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Changes in soil properties influenced by irrigation in an Alfisol of Northern Guinea Savanna of Nigeria

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Abstract

This article analyses the impact of irrigation on soil physical and chemical properties of the soils of the Galma river basin in Nigeria. Two profile pits were sited on irrigated and rain-fed fields respectively. Soil samples were collected from two depths. The soils were prepared and analysed for routine soil physical and chemical properties following a standard procedure. Quantitative data obtained from routine soil physical and chemical analysis were subjected to a T-test. The result of the analysis revealed that all the land use types locations show significant variation for sand, silt, and clay. The sand and silt show a highly significant different ($p<0.001$) across location compared with clay which shows significant variation ($p<0.05$). Bulk density, particle density, total porosity, and saturation index did not differ significantly across the land use types. Soils in irrigated fields showed significantly higher organic carbon, total nitrogen, calcium, and CEC but lower pH compared to soils under rainfed land-use type. Soils Under rain-fed land use had a statistically significant higher pH than soils under the irrigated land-use type. In contrast, differences in the distribution of soil available phosphorus, Na, exchangeable acidity and base saturation values among the two land-use types were statistically insignificant.

Keywords
Zaria, soils, physical, chemical, impact

Introduction

Irrigation has historically been viewed as a mechanism for stabilizing agricultural productivity by overcoming problems associated with drought and allowing crop diversification. Despite the increased production, diversification and associated economic benefit they bring, the sustainability of irrigation is questioned. This is largely due to its detrimental effect on the environment (AL-Jaboobi et *al*., 2014) such as waterlogging, soil salinity and groundwater contamination. Irrigation could change soil properties that play an important role in the transformation, retention, and movement of nutrients present in the applied water (Magesan *et al*., 1998). Magesan, (2001) reported soil microbial and chemical activities are influences by soil physical properties such as soil texture, porosity structure and hydraulic conductivity which influence.

Despite an increase in food production and associated socio-economic benefits, the sustainability of irrigation is to be questioned. This is because of its negative effect on soil properties leading to soil degradation. Hence, it is critical that the long-term environmental effects of irrigation be understood if the negative impacts on soil and water are to be

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avoided. Thus, the objective of this study was to examine the impact of irrigation on soil physical and chemical properties of the soils of the Galma river basin in Nigeria.

Materials and Methods

Location

This study was conducted in Galma floodplain at Dakace in Zaria Local Government area in Kaduna State, Nigeria, located on Latitude N11° 04’ 87” and Longitude 7° 44’ 47” (Figure 1), situated in the Northern Guinea Savanna ecology with a monomodal annual rainfall of about 1011±161 mm concentrated almost entirely in the five months (May/June to September/October), and mean daily temperatures (minimum and maximum) range between 15°C and 38°C (Oluwasemere and Alabi, 2004). The geology of the Galma Basin is dominated by undifferentiated basement complex rock. Land use around the area is basically agriculture. Crops such as maize, rice and vegetable carrot, tomato, onion red pepper are grown.

Soil sampling and laboratory analysis

Fieldwork was carried out so as to investigate the land resource across the study area. An exploratory survey was carried out so as to identify irrigated and rain-fed fields. The site for the profile pit was randomly selected. Two profile pits were sited on irrigated and rain-fed fields respectively and soil samples were taken at the following depths: 0-10 cm, 10-20 cm, 20-40 cm, 40-60 cm, 60-100 cm, 100-150 cm. Core samples were taken at each depth using a known volume metal. The soil samples were air dried and sieved with a 2 mm sieve mesh.

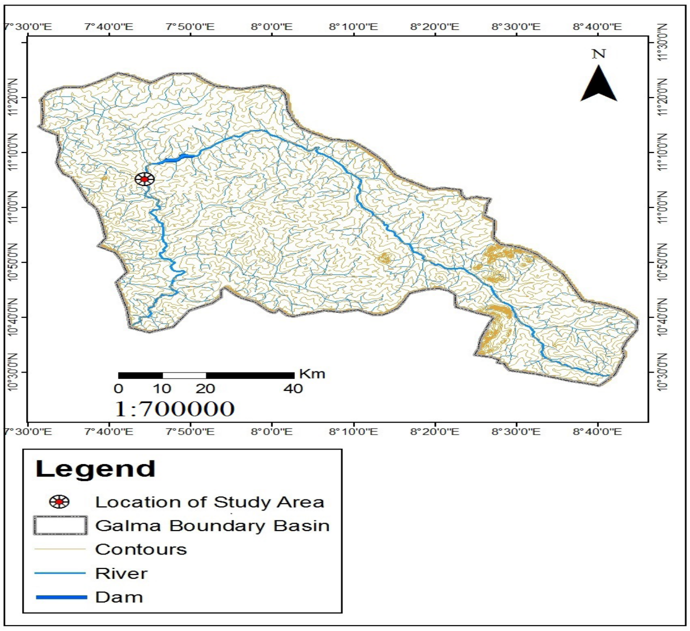

Figure 1. *Digitized and geo-referenced drainage and contour map of Galma basin showing the location of the study area.*

Soil analysis

The less than 2 mm sieved soil samples were analysed for total nitrogen (TN) using the Kjeldahl digestion method (Bremner, 1996), total organic carbon (OC) content was determined according to the Walkley–Black wet oxidation method (Nelson & Sommers, 1996). Particle size distribution was evaluated using the hydrometer method and sodium hexametaphosphate as a dispersant (Gee and Or, 2002). Then soil pH was measured by pH meter using suspension of distilled water to soil solution ratio (1:2.5) and EC measurement was performed using saturated paste extracts. Exchangeable bases and cation exchange capacity (CEC) of the soils were determined by the 1 M ammonium acetate (pH 7) method according to the percolation tube procedure (Van Reeuwijk, 1993). Available phosphorus was determined following the procedure described by

IITA (1979) using the Bray- 1 extraction method (Bray and Kurtz, 1945).

Soil structural index (SI) was estimated according to Reynolds et al. (2007) as:

$$\mathrm{SI} = \frac{1.724 \text{ x OC}}{\%\text{Silt} + \%\text{ Clay}} \text{ X } 100 \qquad [1]$$

Soil moisture retention characteristics of the undisturbed core samples were evaluated using pressure plate extractors (Klute, 1986). The moisture content (θ) was measured at 2, -5, -10, -33, -100, -500 and -1,500 kPa suction levels (h). Thermo-gravimetric core method (Blake and Hartge, 1986)

Data analysis

Data obtained were subjected to T-test for statistical analysis to compare the means of soil properties between irrigated and rain-fed fields and between soils depth using a statistical analysis system (SAS) package (SAS, 2014). Soil samples collected from 0-20 cm were considered as surface soil while soil sample collected from 20-100cm were considered subsurface soil

Results and Discussions

Impact of irrigation on soil physical properties

The results for particle size distribution are provided in Table 1 below. The two land-use types (irrigated and rain-fed) demonstrated significant variation in clay, silt and sand contents. In both land use types; the value of sand and silt fractions were lowest in the irrigated field and highest in the rain-fed field (Table 1). The clay fractions, on the other hand, were highest in the irrigated plots and lowest in the rain-fed fields. This is because increasing precipitation via irrigation does not necessarily correspond to a deeper depth of wetting; the upper part of the irrigated soil profile must surely be wetter for a longer period of time relative to dryland conditions.

Table 1. *Impact of irrigation on soil physical properties*

	Sand	Silt	Clay	BD	PD	TP	FC	PWP	AWC	SI
Land use										
Irrigated	477.1	185.7	337.1	1.48	2.63	43.5	0.37	0.24	0.14	5.07
Rain fed	592.5	265.0	150. 0	1.57	2.60	39.8	0.32	0.19	0.13	7.89
t-value	-4.76	-2.92	6.28	-1.35	1.12	1.86	2.88	2.05	0.95	-0.95
LOS	***	*	***	NS	NS	NS	**	NS	NS	NS
Depth										
Surface	565.0	250	185.0	1.36	2.57	46.9	0.36	0.19	0.17	14.4
sub surface	529.1	220	256.4	1.59	2.63	39.6	0.34	0.25	0.22	3.72
t-value	0.88	0.50	-1.02	-7.41	-3.34	6.43	0.59	-0.84	5.26	2.83
LOS	NS	NS	NS	***	NS	***	NS	NS	***	NS

This could lead to increased mineral weathering in addition to a greater number of shrink-swell cycles. Also, more water can carry greater loads of suspended solids in solution. Thus, irrigation can affect the particle size distribution, namely the clay content, by increasing clay movement within the soil profile. There was no significant difference in particle size distribution with depth. Although, surface soil has a higher content of sand, silt, and clay than the subsurface soil. A general trend in both land-use types was a decrease in the sand and silt content with an increase in soil depth. A similar trend was reported by Maniyunda and Gwari (2014) and Shehu *et al*. (2016) in a tropical Alfisol of northern Nigeria. Under sparser vegetation covers, the clay fractions are likely to be lost to processes of selective erosion and migration down the soil profile.

The Bulk density (BD) of the soils was generally low. It was lowest in areas under irrigated land-use type and highest in rain-fed areas (Table 1) however, the result of the T-test does not indicate any significant difference in land use type but there was a highly significant difference ($p \leq 0.001$) in bulk density across the depth. Higher bulk density was observed in the subsurface (1.59 Mg m^{-3}) compared with the surface soil (1.36 Mg m^{-3}). Higher bulk density in

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the subsurface soil could be attributed to decreasing organic matter as well as compaction caused by the weight of the overlying layers are some of the possible reasons for this result (Idoga *et al*., 2007).

Particle density was not statistically different across the land use type and soil depth. (Table 1). The particle density ranged from 2.60- 2.63 Mgcm^{-3} indicating that quartz, feldspar, micas and the colloidal silicates with densities between 2.60- 2.75 Mgcm^{-3} forms the major portion of minerals in the study area (Brady and Weil, 2008). The lack of significant difference in particle density implies that irrigation did not influence the soil minerals of the area.

Total porosity is related to organic matter and clay content of the soil as well as to root and earthworm activities. To this end, there was no significant difference in total porosity between the land use types. This also explains why there was a highly significant difference ($P<0.001$) in total porosity with depth. Generally, the total porosity decreases with depth. Higher value in the surface soil may be attributed to root penetration and high organic carbon content (Idoga *et al*., 2007).

The higher moisture at Field Capacity (FC), Permanent Wilting Point (PWP) and Plant Available Water Content (PAWC) in irrigated fields compared to the rain-fed field were as a result of its high clay content of the soil as depicted in Table 1. Gomez-Plaze *et al*. (2001) reported a positive relationship between soil moisture retention and clay content. There was no significant difference in soil moisture at FC and PWP with depth while there was a highly significant difference ($P\leq 0.001$) in PAWC with depth. The values of PAWC in the two land-use systems were less than the optimal range of ≥15.0% (Reynolds, *et al*., 2009), considered limited for ideal root growth and function. This suggests that all the fields still have the capability to quickly drain excess water and facilitate good aeration.

The SI as a measure of structural degradation of soil and did not significantly differ between the two land-use systems, where all the values fell below the optimal range of 7%. Low values of SI observed in this study indicate a structurally degraded condition of the fields (Reynolds *et al*., 2007). One of the probable reasons for low SI was the sub-optimal level of OC observed in all the two land-use systems.

Impact of irrigation on soil chemical properties

The impact of irrigation on chemical properties soil are presented in Table 2 below;

Organic carbon was higher than 10 g/kg in the surface soil and less than 10 g/kg in the subsurface soil (Table 2). Hence, surface soil was considered to have a medium concentration of organic carbon while the subsurface soil was rated low. A highly significant difference ($P<0.001$) in organic carbon across soil depth. Higher mean value in mean values in the surface soil may be due to decomposition of organic matter. A significant difference ($P<0.05$) was also observed between the irrigated and rainfed fields. The higher mean value in the irrigated plots might be due to high accumulation of organic matter and reduced microbial activities due to high soil moisture content. Some researchers have reported an increase in soil organic carbon with irrigation for instance; Bordovsky *et al*. (1999) found that irrigation led to a significant increase in organic matter content in some sandy, semiarid soils in Texas. Factors such as higher moisture content create a condition of low aeration (slow oxidation) and low temperature which slows down the rate of decomposition. Similarly, Bewket and Stroosnijder, (2003), stated that in the rain-fed field, the types of crop grown might also contribute to the observed difference in organic carbon content of the soil. Land use practice that has detrimental effects on organic carbon content have far-reaching implication because of the multiple roles soil organic carbon have on soil (Wild, 1996). The impact of irrigation on total nitrogen is presented in Table 2, the result indicated that the total nitrogen content of the soils across the different land use are low (<1.50 g/kg) and decreases with an increase in soil depth. The total nitrogen content of the soils showed variation among the land use types matching the organic carbon distribution. There was a significant ($P<0.05$) difference in the concentration of total nitrogen (Table 2) across the land use type and soil depth. A higher concentration of total nitrogen in the irrigated field could be attributed to higher soil organic matter distribution due to the low decomposition of organic matter.

The result of the analysis shows the mean available phosphorus content in the irrigated field was lower compared with the rain-fed field. A low concentration of available P in the irrigated field could be attributed to a low mean pH value (<5.5) of the soil (Table 2). According Akpan-Idiok *et al*. (2013) attributed low available phosphorus in irrigated land may be due to phosphorus fixation occasion by low soil pH. There was no significant difference in available phosphorus between the land use types and soil depth as shown by the t-test.

The calcium accounted for the lion's share of the exchangeable bases in the exchange. The soils under the different land use types significantly ($P<0.05$) differed in Calcium content (Table 2), with higher content being in the irrigated field. This may be ascribed to the deposition of calcium bearing material contained in irrigation water during irrigation. The variation in exchangeable Ca distribution differ highly significantly ($P<0.01$) with depth, with the surface soil having a higher mean of 9.53 cmol/kg while the sub surface soil has a mean of 6.14 cmol/kg. Higher mean value of exchangeable magnesium (Mg) was observed in irrigated land was attributed to capillary rise in water table bearing magnesium in solution. There was no significant difference in Mg with depth however, the surface soil had higher Mg concentration. Exchangeable potassium was highly significantly ($P<0.001$) influenced by irrigation (Table 2). This is most likely due to the higher K content of the water used in irrigating the field. There were no significant differences ($p>0.05$) in the mean value of available potassium between the surface and subsurface soils and the land use types. Exchangeable Na contents of the soils showed statistically insignificant ($p>0.05$) differences among the land use types and soil depth. This suggests the absence of any effect that can be linked to land use dynamics in the watershed. Exchangeable acidity (EA) was rated low (Table 2) in all the land use. Low EA indicates the absence of the possibility of aluminium toxicity and could be attributed to intensive weathering of parent material in the tropic. There was no significant ($p>0.05$) difference in EA concentration across the land use.

Table 2. *Impact of irrigation on soil chemical properties*

	OC	TN	AP	Ca	Mg	K	Na	EA	CEC	BS	pH w	pHs	EC
Land use													
Irrigated	9.81	0.63	7.10	8.54	2.20	0.32	0.30	0.96	20.86	55.43	5.60	4.98	0.05
Rain fed	5.38	0.28	11.61	5.73	1.05	0.09	0.21	0.56	12.13	57.46	6.26	5.37	0.03
t-value	2.64	2.41	0.084	2.55	4.77	5.99	1.59	2.65	8.05	-0.25	-3.52	-4.69	-2.51
LOS	*	*	NS	*	***	***	NS	NS	***	NS	*	**	*
Depth													
Surface	12.425	0.95	20.65	9.53	1.72	0.22	0.31	1.08	16.275	73.768	6.255	5.32	0.06
sub surface	5.63	0.25	5.46	6.14	1.53	0.19	0.23	0.63	16.17	50.25	5.84	5.13	0.04
t-value	5.86	4.20	1.82	3.58	0.42	0.31	0.97	3.35	0.04	4.67	1.96	1.36	1.58
LOS	***	*	NS	**	NS	NS	NS	**	NS	***	NS	NS	NS

The variations in the pH of soils under the different land-use types were generally small (Table 2). Soils under rainfed land use were slightly acidic (pH ranging from 6.11 to 6.55), while soil under irrigated land use had pH ranging from strongly acid to slightly acidic (pH ranging from 5.15 to 6.56). In both land use types; the soil pH was higher in the surface layers than in the subsurface layers (Table 2). Higher pH in surface than the subsoil, and may be attributed to the influence of organic matter through biogenetic cycling of bases, capillary rise in water within the basin this process reduces the acidification of soils (Mohammad, 2011), the addition of bases cation to the surface soil layer as loess during the harmattan (Aliyu, 2016) or partly due to the aluminosilicate clay minerals releasing Al^{3+} and H^{+} into the soil solution through isomorphous substitution (Lawal *et al.,* 2012). The pH value across the land-use types falls within the normal range of 5.5-7.0 reported being optimum for the release of plant nutrients (Sharu *et al.,* 2013).

The electrical conductivity of the soil saturation extract (ECe) is a good indicator of the degree of salinity of the soil. The exchangea ble acidity of the soil in the study area was low (EC < 4 dSm^{-}) (Table 2). All the land use showed low ECe values with a mean of 0.03 to 0.05 dSm^{-1} (Table 2) for rainfed and irrigated land-use respectively indicating the non-saline nature of the soils. Exchangeable acidity showed significant ($P < 0.05$) variation with land use (Table 2). Variability in

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ECe was caused by extrinsic factors such as irrigation water and fertilizer application. Malgwi (2001) reported that higher value ECe in irrigated land use may be due to the accumulation of salts brought by irrigation water and subsequent deposition.

Conclusions

The study examined the impact of irrigation on soil physical and chemical properties of soils with the Galma basin. The results obtained show that the texture of the soils is generally sandy. All the land use types of locations show significant variation for sand, silt, and clay. The sand and silt show a highly significant ($p>0.001$) different across locations compared with clay which shows significant ($p>0.05$) variation. Bulk density, particle density, total porosity, and saturation index did not differ significantly across the land use types. Soils in irrigated fields showed significantly higher organic carbon, total nitrogen calcium, and CEC but lower pH compared to soils under rainfed land-use type. Soil Under rain-fed land use had a statistically significant higher pH than soils under the irrigated land-use type. In contrast, differences in the distribution of soil available phosphorus, Na, exchangeable acidity and base saturation values among the two land-use types were statistically insignificant, suggesting an absence of a considerable effect that could be directly associated with land-use dynamics. Irrigated soils showed the highest nutrient contents than the rain-fed field suggests the general trend in the land-use change in the watershed.

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