Research Article

Kehinde Abodunde Adegbite, Aruna Olasekan Adekiya*, Ojo Timothy Vincent Adebiyi, Elizabeth Temitope Alori, Wutem Sunny Ejue, Adeniyi Olayanju, Charity Aremu

Baseline fertility status of a gravelly Alfisol in a derived savannah agro-ecological zone of Nigeria

https://doi.org/10.1515/opag-2020-0059
received November 13, 2019; accepted April 27, 2020

Abstract: Farmers have not tested their soils for nutrient status and therefore are unaware of the fertility status of their soils. Therefore, a baseline fertility survey of 50 hectares of land of a gravelly Alfisol in the Teaching and Research Farm of Landmark University, Omu-Aran, Kwara State, Nigeria was carried out with a view to identifying soil health constraints and site-specific sustainable land management practices for optimizing crop production. Standard field protocols and laboratory analytical procedures were employed for all sample parameters measured. Results show that the soil textural classes vary from sand to loamy sand, exchangeable acidity, Ca, Mg, K, and Na and the effective cation exchange capacity has the surface and subsurface soil values of 0.0–0.92 and 0.00–0.89 cmol kg^{-1}, 1.6–7.7 and 2.0–5.8 cmol kg^{-1}, 1.2–11.5 and 0.7–8.0 cmol kg^{-1}, 0.09–0.33 and 0.09–0.43 cmol kg^{-1}, 0.0–0.16 and 0.04–0.16 cmol kg^{-1}, 7.2–12.10 and 0.9–12.5 cmol kg^{-1}, respectively. *P* values lie in the ranges of 2.5–68.9 mg kg^{-1} and 2.0–37.7 mg kg^{-1} in the surface and subsurface soils, respectively, organic C values were 0.86–2.81% and 0.68–3.49%, respectively, in the surface and subsurface soils while the values of N were 0.12–0.61% in the surface and 0.11–0.56% subsurface soils. Land evaluation shows that the soils of the project site are very fragile and poor in native fertility. Compound fertilizers low in nitrogen contents but high in phosphorus and potassium are recommended for gravelly Alfisol in a derived savannah ecological zone of the Kwara State, Nigeria to avoid a nutrient imbalance that may create artificial deficiencies of otherwise adequate nutrient elements.

Keywords: soil fertility, textural class, nitrogen, phosphorus, potassium, cropping systems, Omu-Aran

*** Corresponding author: Aruna Olasekan Adekiya,** Department of Agriculture, College of Agricultural Sciences, Landmark University, PMB 1001, Omu-Aran, Kwara State, Nigeria,
e-mail: adekiya2009@yahoo.com,
tel: +234-803-481-3715
Kehinde Abodunde Adegbite, Ojo Timothy Vincent Adebiyi, Elizabeth Temitope Alori, Wutem Sunny Ejue, Charity Aremu: Department of Agriculture, College of Agricultural Sciences, Landmark University, PMB 1001, Omu-Aran, Kwara State, Nigeria
Adeniyi Olayanju: Department of Agricultural & Bio-system Engineering, Landmark University, PMB 1001, Omu-Aran, Kwara State, Nigeria

1 Introduction

Food is one of the most important basic necessities of man. Low soil fertility could threaten the security of food in the sub-Saharan Africa (Adekiya and Agbede 2009). This is so because, soil provides food, fodder and fuel for meeting the basic human and animal needs (Schoonover and Crim 2015). However, continuous cultivation and indiscriminate deforestation through the use of fuel wood as a source of alternative energy are attributed to be the main sources of decline in productivity and fertility, especially in savanna soils (Umar et al. 2018).

In addition, farmers have not tested their soils for nutrient status and therefore are unaware of the fertility status of their soils (Knight et al. 2010). Asgelil Dibabe (2000) reported that for tropical soils, nitrogen (N) and phosphorus (P) are low and hence are limiting crop production. Little information is currently available to farmers on the available soil fertility nutrient management of their soils. This information is necessary if the soils are to produce crops on a sustainable basis (Hassan et al. 2013). For a given soil to be sustainable according to Greenland (1975), chemical nutrients removed by crops must be assessed and replenished and even the physical condition of the soil must be regularly assessed and improved.

Generally, there is scarcity of information on the fertility status of the derived savanna soil of Nigeria.

Shehu et al. (2015) found organic carbon, total N and effective cation exchange capacity (ECEC) within the very low and low fertility classes in Sudan savanna ecological zone of Nigeria, whereas very low and low available P was found in the majority of locations. Majority of the soils were also low in K. The authors recommended that the current fertilizer needs to be reviewed and should contain other nutrients in addition to primary macronutrients. However, Adeboye et al. (2009) recommended for southern guinea savanna of Nigeria the judicious use of inorganic and organic fertilizers for soil fertility maintenance in the ecological zone for optimum and sustainable soil fertility. Oyinlola and Chude (2010) recommended that boron (B) and zinc (Zn) applications are needed for a successful and profitable crop production in northern guinea and Sudan savanna zones of Nigeria. For the derived savanna ecological belt of Nigeria, such data and recommendation are lacking. It is therefore imperative to provide a baseline fertility of a derived savanna soil, so that such information will provide a useful guide for the management of soil. Therefore, the objectives of this study were to determine the baseline fertility status of the soils of the area and to offer soil management strategies to improve it and hence sustain crop production.

2 Materials and methods

2.1 Ecology, soil and land use types of the area

The research was conducted in the Landmark University Teaching and Research farms, Omu-Aran, Kwara State in the transitionally derived savanna agro-ecological zone of Nigeria, which lies within Latitudes 08° 37′ and 12° 59′N and Longitudes 03° 10′ and 07° 27′E. The main occupation of the people of Kwara State is agriculture. Because this state falls along the middle belt of Nigeria, the climate favours the growth of several varieties of food and cash crops. About 70% of the population practise subsistence agriculture with more importance attached to food crops than cash crops. The food crops include yam, cassava, maize, plantain and millet.

The area lies in the derived savanna vegetation zone of Nigeria. Derived savanna is evolved from the rain forest by human activities such as regular fire, deforestation and farming (Adekiya et al. 2018). Only a few fire-tolerant trees are found and the area can advance to forest if communal burning is stopped. The terrain is highly undulating and rugged with a rolling landscape of various slopes in various directions, and is generally well drained with the main hydrological feature being river Orisa, a perennial rivulet. The mean annual rainfall in the area is about 1,300 mm and falls under the Typic Ustic moisture regime (FDALR 1990). The concept of the Ustic moisture regime (USDA 1999) is one of limited moisture, but the moisture is present at a time when conditions are suitable for plant growth. Temperature varies throughout the year. The mean annual temperature is about 32.5°C, with an estimated annual soil temperature of about 34°C. Thus, the area can be regarded as an iso-hyperthermic temperature regime (USDA 1999). Relative humidity seldom varies from the average of about 60% throughout the year. This results in substantial evapotranspiration which effects a critical balance situation between water supply and water that is available to crops. The area enjoys an average of 8–10 h of sunshine daily, the sun being directly overhead throughout the year. This facilitates a sufficient photosynthetic activity necessary for crops.

The area has been completely cleared of most of the tree vegetation for farming. However, in the surrounding areas, the vegetation can presently be regarded as anthropogenic because it has suffered various degrees of human interference. The present vegetative cover is in between secondary forest (this vegetation is as a result of the heavy rainfall incidence which usually occurs in the area, and the forest species include *Milicia excelsa*, *Anogeissus leiocarpus*, *Daniellia oliveri*, *Elaeis guineensis* (oil palm), *Borassus* (palm) and savanna woodlands (*Vitellaria paradoxa*, *Terminalia avicenmioides*, *Annona senegalensis* and *Bauhinia monandra*). The communities surrounding the project site (Landmark University) are mainly agrarian, and the University is an Agriculture-based University. This area is well recognized for intensive agricultural activities. The major crops produced in this area include root and tuber crops like yam (*Dioscorea* spp.), cassava (*Manihot esculenta*), cocoyam (*Colocasia esculenta*) and sweet potatoes (*Ipomoea batatas*). Other crops include cereals like maize (*Zea mays*), rice (*Oryza sativa*) and guinea corn (*Sorghum* spp.). Vegetables like okra (*Abelmoschus esculentus*), tomatoes (*Lycopersicuum* spp.), pepper (*Capsicum* spp.), eggplant (*Solanum* spp.) as well as leaf vegetables like green (*Amaranthus* spp.), Ewedu (*Corchorus olitorius*) and Ugwu (*Telfairia occidentalis*) are produced in large quantities. Legumes like groundnut (*Arachis hypogaea*), soybean (*Glycine max*), cowpea (*Vigna unguiculata*) and bambara groundnut (*Voandzeia subterrenea*) are also commonly grown. Shifting and fallow systems of cultivation are predominant among the indigenous farmers of the area. There is a dearth of soil information in this area, despite its strong agrarian culture.

2.2 Field study

The area was 50 hectares of land of a gravelly Alfisol in the Teaching and Research Farm of the Landmark University. The base maps that were used for the surveys were obtained from the Director of Physical Planning and Development of the University. The entire area was then gridded into rectangular polygons 200 m by 200 m to obtain one composite soil sample in 4 hectares. A strict grid method was thus employed for the survey, and where possible and feasible, this method was supplemented with a free system of survey.

The perimeter survey map provided by the University at a scale of 1:10,000 was used as a base map for the exercise. At each sampling point, the following observations were recorded: coordinate (longitude, latitude and elevation) using a handheld GPS (Figure 1), land use, topography, erosional and depositional features, surface pans, rock outcrops, vegetation, etc. Also at each sampling point, soil samples were collected from 0 to 15 cm and 15 to 30 cm soil depth. Soil samples collected were kept in a polythene bag for laboratory analyses.

2.2.1 Laboratory analysis

The soil samples collected were air-dried and sieved using a 2 mm sieve and later analysed for soil physical and chemical properties using the method described by Carter (1993). The particle size distribution was determined by the hydrometer method (Sheldrick and Hand

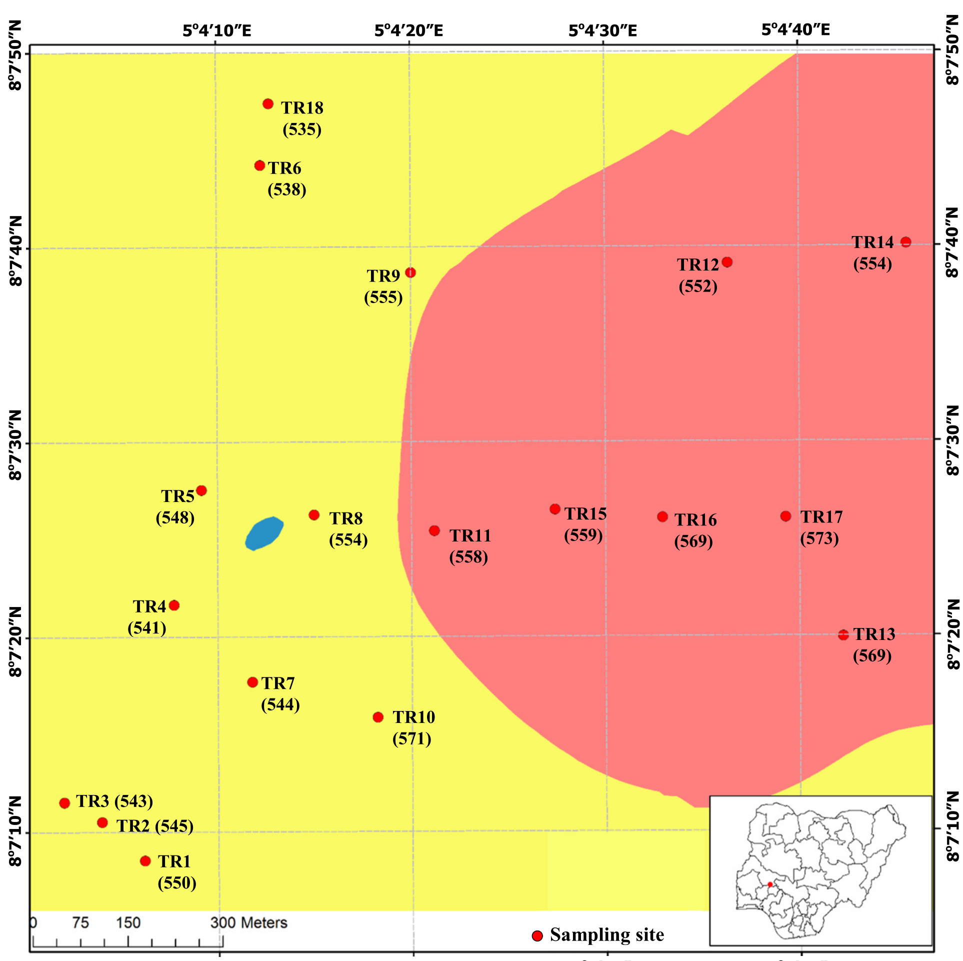

Figure 1: A map of the sample collection point with coordinates.

Wang 1993). The soil pH was determined using a glass electrode pH meter (Ibitoye 2006). Total nitrogen content was determined using the micro-Kjeldahl digestion method (Bremner 1996). Phosphorus was determined by the Bray 1 method followed by molybdenum blue colourimetry (Frank et al. 1998). Organic carbon was determined by the Walkley and Black method using the dichromate wet oxidation method (Nelson and Sommers 1996). Exchangeable cations (potassium, calcium, sodium and magnesium) were extracted using 1 N ammonium acetate. K and Na in the extract were read on a flame photometer, while Ca and Mg were read on an Atomic Absorption Spectrophotometer (Model: Buck 205; Brand: Buck Scientific; Country of manufacture: USA). Effective CEC was the summation of NH_4OAc bases and KCl exchangeable Al and H. The base saturation was obtained by expressing total exchangeable bases as a percentage of ECEC (Adegbite et al. 2019).

2.2.2 Statistical analysis

Data collected from each soil sample were expressed as means ± standard deviation of the various other samples. The data were subjected to one-way Analysis of Variance to determine the significant difference at 5% level of acceptance using SPSS Version 21 (SPSS IBM Corp 2012).

3 Results and discussion

3.1 Physical characteristics of the soils of the area

Soil textural classes vary from sand to loamy sand (Table 1), thus implying light textured soils. Sand composition varies from a minimum of 78.1% to a maximum of 87.1%. Silt varies from 8.6% to 15.6%, while clay varies from 4.3% to 8.3%. The variability of gravel, clay and sand in the 0–15 cm soil level is less compared with the same soil particles in the 15–30 cm soil depth. The variability of silt in the 15–30 cm soil layer is less compared with that of silt in the 0–15 cm layer. It is also significant that the soils of the area generally have high plinthite contents ranging from a minimum of 25.4% to a maximum of 79.3%, a situation that has

Table 1: Soil texture and gravel contents

Grid code	0–15 cm				15–30 cm			
	% Gravel	% Clay	% Silt	% Sand	% Gravel	% Clay	% Silt	% Sand
TR1	59.5	5.3	9.6	85.1	58.6	4.3	8.6	87.1
TR2	69.6	5.3	11.6	83.1	71.4	6.3	11.6	82.1
TR3	70.3	6.3	11.6	82.1	70.4	4.3	12.6	83.1
TR4	56.4	5.3	8.6	86.1	56.7	6.3	9.6	84.1
TR5	63.0	7.3	11.6	81.1	53.0	8.3	12.6	79.1
TR6	61.6	4.3	10.6	85.1	60.0	4.3	9.6	86.1
TR7	57.7	5.3	10.6	84.1	52.2	6.3	12.6	81.1
TR8	47.2	5.3	11.6	83.1	47.2	6.3	13.6	80.1
TR9	75.7	5.3	11.6	83.1	70.4	6.3	10.6	83.1
TR10	55.1	4.3	10.6	85.1	44.8	6.3	11.6	82.1
TR11	75.9	6.3	15.6	78.1	74.1	6.3	12.6	81.1
TR12	65.0	8.3	8.6	83.1	68.4	4.3	9.6	86.1
TR13	51.3	5.3	10.6	84.1	48.8	5.3	9.6	85.1
TR14	71.1	4.3	9.6	86.1	67.3	4.3	12.6	83.1
TR15	69.0	4.3	10.6	85.1	61.6	4.3	11.6	84.1
TR16	75.1	5.3	11.6	83.1	66.6	6.3	8.6	85.1
TR17	78.9	4.3	10.6	85.1	79.3	4.3	8.6	87.1
TR18	25.4	4.3	14.6	81.1	17.4	5.3	12.6	82.1
Median	64.0	5.3	10.6	83.6	60.8	5.8	11.6	83.1
Mean	62.66	5.36	11.1	83.5	59.3	5.5	11.04	83.4
SD±	13.00	1.11	1.76	2.06	14.4	1.17	1.69	2.35
CV	20.7	20.7	15.9	2.46	24.3	21.3	15.3	2.81

Note: TR1, TR2, TR3,…,TR18 are sample points in the Teaching and Research Farm, Landmark University.

negative implications for land preparation implements. The soil physical condition observed in the site does not pose any serious limitation to crop production; even in areas where the soil depth is <45 cm, ridging of the land could be adopted to increase the soil depth. This might be because of the thin layer of the plinthite. It has been reported (Oluwatosin et al 2019) that the striking differences in plinthite that spread in savanna agro-ecology of southwestern Nigeria were the depth to plinthic layer (pan), structure and thickness of the pan.

3.2 Chemical characteristics of the soils of the area

The results of the chemical characteristics of the soils are presented in Table 2a and b. The soils had exchangeable acidity (TEA) that varied between 0.0–0.92 for the surface soil and 0.00–0.90 cmol kg^{-1} for the subsurface soil. Like most tropical soils, the exchange sites of these soils were dominated by exchangeable calcium and magnesium. The exchangeable calcium (Ca^{2+}) ranged in values between 1.6 cmol kg^{-1} and 4.5 cmol kg^{-1} in the surface soils and from 2.0 cmol kg^{-1} cmol kg^{-1} to 3.5 cmol kg^{-1} in the subsurface soils (Table 2a). Magnesium (Mg^{2+}) contents ranged from 3.8 to 9.2 cmol kg^{-1} in the surface soils and from 3.9 to 7.2 cmol kg^{-1} in the subsurface soils. Exchangeable K^+ varied from 0.25 to 0.30 cmol kg^{-1} in the surface soils, with the subsurface soils posting 0.24–0.31 cmol kg^{-1}. The exchangeable sodium (Na^+) contents of the soils ranged from 0.04 to 0.07 cmol kg^{-1} in the surface soils, with subsurface contents ranging from 0.04 to 0.13 cmol kg^{-1}.

The average values of exchangeable calcium within the rooting zones are well above the suggested critical value (1.50–2.0 cmol kg^{-1}) for most arable crops grown in the savanna agro-ecological zone of Nigeria (Akinrinde and Obigbesan 2000). This means that the Ca^{2+} supply should not limit crop production in these soils.

However, with a mean value of K which was lower than the suggested critical value of 0.28 cmol kg^{-1}, a profitable crop production in these soils will require an external input of K^+ in fertilizer form. Exchangeable K is widely used for evaluating the soil K status and prediction of crop K requirements (Samadi 2006), while in some countries, the K saturation index (%) is used for the assessment of soil K status (Mutscher 1995). Soils with exchangeable K less than 0.13 cmol kg^{-1} have been classified as being poor in K, and those that contained K between 0.13 and 0.31 cmol kg^{-1} as being moderately endowed with K, while those having exchangeable K that is greater than 0.31 cmol kg^{-1} were regarded as being adequate in K. In Nigeria, the recommended critical K level for most crops ranged between 0.21 and 0.30 cmol kg^{-1} (FFD 2011). For this study, all samples in 0–15 cm and 17 samples in 15–30 cm (94%) are critical in K. Based on the above recommendation, the supply of K is expected to limit crop production in these soils. Also, the low K^+:Ca^{2+} or K^+:(Ca^{2+} + Mg^{2+}) ratio is likely to aggravate the problem of K^+ uptake in these soils. Kirkman et al. (1994) noted that the displacement of K^+ by Ca^{2+} is particularly important in the soils because of selective adsorption of Ca^{2+} which resulted in the leaching of K^+. Parfitt (1992) also reported that a high solution concentration of Ca^{2+} led to a complementary ion effect occurring between Ca^{2+} and K^+ and that this led to a reduced K^+ uptake by plants. Application of K fertilizer is a critical requirement for sustainable use of these soils for agricultural production. For this study, calcium and magnesium vary more than potassium, which was adduced to the fact that Ca and Mg are the most dominant cations in the soil of the study area (savannah soils). Ayodele and Omotosho (2008) and Adegbite et al. (2019) also found that Ca and Mg are dominant in savannah soils. Exchangeable sodium (Na^+) contents of the soils were low and will not constitute any hindrance to crop production on these soils.

The effective ECEC of the soils were generally low and varied between 7.2 and 14.8 cmol kg^{-1} in the surface soils, while the subsurface soils on the other hand had ECEC values ranging from 6.9 cmol kg^{-1} to 17.8 cmol kg^{-1}, with one sampling point having moderate values of 0–15 cm and 15–30 cm. The value of the percentage base saturation (Bsat) was 100.0% in the surface and subsurface horizons, as the soils had no detectable exchangeable acidity. In most of the profiles, the sum of Ca^{2+} and Mg^{2+} accounted for more than 70% of the exchangeable bases and ECEC. The high variability of Al + H can be the corresponding pH of the soils. Abreu Jr. et al. (2003) reported a negative correlation of pH with Al saturation. For the experiment, the correlation coefficients between Al and pH (water) and pH $CaCl_2$ were −0.27 and −0.13, respectively.

The soils showed reactions ranging from strong acid (5.24) to neutral (7.23). Overall, the soil pH in water (pHw) varied in values between 5.9 and 6.67 in the surface soil and 5.9 and 7.23 in the subsurface soil, while the pH in molar potassium chloride (pHk) varied between 5.24 and 6.03 in the surface soil and 5.00 and 6.60 in the subsurface soil, respectively (Table 2b). This

Table 2: (a) Chemical properties of the soils. (b) Chemical properties of the soils

Grid code	0–15 cm							15–30 cm						
	cmol (+)/kg						% BS	cmol (+)/kg						% BS
	Ca^{2+}	Mg^{2+}	K^+	Na^+	Al + H	CEC		Ca^{2+}	Mg^{2+}	K^+	Na^+	Al + H	CEC	
(a)														
TR1	2.4	5.8	0.29	0.07	0.00	8.6	100.0	2.5	7.2	0.29	0.04	0.40	10.4	96.0
TR2	2.5	4.7	0.30	0.04	0.20	7.8	97.2	2.6	6.1	0.30	0.07	0.30	9.4	96.6
TR3	2.7	5.0	0.29	0.04	0.00	8.0	99.8	2.5	3.9	0.28	0.04	0.90	7.6	88.0
TR4	2.5	4.4	0.27	0.04	0.00	7.2	100.0	2.1	4.9	0.27	0.07	0.00	7.3	100.0
TR5	2.6	5.1	0.30	0.04	0.72	8.8	91.8	2.3	4.1	0.31	0.04	0.12	6.9	98.3
TR6	2.4	5.7	0.30	0.04	0.22	8.7	97.5	2.1	5.7	0.28	0.07	0.22	8.4	97.4
TR7	3.2	4.3	0.30	0.04	0.00	7.8	100.0	2.9	4.2	0.28	0.07	0.12	7.6	98.4
TR8	3.1	3.9	0.29	0.04	0.22	7.5	97.1	2.5	4.1	0.29	0.07	0.62	7.6	91.8
TR9	3.8	4.4	0.30	0.07	0.00	8.6	100.0	2.6	4.7	0.29	0.04	0.22	7.8	97.2
TR10	2.5	5.4	0.28	0.04	0.22	8.4	97.4	2.4	4.1	0.26	0.04	0.32	7.1	95.5
TR11	3.0	3.8	0.25	0.04	0.42	7.5	94.4	2.7	5.1	0.25	0.07	0.00	8.1	100.0
TR12	2.4	5.6	0.25	0.04	0.62	8.9	93.0	2.1	6.0	0.27	0.13	0.72	9.2	92.2
TR13	2.9	4.6	0.25	0.07	0.92	8.7	89.5	2.3	5.4	0.26	0.04	0.62	8.6	92.8
TR14	2.3	4.8	0.25	0.04	0.22	7.6	97.1	2.0	5.2	0.24	0.04	0.12	7.6	98.4
TR15	2.6	4.6	0.28	0.07	0.42	8.0	94.7	3.5	4.2	0.26	0.07	0.82	17.8	45.0
TR16	4.5	3.8	0.30	0.07	0.42	9.1	95.4	3.4	6.4	0.27	0.04	0.62	10.7	94.2
TR17	4.5	9.2	0.28	0.04	0.82	14.8	94.5	2.2	5.3	0.25	0.04	0.32	8.1	96.1
TR18	1.6	6.0	0.27	0.04	0.72	8.6	91.7	—	—	0.29	0.07	0.52	—	—
Median	2.6	4.7	0.28	0.04	0.22	8.5	97.1	2.45	5.0	0.27	0.06	0.32	7.9	96.1
Mean	2.87	5.06	0.28	0.05	0.34	8.59	96.17	2.37	4.81	0.27	0.06	0.89	8.34	87.6
SD ±	0.75	1.24	0.02	0.01	0.31	1.65	3.26	0.72	1.52	0.02	0.02	2.40	3.24	25.2
CV	26.1	24.5	7.1	20.0	91.1	19.2	3.39	30.4	31.6	7.41	33.3	269.6	38.8	28.7

Grid code	0–15 cm					15–30 cm				
	pH (1:2)		% N	% C	Avail. P mg/kg	pH (1:2)		% N	% C	Avail. P mg/kg
	Water	0.01 M $CaCl_2$				Water	0.01 M $CaCl_2$			
(b)										
TR1	6.30	5.78	0.14	1.02	17.1	6.38	5.53	0.12	1.06	14.6
TR2	6.34	5.70	0.16	1.20	13.6	6.24	5.00	0.13	0.68	13.6
TR3	6.44	5.62	0.17	1.46	21.6	6.07	5.61	0.15	1.04	13.8
TR4	6.07	5.24	0.14	1.20	36.7	6.12	5.22	0.14	0.92	20.2
TR5	6.02	5.28	0.15	1.22	14.7	5.90	5.24	0.15	1.20	16.0
TR6	6.53	5.94	0.12	1.16	12.0	6.52	5.97	0.18	0.80	10.2
TR7	6.44	5.85	0.18	1.10	10.7	6.00	5.79	0.15	1.20	21.6
TR8	6.53	5.73	0.13	1.08	12.9	6.07	5.70	0.14	0.92	13.1
TR9	6.20	5.98	0.61	1.08	12.7	6.14	5.72	0.56	1.18	8.9
TR10	6.40	6.02	0.42	1.80	8.9	6.37	5.60	0.41	2.03	10.4
TR11	6.55	6.02	0.23	1.78	25.8	6.48	5.31	0.24	1.58	14.6
TR12	6.36	5.56	0.24	1.56	10.0	6.43	5.60	0.20	1.28	12.2
TR13	6.05	5.83	0.14	1.60	10.0	6.48	5.68	0.15	1.00	7.3
TR14	6.67	5.83	0.19	1.80	15.5	5.88	5.66	0.16	1.78	8.0
TR15	6.27	5.70	0.23	2.00	8.9	6.30	5.58	0.23	2.00	10.6
TR16	5.90	5.46	0.22	1.82	16.0	6.01	5.68	0.21	2.57	20.0
TR17	6.33	6.03	0.24	2.21	15.3	7.23	6.60	0.24	1.74	9.8
TR18	6.42	5.32	0.17	1.00	8.5	6.67	5.18	0.17	0.90	6.9
Median	6.35	5.75	0.18	1.34	13.2	6.27	5.60	0.17	1.19	12.6
Mean	6.32	5.72	0.22	1.45	15.05	6.29	5.59	0.21	1.33	12.88
SD±	0.21	0.26	0.18	0.38	7.04	0.33	0.35	0.11	0.51	5.42
CV	3.3	4.5	81.8	26.2	46.8	5.24	6.26	52.4	38.3	42.1

Note: TR1, TR2, TR3,…,TR18 are sample points in the Teaching and Research Farm, Landmark University.

range of pH values favours nutrient availability to crop plants since the pH of most agricultural soils in Nigeria has been reported to range from 4.00 to 6.5. (Hartly 1988; Ojomah and Joseph (2017) also found that for Kogi East agro-ecological zone of Kogi State Nigeria, the pH of soils was within the critical level of 5.0–6.8 for crop production.

Available P was generally adequate (>10 mg kg^{-1}) in the surface and subsurface horizons (Akinrinde and Obigbesan 2000) of the soils, although there are very few areas with low values. For this study, samples that were adequate in P were 77.8%, while those inadequate were 22.2% for both the surface and the subsurface soil layers.

Available P in these soils ranged between 8.5 mg kg^{-1} and 36.7 mg kg^{-1} in the surface horizons and 6.9–21.6 mg kg^{-1} in the subsurface samples (Table 2b). Also, Olaniyan (2013) reported on the characterization, classification and agricultural potential of some selected soils of Kwara State, Nigeria under derived savannah agro-ecological zone and that available values of P range between moderate and high. Likewise, Ahukaemere et al. (2016) reported higher P contents of the soil in the acid sand soil of southeastern Nigeria. The soils had moderate to high organic carbon contents. Organic carbon content of the surface soils ranged between 1.0% and 2.21%, while the subsurface horizons had organic carbon contents that ranged from 0.68% to 2.57%. The high values observed in some of the subsurface samples were most likely due to the poultry manure dump. The surface and subsurface horizons of these soils had average values of organic carbon greater than the critically recommended level of 1.2% for agricultural land in Nigeria (FFD 2011). At the surface and subsurface layers, 55.6% and 38.9% soil samples were adequate, while 44.4% and 61.1% were inadequate respectively.

The total nitrogen (N) contents of the soil were generally adequate (>0.15%) in all the samples, except in few cases. This is in sharp contrast to trends in Savannah ecology. For this study, samples that were adequate in N were 66.7% and 55.6% for 0–15 cm and 15–30 cm, respectively.

Generally, in the savanna ecology of Nigeria, reports from several sources indicated that the nitrogen content of the soils was low due to high rate of mineralization, immobilization, volatilization and the effects of annual bush burning. The total nitrogen content of the area ranged from 0.12% to 0.61% in the surface, with the subsurface horizons ranging from 0.11% to 0.56%. The total N content of the soil is thus generally above the critical requirement for the production of most arable crops within the savanna ecology of Nigeria (FFD 2011). Idoga and Azagaku (2005) also reported that the percentages of organic C and N are moderately high for savannah soils. This they adduced to the "aquic" conditions of the floodplains which reduce soil temperature and consequently lower the rate of organic matter decomposition. Thus, production of any crop on the soil of this farm site will require a minimum input of supplementary nitrogen fertilizer for the first one or two cropping seasons for optimum yield. The variability of Ca, Mg, K, Na, CEC, pHw, pHk and organic C in the surface soil was less compared with the same soil chemical properties in the subsurface soil. However, the variability of N and P in the subsurface soil was less compared with that in the surface soil. The litter on the soil surface layers and high biomass production generally result in a high biological activity in the soil surface and hence a high organic C at the surface compared with the sub-surface. Organic matter affects both the chemical and physical properties of the soil and its overall health. Properties influenced by organic matter include: soil structure; moisture holding capacity; diversity and activity of soil organisms; hence, it is expected that there will be better nutrient availability and soil fertility at the surface soil compared with the sub-surface. It also influences the effects of chemical amendments, fertilizers, pesticides and herbicides (Bot and Benites 2005).

Land evaluation shows that the soils of the project site are very fragile and poor in native fertility. According to the FAO (2006), preservation of the surface soil with its all-important organic matter is of utmost importance in the conservation and management of these soils.

Fertilizers low in nitrogen contents but high in phosphorus and potassium are required for this soil. Application rate of 15–20 tonnes of poultry manure per hectare and compound fertilizer containing NPK in the ratio of 10:20:20 at the rate of 300 kg ha^{-1} are recommended. Cereals, especially rice, are important crops grown in the agro-ecological zone. Smith (2006) recommended 100 kg ha^{-1} N, 400 kg ha^{-1} P and 150 kg ha^{-1} K fertilizer for paddy rice. Also, in Owo, the forest – savannah transition zone of Nigeria, Agbede and Adekiya (2012) recommended 10–40 t ha^{-1} poultry manure for improved soil productivity and increased yam yield. Agbede et al. (2013) also recommended 20 t ha^{-1} of organic manures in the form of goat manure, poultry manure, oil palm bunch and spent grain and their combinations for improved soil productivity on an Alfisol located at Owo, Nigeria.

4 Conclusions and recommendations

The soils are of less optimum nutrient values due to excessive cropping and will therefore require regular rehabilitation and management practices if it would be sustainably used for profitable agricultural production. The sparse surface vegetal cover due to initially excessive bush clearing and over-cropping will lead to low aggregate stability, water infiltration and this will make the land prone to more erosion as a result of exposure to the direct impact of raindrops.

For agricultural activities, high plinthite and stoniness at shallow soil depth are also major limitations. This makes mechanization a little bit difficult. Mounding and minimum tillage practices are the only tillage options that can be used to manage these soils productively.

Soil fertility management on gravelly Alfisol in a derived savannah ecological zone of Kwara State, Nigeria should combine organic and inorganic fertilizer amendments in an integrated system. Sound management of organic residue should be adopted and cropping systems, such as crop rotation and intercrops including legumes, should be encouraged. Fertilizers low in nitrogen contents but high in phosphorus and potassium are recommended to avoid nutrient imbalance that may create artificial deficiencies of otherwise adequate nutrient elements. Presently, an application rate of 15–20 tonnes of poultry manure per hectare and compound fertilizer containing NPK in the ratio of 10:20:20 at the rate of 300 kg ha^{-1} are recommended. However, soil tests for nutrient evaluation should be carried out at least once in two years.

Conflict of interest: Authors declare no conflict of interest.

References

[1] Abreu Jr CH, Muraoka K, Lavorante AF. Relation between acidity and chemical properties of Brazilian soils. Sci Agri. 2003;60(2):337–43.

[2] Adeboye M, Osunde A, Ezenwa M, Odofin A, Bala A. Evaluation of the fertility status and suitability of some soils for arable cropping in the southern guinea Savanna of Nigeria. Nigerian J Soil Sci. 2009;19(2):115–20.

[3] Adegbite KA, Okafor ME, Adekiya AO, Alori ET, Adebiyi OTV. Characterization and classification of soils of a toposequence in a derived savannah agroecological zone of Nigeria. Open Agric J. 2019;13:44–50.

[4] Adekiya AO, Agbede TM. Growth and yields of tomato (*Lycopersicon esculentum* Mill) as influenced by poultry manure and NPK fertilizer. Emirate J Food Agric. 2009;21(1):10–20.

[5] Adekiya AO, Aboyeji CM, Dunsin O, Agbede TM, Bazuaye H. Effects of cocoa pod ash and urea on soil chemical properties and the performance of kale (*Brassica oleracea* L.) in derived savanna zone of Nigeria. Trop Agric. 2018;95(2):115–23.

[6] Agbede TM, Adekiya AO. Effects of poultry manure and soil fertility, growth and yield of white yam and yellow yam. U. of K. J Agric Sci. 2012;20(3):286–303.

[7] Agbede TM, Adekiya AO, Ogeh JS. Effects of organic fertilizers on yam productivity and some soil properties of a nutrient-depleted tropical Alfisol. Arch Agron Soil Sci. 2013;59(6):803–22.

[8] Ahukaemere CM, Onweremadu EU, Akamigbo FOR, Ndukwu BN. Suitability evaluation of soils of the coastal plain sands for rain – fed maize production in acid sands of south-eastern Nigeria. Nigerian J Soil Sci. 2016;26:138–45.

[9] Akinrinde EA, Obigbesan GO. Evaluation of the fertility status of selected soils for crop production in five ecological zones of Nigeria. In: Babalola O, editor. Proceedings of the 26th Annual Conference of Soil Science Society of Nigeria; 2000 Oct 30–Nov 3. Ibadan, Nigeria; 2000. p. 279–88.

[10] Dibabe A. Effect of fertilizer on the yield and nodulation pattern of Faba bean on a Nitosol of Adet North Western Ethiopia. Ethiopian J Nat Resour. 2000;2:237–44.

[11] Ayodele OJ, Omotosho SO. Nutrient management for maize production in soils of the savannah zone of south-western Nigeria. Int J Soil Sci. 2008;3(1):20–7.

[12] Bot A, Benites J. The importance of soil organic matter. Key to drought-resistant soil and sustained food and production. FAO land and plant nutrition management service. FAO Soils Bull. 2005;80:95.

[13] Bremner JM. Nitrogen-total. In: Sparks DL, editor. Methods of soil analysis. Part 3. Chemical methods. 2nd edn. SSSA Book Series No. 5 Madison, WI: ASA and SSSA; 1996. p. 1085–121.

[14] Carter MR. Soil sampling and methods of analysis. Canadian society of soil science. Boca Raton, FL: Lewis Publishers; 1993. p. 823.

[15] FAO. Guidelines for soil description. Rome: FAO; 2006. p. 109.

[16] FDALR. The Reconnaissance Soil Survey of Nigeria. 1990; vol. 2.

[17] FFD. Fertilizer use and management practices for crop production in Nigeria. 4th edn. Abuja Nigeria: Fed. Min. of Agric. and Rural Dev; 2011. p. 1–300.

[18] Frank K, Beegle D, Denning J. Phosphorus. In: Brown JR, editor. Recommended chemical soil test procedures for the North Central Region, North Central Regional Research Publication No. 221 (revised). Columbia, MO: Missouri Agric. Exp. Station; 1998. p. 21–6.

[19] Hartly CWS. The oil palm (Elaeis guinensis jacq). 2nd edn. London and New York: Longman; 1988. p. 824.

[20] Hassan M, Saddiq AM, Ibrahim A. Fertility evaluation of some soils in Adamawa State, Nigeria. Nigerian J Soil Sci. 2013;23(1):110–4.

[21] Ibitoye AA. Laboratory manual on basic soil analysis. 2nd edn. Akure, Ondo State: Foladaye Publishing Company; 2006. p. 82.

[22] Idoga S, Azagaku DE. Characterization and classification of soils of Janta area, Plateau state of Nigeria. Nigerian J Soil Sci. 2005;15:116–22.

[23] Kirkman JH, Basker A, Surapaneni A, MacGregor AN. Potassium in the soils New Zealand – a review. New Zealand J Agric Res. 1994;37:207–27.

[24] Knight JD, Buhler R, Leeson JY, Shirtliffe SJ. Classification and fertility status of organically managed fields across Saskatchewan, Canada. Can J Soil Sci. 2010;90:667–78.

[25] Mutscher H. Measurement and assessment of soil potassium IPI Research Topics No 4 (revised version). Switzerland: International Potash Institute Bassel; 1995; p. 102.

[26] Nelson DW, Sommers LE. Total carbon, organic carbon and organic matter. In: Sparks DL, editor. Methods of Soil Analysis, Part 3. 2nd edn Madison, WI, USA: ASA and SSSA; 1996. p. 961–1010. SSSA Book Series No. 5.

[27] Ojomah FO, Joseph PO. Assessment of soil fertility status in some areas of Kogi east agroecological zone of Kogi State. J Agric Rural Res. 2017;1(2):44–50.

[28] Olaniyan JO. Characterization, classification and agricultural potential of some selected soils of Kwara State, Nigeria. Nigerian J Soil Sci. 2013;23(1):94–101.

[29] Oluwatosin GA, Are KS, Adeyolanu OD, Idowu OJ. Characteristics and agricultural potential of soils with plinthic materials in the savanna ecology of south western Nigeria. Arch Agron Soil Sci. 2019. doi: 10.1080/03650340.2019.1696017

[30] Oyinlola EY, Chude VO. Status of available micronutrients of the basement complex rock – derived Alfisols in northern Nigeria savanna. Tropic Subtropic Agroecosyst. 2010;12:229–37.

[31] Parfitt RL. Potassium–calcium exchange in some New Zealand soils. Australian J Soil Res. 1992;30:145–58.

[32] Samadi A. Potassium Exchange Isotherms as a Plant Availability Index in Selected Calcareous Soils of Western Azarbaijan Province. Iran Turk J Afric For. 2006;30:21–222.

[33] Schoonover JE, Crim JF. An introduction to soil concepts and the role of soils in watershed management. J Contemp Water Res Educ. 2015;154(1):21–47.

[34] Shehu BM, Jibrin JM, Samndi AM. Fertility status of selected soils in the Sudan savanna biome of northern Nigeria. Int J Soil Sci. 2015;10(2):74–83. doi: 10.3923/ijss.2015.74.83.

[35] Sheldrick B, Hand Wang C. Particle-size distribution. In: Carter MR, editor. Soil Sampling and Methods of Analysis. Ann Arbor, MI, USA: Canadian Society of Soil Science, Lewis Publishers; 1993. p. 499–511.

[36] Smith B. The farming handbook. South Africa: University of KwaZulu-Natal Press Scottville 3209; 2006.

[37] SPSS. IBM Corp. Released 2012. IBM SPSS Statistics for Windows, Version 21.0. Armonk, NY: IBM Corp.

[38] Umar B, Idris S, Ali S, Abdullahi BU, Aliyu MD. Evaluation of indigenous soil fertility assessment of the sudan savannah agro-ecological zone of Nigeria – a paper review. IOSR J Agric Vet Sci. 2018;11(10):1–9.

[39] USDA Soil Taxonomy. Soil Survey Staff, Agriculture Handbook, No. 436, 2nd edn. Washington, DC: United States Department of Agriculture, Natural Resources Conservation Service; 1999. p. 869.