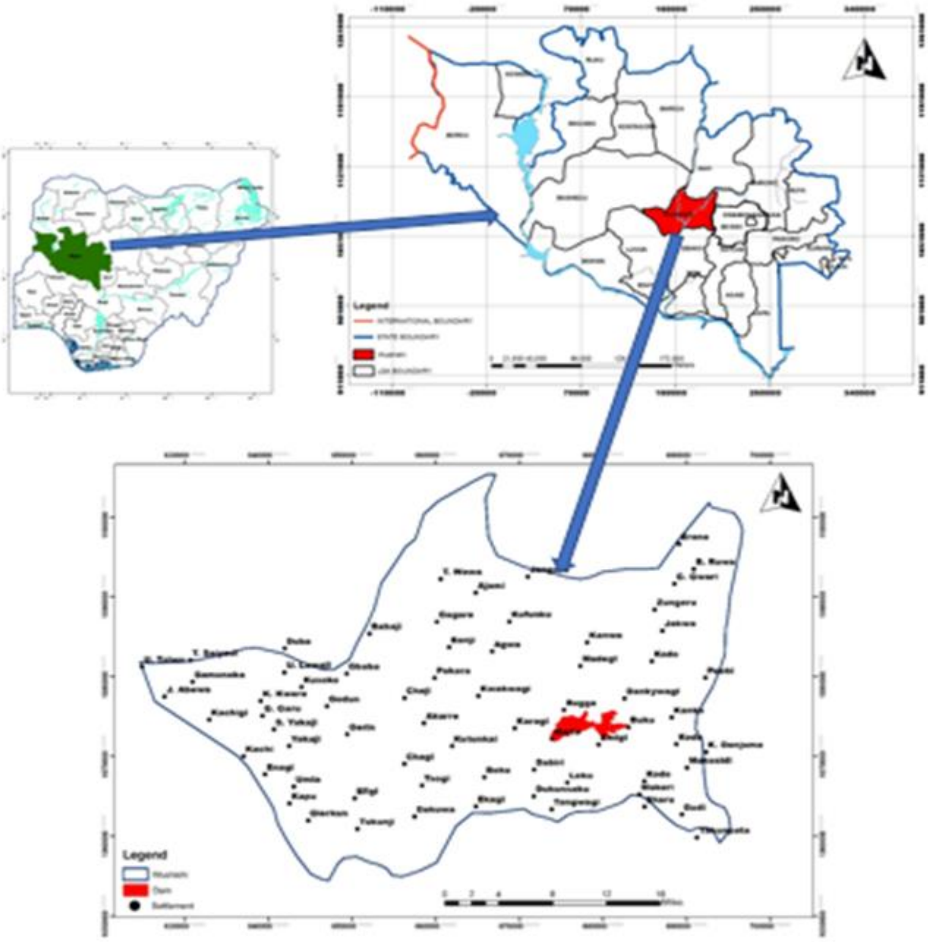

Fig. 1. Extracted map of Wushishi Local Government Area showing Tungan Kawo Irrigation from the map of Niger State and Nigeria

Soil Sampling

Soil samples were collected from a continuously cropped rice field using the random uniform grid method at depths between 0 – 15 cm, 15 – 25 cm, 25 – 50 cm and 50 – 75 cm to account for the crop rooting depth. Four soil samples were collected from each of the plots using the soil auger which a diameter of 5 cm and a height of 5 cm. All samples were collected with five replicates, mixed and homogenized. This soil sampling method is following the works of: Stare et al., 2013; Musa et al., 2017; Musa et al., 2018.

These cores were air-sealed with plastic lids and transported to the laboratory for testing. In the laboratory, all soil samples were stored in polyethylene bags and divided into two parts; the first part was air-dried, passed through a 2 mm, 0.25 mm, and sieved to 0.149 mm. 200 g of the soil separates were determined by hydrometer method of Bouyoucos, to establish the physical content of the soils, which is in accordance with works of Ipadeola et al., 2017.

Some quantity of the samples were allowed to determine the EC, pH, soil organic carbon (SOC), total nitrogen (TN) and total phosphorus (TP), and the second was stored in a cooler at 4 ˚C to determine the chemical content of the samples. This is also like the works of Brunet et al., 2007.

Soil Moisture Content

The soil moisture content was decided in-situ in the field. Using laboratory method, the difference in moisture content is determined through the difference in weight before and after oven drying of the samples at a temperature of 105 ˚C for seventy-two hours (Faanu et al., 2011). Soil moisture content is said mathematically as:

$$M_c = \frac{(W_{ms}+Coontainer)-(W_{ds}+Coontainer)}{(W_{ds}+Coontainer)}; \qquad [1]$$

Where:

M_c is the Soil moisture content;
W_{ms} is the Weight of moist soil;
W_{ds} is the Weight of dried soil.

Soil bulk density

The soil bulk density was determined by taking the ratio of dry soil sample weight to the total volume of core sampler. This is in accordance with the works of Walter et al., 2016.

$$\text{Bulk density} = \frac{Wd}{V}; \qquad [2]$$

Where:

Wd is the weight of dry soil sample (g);
V is the volume of core sampler (cm^3).

Bulk density reflects the soil's ability to function for structural support, water and solute movement and soil aeration (Elliott et al., 1998).

RESULTS AND DISCUSSION

Results

Physical Properties of Soil Samples

The result of the soil textural classification for the randomly selected points is presented in Table 1. The Table presents the particle size distribution at varying depths ranging between 0 and 75 cm. the rice field shows a slight variation in the percentages of sand, silt, and clay content. The USDA classification system showed that the various soil samples collected at the 0 - 15 cm, 25 - 50 cm depth were Sandy clay loam while those of 15 - 25 cm and 50 - 75 cm depths are sandy clay and sandy loam.

Chemical Characteristics of Soil Samples

The management practice of soil quality and its effect on the ecosystem and the productivity rate of the plants has called for the evaluation of the chemical content of soils. Chemical constituents of soils majorly depend on the soil collides (Kang et al., 2019). These constituents include the inorganic cations-for example, calcium (Ca), sodium (Na), magnesium (Mg), and potassium (K). These constituents were mostly adsorbed from the soil surface.

All forms of chemical characteristics are affected by anthropogenic activities (Zhang et al., 2011), which occur on the surface of the soil to a maximum depth of 30 cm which is considered to the root depth zone of crops.

The difference in the chemical constituents present at the various sample points show the effect rate of application both organic and inorganic fertilizers to the soil. The major effect of fertilizer and water application rates to the soil was mostly seen within the first 15 cm of the upper layer of the soil based on the management and crop practice. The chemical content of the various soil samples from the various locations are presented in Table 2.

Discussion

Physical Properties of Soil Samples

The highest value of sand was 68 % at a depth range between 50 - 75 cm and within the same range clay particle was seen to be lowest. It was seen that the soil textural classification throughout the study area had a relatively high percentage of sand particles. This high percentage of sand particles is in accordance with the works of Greenwood and Buttle, 2014, for studies carried out at the southern part of Ontario Canada.

Table 1.

Soil textural classification and Characteristics for selected locations within the farm layout

Study location	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	USDA Textural class	Soil Characteristics					
						Wilting point (%)	Saturation (%)	Field Capacity (%)	Saturated Hydraulic Conductivity (cm/hr)	Bulk Density (g/cm^3)	Available Water (cm/cm)
Sample point 1	0-15	52	16	32	sandy clay loam	18.00	48.20	28.20	0.21	1.37	0.10
	15-25	50	8	42	sandy clay	22.80	49.90	32.50	0.12	1.33	0.10
	25-50	58	12	30	sandy clay loam	17.20	47.40	26.60	0.23	1.39	0.09
	50-75	66	14	20	sandy loam	13.70	45.50	23.50	0.49	1.44	0.09
Sample point 2	0-15	64	12	24	sandy clay loam	14.60	45.70	23.60	0.38	1.44	0.09
	15-25	56	19	25	sandy clay loam	14.90	46.50	25.10	0.37	1.42	0.10
	25-50	68	11	21	sandy clay loam	13.40	44.70	22.10	0.53	1.47	0.09
	50-75	65	17	18	sandy clay	12.10	44.00	21.50	0.77	1.48	0.09
Sample point 3	0-15	58	16	26	sandy clay loam	15.40	46.60	25.10	0.33	1.42	0.10
	15-25	56	22	22	sandy clay loam	14.00	46.10	24.40	0.46	1.43	0.10
	25-50	54	20	26	sandy loam	15.30	46.90	25.70	0.34	1.41	0.10
	50-75	55	23	22	sandy clay loam	13.50	46.00	24.50	0.52	1.43	0.11
Sample point 4	0-15	67	18	15	sandy loam	10.80	42.90	20.40	1.15	1.51	0.09
	15-25	63	18	19	sandy loam	12.40	44.50	22.20	0.69	1.47	0.10
	25-50	65	22	13	sandy loam	10.00	42.10	19.80	1.51	1.53	0.10
	50-75	60	18	22	sandy clay loam	13.70	45.50	23.50	0.49	1.44	0.10

Table 2.

Various Parameters Analyzed in the Soils from the Various Locations.

Sample	pH in H_2O	Mn (mg/l)	Cu (mg/l)	Phosphorous (mg/l)	Excess Base				EC (µS/cm)	CEC (Cmol/kg)	Fe (mg/l)	% O/C	% O/M
					Na^+ (Cmol/kg)	K^+ (Cmol/kg)	Mg^+ (Cmol/kg)	Ca^{2+} (Cmol/kg)					
Sample Point 1	6.48	0.18	0.16	11.00	0.14	0.09	1.30	2.00	12.00	3.00	0.06	0.28	0.48
Sample point 2	6.47	0.28	0.23	12.50	0.18	0.12	2.30	2.70	13.20	4.00	0.16	0.28	0.48
Sample point 3	6.44	0.19	0.13	8.50	0.14	0.04	1.50	2.10	10.04	1.80	0.11	0.38	0.66
Sample point 4	6.45	0.20	0.17	12.50	0.16	0.14	1.70	2.40	12.50	3.80	0.18	0.26	0.45
Maximum	6.48	0.28	0.23	12.50	0.18	0.14	2.30	2.70	13.20	3.80	0.18	0.38	0.66
Minimum	6.44	0.18	0.13	8.50	0.14	0.04	1.30	2.00	10.04	1.80	0.06	0.26	0.45
Median	6.46	0.20	0.17	11.75	0.15	0.11	1.60	2.25	12.25	3.40	0.14	0.28	0.48
Average	6.46	0.21	0.17	11.13	0.16	0.10	1.70	2.30	11.94	3.15	0.13	0.30	0.52

It was recorded from that study that a high sand particle percentage existed within the study area. The high rate of the sand particle may be as a result of the continuous working of the land for rice plantation.

Agronomic practices require the detail knowledge of the amount of water present within the soil of proposed farmlands. Thus, soil is said to be the storage point of water which is released gradually to the plant roots for its growth which also is the factor that influences the productivity of both the crops and the land. Wilting point or Permanent Wilting Point (PWP) is said to be the minimum moisture present in soil required by a plant not to wilt. Thus, at this point, any reduction in the soil moisture will lead to the wilting of the plant which is seen when the plants lose their leaves either by dropping off or withering (Kosma et al., 2009).

The results in Table 1 revels that the PWP of upper layer of the soil of the study area (i.e., 0 – 15 cm) had values ranging between 10.80 and 18.00 % which could be linked to the presence of mulching materials in the soil as moisture is lost through direct evaporation and is in conformity with work of Mbah, 2012. The lower layers of 15 – 25 cm, 25 – 50 cm and 50 – 75 cm had the PWP values ranging between 12.40 to 22.80 %, 10.00 to 17.20 % and 12.10 to 13.70 % respectively. The results shows that the PWP of the upper and lower layers were different from each other which could be due to variations in particle size distribution of the soil and the presence of organic matter in the form of root hairs and rice straws.

Saturation Point of a soil sample is described as the point at which ability of the soil to absorb water and when it gets to its maximum the soil starts to expel water as surface runoff.

With the nature of the soil in the study area, it was seen that the saturation points of the various soil samples collected ranged between 42.10 and 46.90 %. This result corroborates the nature of soil within the study area.

These percentages seen could be linked to the organic matter content, the root hairs present within the soil structure and the extent at which the land had been worked upon.

Field capacity (FC) is a soil parameter that is widely used in soil hydrology, land management, and irrigation and drainage engineering. The use of FC under field conditions is motivated by the constant movement of water within the various soil layers which is associated with the wetting condition of the soil. The FC at the four selected points of observation varied between 19.80 and 32.50 %. This implies that the rate at which water is drained from the surface layer of the soil to the lower ones. This confirms the nature of soil within the study area as that which resist water movement to a certain level as seen in Table 1. The poor movement of water within the soil layers reduces the level of soil aeration thus the FC is assumed to be practical upper limit for soil water storage for plant use and its corresponding air content as lower air capacity limit.

A study conducted in Niger River loop in Mali (Diallo and Mariko, 2013), showed that the field capacity (FC) and permanent wilting point (PWP) of clay soils developed on Quaternary alluvium were like that conducted in this study area.

The movement of water in soils depends on its composition with respect to biological composition, degree of decay, structure, texture, and their physical-water properties. The presence of decomposed materials in soil is occasioned with high permeability rate of water. When the rate of decay in the soil increases the rate of permeability of water decreases also (Kazemian et al., 2011). Under hilling the process of hydraulic conductivity is important for agricultural activities as it figures out the water flow rate and the size of ditches to be constructed on the farm.

Soil saturated hydraulic is needed for deciding the flow rate of water in a layered saturated soil. The saturated hydraulic conductivity varied from the upper layer to the lower layers as seen in Table 1 for the four locations where soil samples were collected. For layers between 0 and 15 cm, the saturated hydraulic conductivity ranged between 0.21 and 1.15 cm/hr while for the soil zone of 15 and 25 cm, the value varied between 0.12 and 0.69 cm/hr. The soil hydraulic conductivity for the zone of 25 to 50 cm had values ranging between 0.23 and 1.51 cm/hr while the fourth zone considered had values ranging between 0.49 and 0.77 cm/hr.

The flow rate of water at the upper zone of 0 -15 cm showed that there is poor movement of water which is connected to the constant working of the land and the burning of the rice straws before the start of another planting season. During this process of the straw burning, the ash particles produced find their ways into the various pore spaces thus reducing the amount of air and water that will enter the soil zone. The values of the soil hydraulic conductivity for the second were seen to be high.

Bulk density (BD) with respect to agriculture is an essential property that decides the amount of soil solids present within a given area over a given depth range (Harrison et al., 2011).

BD as a parameter that helps in the assessment of soil carbon, soil nutrients and its packing structure which are all of interest for land management practices, as it helps to describe the drainage characteristics of the soil (Rezanezhad et al., 2016).

BD of the first soil depth of between 0 and 15 cm ranged between 1.37 and 1.51 g/cm^3. Soil BD showed a significant decrease in determined values for soil depth of 15 to 25 cm, which ranged between 1.33 and 1.47 g/cm^3. This could so because the upper layer of the four points, where the soil samples were collected are constantly worked upon by the farmers. The BD of the soil depth of 25 to 50 cm varied between 1.39 and 1.53 g/cm^3. The values were seen to be slightly high which could be the linked to the texture of the soil. The final soil depth of 50 – 75 cm had BD ranging between 1.43 and 1.48 g/cm^3. The values were seen to be remarkably close which shows less of human and vehicular traction which is similar to the works of Major et al., 2010.

Water within the root crop zone has many functions, as it is the main source of water for plants during growth and production stages (Malézieux et al., 2009). Water supply into this zone is mostly obtained from the biosphere as rainfall which in most cases results in surface runoff which serves as the first water source while the second is the groundwater. Changes in soil moisture is a common factor because of changes in soil temperature which accounts for water present within the root zones which are key parameters to surface water and groundwater state and total hydrological and energetic balance (Malézieux et al., 2009). Thus, in agricultural practice, it is imperative to monitor the available moisture within the soil and maintain it in levels that is required for plant taking into consideration the amount of water to be irrigated and the amount of water the plant will also require for its growth.

Chemical Characteristics of Soil Samples

pH: pH of the soil within the study area is described as the degree of acidity or alkalinity of the soil within the area where the samples were collected. The pH values obtained from this study location during the dry season of the year 2018 ranged between 6.44 and 6.88 with a mean value of 6.46, which implies that the soils were moderately acidic. These values shows that the soil is slightly acidic in nature, which could be linked to the type of on-farm treatment given to the crops previously planted. The weak acidic nature of the soils in the study location is in line with the study of Tittonell et al., 2008.

The values reported in this study are within the range for best plant growth and are in the same range with those reported by Romero et al., 2012. Several studies have shown that reduction in pH may allow the release of toxic metals which could be adsorbed in the soil (Beesley et al., 2011). The values of pH within the soils of the study area shows a high tendency for high availability of the metals thereby increasing the risk of heavy metal presence and so uptake by plants which eventually has an adverse effect on man through food chain. pH value within the range of 2 and 6 enables the availability and mobility of trace metals in soils though the trace metals are not in any way harmful to the human health. The values saw in this study were outside this range.

A regular pattern was seen in the pH values of the study area during the dry season for the soil samples collected. This could be connected to the presence of the soil organic matter through biogenetic cycling of the bases present within the soils. This process of biogenetic cycling reduces acidification of the soils.

Manganese (Mn): The values obtained for the various soil samples at the four locations of the study area during the dry season of the year 2018 ranged between 0.18 to 0.28 mg/l during the dry season of 2018. This result shows a low concentration of manganese content within the study area. These might be due to the organic and inorganic fertilizers that are applied on the farms and the nature of the soil properties. When these results were compared with those of Diacon and Montemurro, 2011, they were found to be similar. They found out that due to inefficient and poor distribution of water by inadequate drainage management could lead to salinity.

Copper (Cu): The Cu content seen within the study area ranged between 0.13 and 0.23 Cmol/kg during dry season of the year 2018. This result shows a higher concentration of Cu in the study area for the dry season when compared with the results obtained in the studies conducted by: Matthews-Amune and Kakulu, 2012; Yin et al., 2012; Wongsasuluk et al., 2014. The copper content observed within the study area could be linked to surface washed materials deposited into the dam, which is passed to the farmlands. This shows that during the dry period there is a possibility of high accumulation of Cu compared to the raining period. The low content that may be seen drying wet season might be due to consistent rainfall which tends to leach away most of the available nutrient including Cu.

Phosphorus: The level of phosphate concentration within the study area ranged between 8.50 and 12.50 mg/L with a mean average of 11.75 mg/L. The observed data for the study area were higher in value compared to the works of Fonseca et al., 2011, but lower compared to the works of Sinha et al., 2006. Rice needs between 3 to 4 kg of P to produce one ton of the rice grain and straw (Islam et al., 2010). P is an important plant nutrient that helps transfer energy for biochemical process in the plant which also stimulates both root and shoot development and promotes flowering and grain development (Pérez-Montaño et al., 2014). The high content of P found at the soil surface within the study area could be linked to the farm practice method employed by the local farmers. The farm practice includes flooding method of irrigation used by the farmers. The flooding method of irrigation, surface runoff and leaching are the process through which phosphorus is lost on the farm. The irregular pattern of P within the study area is a replication of what is in existence for soils in the savanna zone of Nigeria.

The deficiency of P in plants, according to Birch et al., 2012, tends to produce red and purple leaf colours and careful observation the systems develop stunted growth. Most artificial fertilizers added to soils experience a degree of phosphate fixation with other soil elements. The degree of fixation is dependent upon the chemical nature of the soil. High level of sodium content in soils reduces the availability of P in soils. Thus, the high level of P within the study area is due to the low sodium content in the soils as seen in Table 2. Soil phosphorous is accessible in exceptionally low quantities to plant since most of it is tied up in insoluble compounds and its availability depends on the soil pH (Atkinson et al., 2010).

Sodium (Na): The existence of sodium in soils is not an essential element for plant growth but its soluble form may increase crop growth (Shrivastava and Kumar, 2015). The values gotten for the soil samples from the various locations on the plot considered for the dry season farming ranged from 0.14 to 0.18 Cmol/kg. The values obtained were observed to be comparatively low and within allowable limits. The amount of Na in the soils of the study area could be linked to the kind of soil improvement and additives that are added to enhance crop growth.

The concentration level within the study area also indicates the plot for which the rice crop is to be planted is free from the threat of salinization, this is as observed by Shrivastava and Kumar, 2015. The values were also observed to be lower when compared to the finding of Dayo-Olagbende et al., 2019. High sodium concentration in the soils in most cases leads to high salt presence in the farmlands which will lead to turbidity of the soils and decrease in the osmotic activity of the soil and reduce the level moisture intake rates by plants. Low concentration rates of Na in the soil have no detrimental effect on the soil as they are needed in minute quantity in the soil. The values of Na content collected at the four points were observed to be irregularly distributed within the soils.

CONCLUSIONS

Rice farmers within the study area of the Kanko community in Niger State, Nigeria, appear not to have adequate knowledge of the soil they are cultivating, and the quality of water being applied for irrigating the farming areas. The farmers' view as regards soil quality is based on dynamic processes of integrating several types of chemicals in the form of inorganic fertiliser and biological application in the form of earlier farms wastes such as rice straws and animal dungs. These forms of addition to the soil are to improve the soil characteristics as they believe to know the indicators for the best quality of soil within the study area.

The farmers within the study areas have local methods through which quality of soil is locally decided which hardly gives the best and realistic results that will decide the amount of fertiliser to be applied to the farm. The best indicator methods can hardly be used because of the limitations set by the various management practices employed by the farmers.

Nevertheless, conventional, and semi-direct management practices on farmlands more than one hectare allow application of farmers' knowledge than the pre-germinated production system when compared to those with smaller farms. The results of this study provide a better understanding of the soil in the context of sustainability of farming systems.

The results obtained showed that the nitrogen content in the soils of the study area were extremely negligible which accounts for the low nitrogen content. It is therefore concluded that the farmer's judgment as regards the soil and water quality is wrong as more nitrogen fertiliser content is regarded for better production of rice within the study area.

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