International Journal of Plant & Soil Science
9(6): 1-10, 2016; Article no.IJPSS.22161
ISSN: 2320-7035

SCIENCEDOMAIN *international*
www.sciencedomain.org

Temporal Variability of Soil Physico-chemical Properties under a Long-term Fertilizer Trial at Samaru, Northern Guinea Savanna of Nigeria

A. H. Girei[1*], N. Abdu[2] and A. Abdulkadir[2]

[1]Department of Soil Science, Faculty of Agriculture, Federal University Dutse, P.M.B. 7156, Jigawa, Nigeria.
[2]Department of Soil Science, Faculty of Agriculture, Institute for Agricultural Research, Ahmadu Bello University, P.M.B. 1044, Zaria, Nigeria.

Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2016/22161
Editor(s):
(1) L. S. Ayeni, Adeyemi College of Education, Ondo State, Nigeria.
Reviewers:
(1) Magdalena Valsikova, Slovak University of Agriculture, Slovakia.
(2) Mohammed Suleiman, Umaru Musa Yar'adua University, Katsina, Nigeria.
(3) Ariovaldo Antonio Tadeu Lucas, Federal University of Sergipe, Brazil.
(4) Agnieszka Wolińska, The John Paul II Catholic University of Lublin, Poland.
Complete Peer review History: http://sciencedomain.org/review-history/12797

Original Research Article

Received 20th September 2015
Accepted 12th November 2015
Published 25th December 2015

ABSTRACT

Studies on the effect of long term land use management practices on the temporal variability of soil properties are limited. This study addressed the temporal variability of soil properties under a long term fertilizer trial in a northern guinea savannah of Nigeria. The long-term dung (D), nitrogen (N), phosphorus (P), potassium (K) trial popularly referred to as DNPK experiment at Samaru is about the oldest manure and mineral fertilizer experiment in West Africa modeled after Rothamstead long-term trials in the United Kingdom. It has been under continuous cultivation from 1950 to 2008 from when it was fallowed up till now. Data on soil physico-chemical properties from previous studies conducted on DNPK experiment were synthesized for this work as well as data from the present work to create a time series graph using Microsoft excel to monitor trend of variability of each property over a long term. The contribution of dung to organic carbon appears to supersede any other treatment across all the years. Soil pH showed a decreasing trend with time with

---

**Corresponding author: E-mail: gireihalilu@yahoo.com;*

increasing rates of Nitrogen fertilization than other treatments. No significant influence of fertilizer management was observed for soil bulk density of the plots across the study years. Saturated hydraulic conductivity and aggregate stability improved when the plots were under cultivation for all fertilization regimes than when they were under fallow due to compacted soil aggregates. This study highlighted the sustainability of integrated nutrient management in sequestering carbon as well as maintaining soil quality over time, and it is therefore recommended as a sustainable management practice for tropical soils.

Keywords: Temporal variability; soil properties; soil organic carbon; fertilizer management; aggregate stability.

1. INTRODUCTION

Variation of soil properties from place to place (spatio) and also with time (temporal) is one of the most inherent and unavoidable feature of the natural environment. Soil properties change in space and time and under anthropogenic activities such as different management practices and under natural conditions by soil-forming factors [1,2]. Every element of the environment is characterized by its own variability, and at the same time each element affects one or more other elements of the environment [3] be it given physical, chemical or biological processes. Soil physical and hydraulic properties vary over space and time from field to field as well as within fields [4,5].

Temporal variability of the biophysical environment may occur by changes in soil characteristics and rainfall patterns over time [6]. For example soil surface characteristics undergoing temporal changes induced by irrigation and tillage practices, rain and wind weathering and biological activities can drastically modify soil structure [7,8].

An understanding of temporal variability of soil and hydraulic properties can provide a framework for developing effective planning of site- and management-specific approaches to sustainable farming practices [3,9].

In previous years, spatial and temporal changes in soil properties have been monitored through long-term field experiments, like Rothamsted Classical Experiments [10] and the Long-term Ecological Research Program [11]. Spatial variability makes it difficult to evaluate the temporal changes of soil properties in a short term [12] but knowledge about temporal variability is crucial to understanding long-term effects of land use management soil quality. Current researches focus more on spatial variability of soil properties under different land uses using geo-spatial tools such as krigging techniques. Information on temporal changes of soil properties is lacking in the guinea savanna agroecological zone, especially of a long term fertility trial in the zone. This knowledge will fill gaps in the current dearth of information needed to monitor system dynamics especially on management-induced effects on soil properties. This study on temporal variability of soil properties is geared to harness the sustainability of certain practice in order to determine the soil quality. In addition, an understanding of temporal variability can provide a framework for developing effective sampling schemes for future site-specific management and efficient experimental designs for research approaches [3]. Thus the objectives of this study were to: (i) determine temporal trends and changes of properties in soils of a long term trial with respect to different management practices (ii) identify interactions between soil properties amongst the treatments as actors of variation.

2. MATERIALS AND METHODS

2.1 Experimental Site

The study was carried out on selected plots in the long-term dung (D) and mineral fertilizer (NPK) trial field (i.e. DNPK) of the Institute for Agricultural Research, Samaru (latitude11° 16' North, longitude 07° 63' East. 686 m altitude) in the Northern Guinea Savanna ecology of Nigeria. Soils are classified as *Typic Halplustalfs* and are ferruginous in nature, according to USDA soil taxonomy [13].

2.2 Plot Descriptions and History of Use

The long-term DNPK experiment is the oldest fertilizer experiment in West Africa that was modeled after the Rothamsted long-term trials in the United Kingdom [14]. It has 81 plots in 3^4 in factorial combination which are randomly arranged with plot size of 220 m^2. Each of these plots has a fertilization history with dung (D), nitrogen (N), phosphorus (P), and potassium (K) or their combinations under continous cultivation from 1950 till 2001 [15] where cultivation continued between 2006 to 2008. The plots received different management practices that range from crop rotation, tillage practices, lime and micro nutrient application, to meet requirements of experimental crops. [16] gave a detailed description of these management practices vis a vis fertilizer combinations and application rates for each of the trial as presented in Table 1.

2.3 Soil Sampling and Analysis

A stratified random sampling technique was use to collect surface soil (0 to 20 cm) from ten (10) selected main plots. Each main plot was divided into three equally subplots. Three replicate of disturbed soil samples and two replicates of undisturbed core samples (5x5 cm in diameter) were taken from each subplot. The undisturbed soil cores were used to determine dry bulk density using the method of [17] and hydraulic properties using the pressure plate apparatus at suction points of 0.3 and 15 bars. Disturbed samples were bulked to form one composite sample per subplot per plot, making a total of three samples from each main plot. Samples were divided into 2 parts, one was sieved with a 5-mm sieve for aggregate analysis and the other part was passed through 2-mm sieve for routine analytical procedure for the determination of soil organic carbon using Walkey –Black wet oxidation method [18]. The hydrometer method [19] was used in determining particle size distribution in the soil. The textural classes of the soil were obtained from the textural triangle of SPAW hydrology model (Version 6.02.72) by entering into the software, measured percentage values of clay and sand.

Results of some soil properties from earlier studies (1959 - 2008) on the long-term DNPK experiments at Samaru, Nigeria were synthesized for this studies. Data collected from literature on soil properties as well as fertilizer management were fitted into time series graph of Microsoft excel (Microsoft, 2007) and trend of their variability with time was observed.

3. RESULTS AND DISCUSSION

3.1 Physical Characteristics of the Soil for the Study

Table 2 shows the physical characteristics of the soil used in the study. Soils were classified as sandy loam in there textural a common characteristic of most savanna soils [16,20]. Though low organic carbon status, DK,DP and DNPK plots had the highest organic carbon content while NPK and K plots recorded the least value. The higher occurrence of soil organic carbon in the dung fertilized pots may be as a result of dung application [21,22]. Dry soil bulk density values were very low across all the treatment plots though slightly higher value was observed in DNPK plot thus indicating low chances of restricting root penetration and subsequent uptake of nutrient and water by the plant [23].

Plots receiving dung treatment reflect high soil moisture retention between field capacity (FC) and permanent wilting point (PWP) among others (Table 2) thus implying the availability of more water for plant uptake in such plots. Several studies have shown the positive effect of dung or organic fertilizer applications on bulk density and moisture retention [16,24].

3.2 Soil Organic Carbon Data from DNPK Plots (1959 - 2008)

Data for soil organic carbon documented between 1959 and 2008 from earlier studies are presented in Figs. 1 and 2. Trend shows initial low organic carbon prior to any farming activity for dung plots. However, the

Table 1. Fertilizer combinations for the various treatments in the experimental plots

Treatment	Abbreviation	Rates (kg ha^{-1})		
Dung	D	0	2500	5000
Urea	N	0	67.5	135.0
Single Super Phosphate (SSP)	P	0	13.5	27.0
Muriate of potash	K	0	29.0	58.0

Each fertilizer applied at 3 levels of 0, 1, 2, (3 x 3 x 3 x 3 = 81). Each row of the application rates represents the level number 0, 1, 2 respectively; (Source: Abdulkadir and Habu, 2013)

Table 2. Selected soil properties of the study plots

Plots	Soil organic carbon (%)	Bulk density (g cm^{-3})	Texture	Moisture at FC (%)	Moisture at PWP (%)
D	1.04	1.43	Sandy loam	17.9	5.9
DK	1.68	1.43	Silty loam	15.0	4.7
NPK	0.63	1.43	Sandy loam	18.0	4.8
N	1.02	1.43	Silty loam	15.0	4.7
DNPK	1.41	1.53	Silty loam	32.0	22.3
DP	1.51	1.44	Sandy loam	17.4	5.9
CONTROL	1.08	1.44	Sandy loam	19.3	7.0
P	1.86	1.43	Sandy loam	16.0	4.7
DN	0.74	1.44	Sandy loam	17.4	5.9
K	0.80	1.43	Sandy loam	17.9	5.9

N, Nitrogen, P, Phosphorus, K, Potassium D, Dung, FC, Field Capacity, PWP, Permanent Wilting Point

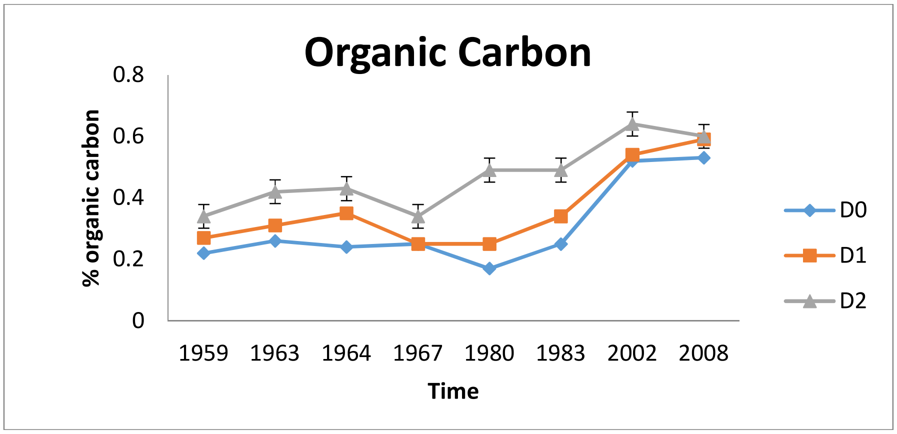


Fig. 1. Trends of organic carbon content under three levels (0,1,2) of dung application rate in dung (D) plots between 1959-2008

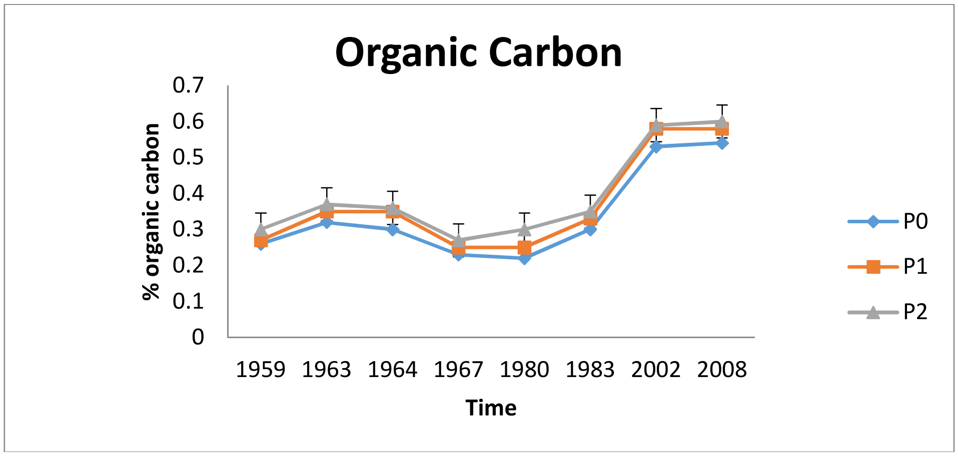


Fig. 2. Trends of organic carbon content as influenced by three levels (0,1,2) of phosphorus (P) application rates in P-plots between 1959-2008

trends across all treatments show a fluctuating (inconsistence) increase and decline in organic carbon level between the year 1959 and 2008. A slight constant state was observed in 2008, though still higher when compared to values observed in 2002 in most cases. This trend is similar for the four treatments, at all levels, over the years. Results show that dung was the main treatment among others that consistently increased soil organic carbon (SOC), up to the highest rate of application. This is reflected by the highest value of organic carbon observed with the highest level of dung applied (i.e. D2) (Fig. 1).

Comparatively higher values of organic carbon and total nitrogen were observed in 2002. This could be attributed to the fact that the field was fallowed for five years. Research reports have shown varied role that fallow played in carbon sequestration in soil. [25] reported low organic carbon content during cultivation periods of DNPK field. They attributed their findings to the highly degraded nature of the soils as a result of annual harvesting of organic matter from these plots while under continuous cultivation. The non-perturbation of soil during the fallow period could also have reduced activities of soil microbes. It is also likely that during fallow periods, water-stable aggregates kept organic matter out of reach of microbes thus impeded decomposition [26]. Conant et al. [27] reported that marginal lands in United States under fallow have potential to sequester about 50 g C m^{-2} yr^{-1}. By 1983, when the experiment was 34 years old, Amapu [28] found that about 32.63 and 65.5 tones C ha^{-1} had been added from 2.5 and 5 tones dung ha^{-1}. Thus, equivalent of 13 and 11.6% of carbon supplied in dung and was retained in the soil as organic matter. This also translates into the mineralization of 87 and 88.4% of the manure applied. These values indicate that quite reasonable amounts of organic material are retained in the soil each year. Diels et al. [29] used ROTHC model and estimated that the DNPK experiment had built up 1 tone C ha^{-1} after 20 years of existence. In another study, it was found that after 45 years of continuous application, the dung-treated plots had carbon contents that are approximately the same level as that of a ‘native’ site [30]. Area-based changes calculated in relation to the ‘native’ site were not significant numerically, further corroborating findings that dung was effective in building up soil carbon. The study by Agbenin and Goladi [30] also showed that, while inorganic fertilizers in combination with dung not only arrested carbon loss, they also increased N and P in relation to a ‘native’ site.

With respect to phosphorus treated plots, organic carbon was found to be increasing significantly with increase in level of phosphorus fertilizer all over the years observed (Fig. 2).This has been attributed, in part, to production of greater root residues from high crop yields on P-treated plots. The observation is also credited to the fact that phosphate fertilizers allow relatively more carbon to be converted into humus by ‘locking’ fertilizer phosphate in organic form, and creation of humic carboxylic acids [31].

The trend of organic carbon content of the study plots with respect to nitrogen and potassium fertilizers treated plots were found to be increasing slightly but not significantly with increase in their levels (Figs. 3a and b). A similar finding was observed by Drinkwater et al. [32] in which slightly lower values of 2.2 t C ha^{-1} were obtained in Pennsylvania in 15 years of using chemical nitrogenous fertilizer.

Raji and Ogunwole [25] also concluded that application of manure over a long period of time resulted in sequestration of more soil organic carbon than application of NPK fertilizer alone did in the long term trial. They recorded 68% or 3.55 t C ha^{-1} increment after 45 years of continuous manure application which they attributed to the ability of organic manure in promoting the formation and stabilization of macro aggregate and particulate organic carbon.

3.3 Soil Reaction (pH) Data from DNPK Plots from 1959 to 2008

An initial decrease in soil pH was observed with increase in level of N fertilizer for the first few years observed (Fig. 4b). However, slight rise in pH was observed which later stabilizes and then begins to decline. The application of nitrogen fertilizers indicates acidifying effects on soils, which is caused by hydrolysis of salt and by acid production during nitrification, leading to leaching of soil bases accompanied by low pH buffering capacity of the soil [33].

However, mean values for soil pH, across treatment levels (Fig. 4a), showed an inconsistent trend in pH with different levels of dung for all the years. The observed increase has been linked to the production of $CaCO_3$ during decomposition of organic residues in dung or production of soil humic substances that can form complexes with aluminum and manganese ions [34]. Effects of phosphorus fertilizer were similar to those of dung (Fig. 4c). Potassium (K) treatment did not seem to have any appreciable effect on soil reaction (Fig. 4d).

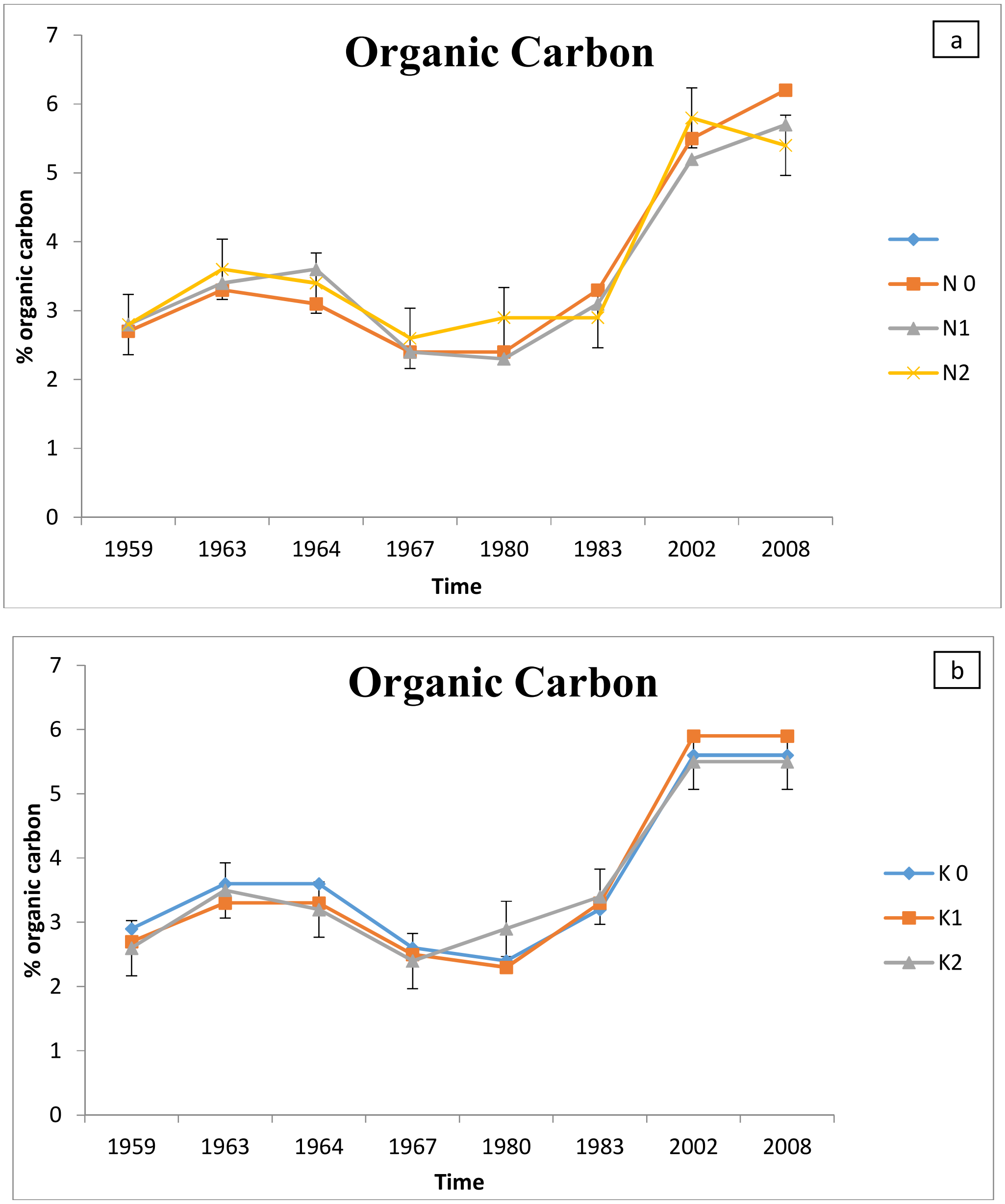
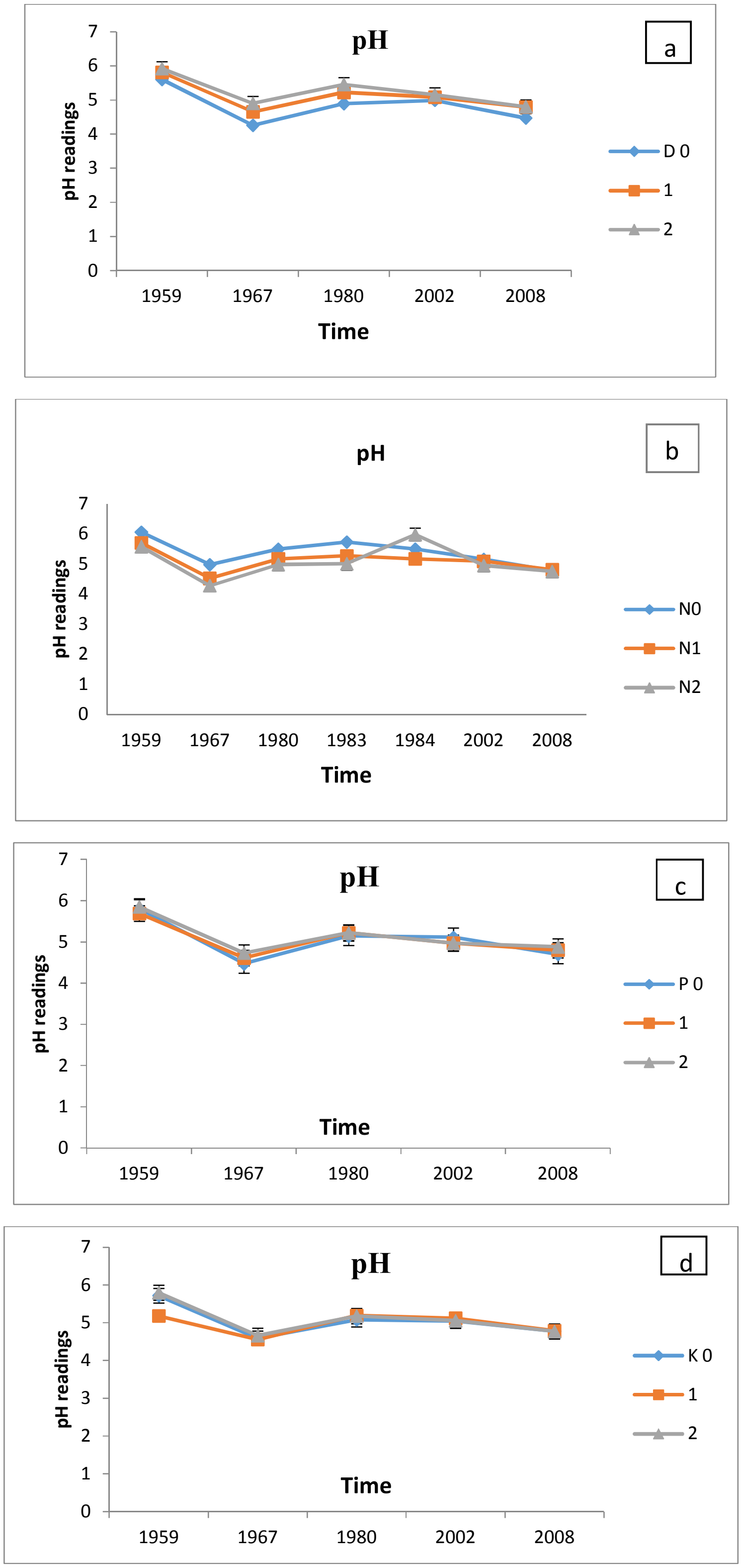


Fig. 3. Trends of organic carbon contents under three levels (0, 1, 2) of (a) Nitrogen; N and (b) Potassium; K application rates in DNPK plots between 1959-2008

3.4 Data from Selected Soil Physical Properties from DNPK Plots (1997 - 2013)

Data collected on soil physical properties were for average mean weight diameter, bulk density and saturated hydraulic conductivity and are presented in Fig. 5. All average values recorded for bulk density were slightly above average values reported by Goladi [35] as 1.51 Mg m^{-3}, although slight but non-significant differences were observed across the years (Fig. 5). This slight differences were attributed to the effect of cultivation on bulk density of savanna soil which is usually short-lived because bulk density quickly returns to its original state at the end of a growing season [35] due to its dynamic nature, thus, management dependent. A similar reasoning was highlighted by Raji and Ogunwole [25].



Figs. 4a-d. Trends of soil pH under three levels (0,1,2) of (a) Dung; D, (b) Nitrogen; N, (c) Phosphorus; P and (d) Potassium; K application rate in DNPK plots between 1959-2008

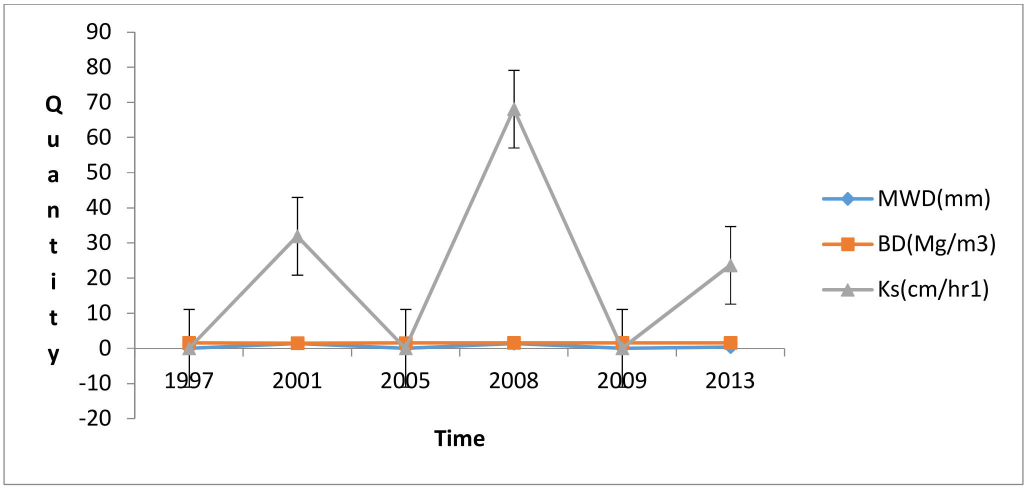


Fig. 5. Trend of some selected soil physical properties of the DNPK plot in Samaru between 1997 to 2013

The stability of the macroaggregate was observed to be decreasing across the years (Fig. 5). This might be attributed to absence of farming activities during the fallow period, since application of fertilizer (organic or inorganic) is believed to have an indirect role in macroaggregate stability because of the role they play in biomass accumulation and root exudation that serve as binding agent [36,37]. Accumulation of biomass from the bushes growing during the fallow periods was low compared with the accumulation during farming activities, thus having less impact on stability of soil macroaggregates. Low microbial activity might have reduced macroaggregate stability. Another reason for the reduced stability of macro aggregate may be attributed to the long-term application of NPK fertilizer as reported by Nyiraneza et al. [38]. However, an improvement of macro stability was noticed in 2008 when the field was cultivated which was attributed to the role of roots in the enmeshment of particles together.

Saturated hydraulic conductivity was found to be decreasing during the fallow periods, although an increase was observed when the field was cultivated in 2008 (Fig. 5). A possible reason for the observed increase may be associated with the soil's structural arrangement of the surface or as a result of improvement in macro aggregate stability, both influenced by the management practices adopted in the field [16]. The influence of pore sizes and geometry on soil hydraulic properties is also suspected to play a positive role on the increase of Ks [39,40]. Observed decrease in Ks during the fallow period was connected to degradation of structural stability of the soil that resulted in tightening of the soil and decrease in the volume of soil pores over time [41].

4. CONCLUSION

This study shows the long term positive impact of integrated nutrient management on soil quality. Organic and inorganic fertilizer application built up soil carbon from inception of the trial as well as buffering of soil pH over time. Soil bulk density and aggregate stability exhibited consistent trend while saturated hydraulic conductivity was highly variable along the temporal dimension. These imply the sustainability of integrated nutrient management in sequestering carbon as well as maintaining soil quality over time. Similar study is encouraged in decadal time intervals to monitor effects of other land uses on soil properties as well as on other plots in the fertilizer trial to provide enough data to make future predictions of soil quality under different soil management practices.

ACKNOWLEDGEMENTS

This work was carried out through an MSc grant by the Volkswagen Stiftung, Hannover, Germany, under the Urban Food Project: “Challenges and Opportunities for Nutrient Efficient Agriculture in West African Cities”.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Usowicz B, Usowicz JB. Spatial and temporal variation of selected physical and chemical properties of soil. Asst. Prof. Cezary S (Ed.), Inst. Agrophysics PAS, Lublin. 2004;5.
2. Sydney MT, Jabro JD, Stevens B, Evans R. Spatial and temporal variability of soil physical and hydraulic properties. Untd Ste Dept Agric J. USA. 2011;1.
3. Ahmed D, Marc van M, Tibor T. Statistical methods for the analysis of soil spatial and temporal variability, principles, application and assessment in soil science, Dr. Burcu E, Ozkaraova Gungor (Ed.), ISBN: 2011;978-953-307-740-6, InTech, Available:http://www.intechopen.com/books/principlesapplication
4. Cambardella CA, Moorman TB, Novak JM, Parkin TB, Karlen DL, Turco RF, Konopka AE. Field-scale variability of soil properties in central Iowa soils. Soil Sci Soc Am J. 1994;58:1501-1511.
5. Strock JS, Cassel DK, Gumpertz ML. Spatial variability of water and bromide transport through variably saturated soil blocks. Soil Sci. Soc Am J. 2001;65:1607-1617.
6. Rao PSC, Wagenet RJ. Spatial variability of pesticides in field soils: Methods for data analysis and cosequencies. Weed Sci. 1985;33(suppl.2):18-24.
7. Imeson AC, Kwaad FJPM. The response of tilled soils to wetting by rainfall and the dynamic character of soil erodibility. In: Boardman J, Foster IDL, Dearing JA, (Eds.), Soil erosion on agricultural land. John Wiley and Sons; 1990.
8. Angulo-Jaramillo R, Vandervaere JP, Roulier S, Thony JL, Gaudet JP, Vauclin M. Field measurement of soil surface hydraulic properties by disc and ring infiltrometers: A review and recent developments. Soil Till. Resch. 2000;55:1-29.
9. Mzuku M, Khosla R, Reich R, Inman D, Smith F, MacDonald L. Spatial variability of measured soil properties across site-specific management zones. Soil Sci. Soc. Am J. 2005;69:1572-1579.
10. Johnston AE, Goulding KWT, Powlton PR. Soil acidification during more than 100 years under permanent grassland and woodland at Rothamsted. Soil Use Mgt. 1986;2:3-10.
11. Risser PG (Ed.). Long-term ecological research, an international perspective. Wiley, New York. 1991;1-290.
12. Sun B, Zhoub S, Zhao Q. Evaluation of spatial and temporal changes of soil quality based on geostatistical analysis in the hill region of subtropical China. Geoderma. 2003;115:85-99.
13. Ogunwole JO, Babalola AO, Oyinlola EO, Raji BA. Properties and classification of soils of part of Samaru, Zaria. Samaru. J Agric Resch. 2001;17:24-35.
14. Amapu IY. Brief on the long term DNPK experiments in Samaru northern Nigeria. Global Soil Change Workshop, 10-13 Dec, 2007, North Carolina, United States of America (USA); 2007.
15. Ogunwole JO. Soil aggregate characteristics and organic carborn concentrations after 45 annual application of manure and inorganic fertilizer. Biol. Agric. Hort. 2008;25(3):223-233.
16. Ogunwole JO, Ogunleye PO. Influenced of long-term application of organic and mineral fertilizers on quality of savanna Alfisol. J Sust Agri. 2005;26(3):5-13.
17. Blake GR, Hartge KH. Bulk density. In A. Klute (ed.). Methods of soil analysis. agronomy 9, part 1, 2nd edition, ASA and SSSA, Madison, WI. 1986;363-376.
18. Allison LE. Soil organic matter. In Black CA, Evans DD, White JL, Ensminger LE, Clark FE, (eds). Methods of soil analysis, part 1, American Society of Agronomy, Madison, WI. Monograph. 1965;9:1367-1378.
19. Gee GW, Bauder JW. Particle size analysis. In: Klute A, ed. Methods of soil analysis, Part 1: Physical and Mineralogical Methods, Monograph No. 9. Am Soc Agron. Madison, WI; 1986.
20. Jones MJ, Wild A. Soil of the West Africa. Commonwealth Bureau of Soils, Harpenden, Savanna. Tech. Comm. 1975; 55-246.
21. Sanchez PA, Miller RH. Organic matter and soil fertility management in acid soils of the tropics. In: Proceedings of the transactions of the 13th Congress of ISSS. 1986;5:361-370.
22. Abdulkadir A, Habu ST. Soil properties of a fallow field under long-term cultivation and fertilization regimes in Northern Guinea savanna. Nigeria. AJ Agric Resch. 2013; 8(42):5211-5220.
23. Abdulkadir A, Girei AH, Aliyu J, Jibril I. Evaluating different values of van Genuchten (vG) parameters on soil quality

index (s-index) of a Nigerian savanna alfisol. Proceedings of the 39th Annual Conference of SSSN; 2015. (In press).

24. Zhang S, Yang X, Wiss M, Grip H, Lovdahl L. Changes in physical properties of aloes soil in China following two long-term fertilization regimes. Geoderma. 2006; 136:579- 587.
25. Raji BA, Ogunwole JO. Potentials of soil carbon sequestration under various land use in the sub-humid and semi-arid Savanna of Nigeria: lessons from long-term experiments. Int J Soil Sci. 2006;1(1):33-43.
26. Hassink J. The capacity of soils to preserve organic C and N by their association with clay and silt particles. Plant and soil. 1997;191:77-87.
27. Conant RT, Paustian K, Elliott ET. Grassland management and conversion into grassland effects on soil carbon. Ecol. Appl. 2001;11:343-355.
28. Amapu IY. Institute for agric research (IAR): DNPK research log book series; 1984
29. Diels J, Vanlauwe B, Sanginga N. Coolon E, Merckx R. Temporal variation in ^{13}C values and implication for using the ^{13}C techniques in long-term soil organic matter studies. Soil Biol. Biochem. 2001;33:1245-1251.
30. Agbenin JO, Goladi JT. Carbon, nitrogen and phosphorus dynamics under continuous cultivation as influenced by farmyard manure and inorganic fertilizers in the Savanna of Northern Nigeria. Agric Eco & Environ. 1997;63:17-24.
31. Russell EW. soil conditions and plant growth, 10th ed. Longman, London; 1973.
32. Drinkwater LE, Wogoner P, Sarrantonio M. Legume-based cropping systems have reduced carbon and nitrogen losses. Nature.1998;396:262-264.
33. Mohammed I. Long-term effects of treatments on soil physical properties in Samaru in the Northern Guinea Savanna Ecological Zone of Nigeria. Lambert Academic Publishers, Germany; 2010.

    ISBN 978-3-8465-1204.
34. Batche BW, Heathcote RG. Long-term effect of fertilizers and manure on soil and leaves of cotton. Expt Agric. 1969;5:241-247.
35. Goladi JT. Carbon, nitrogen and phosphorus dynamics induced by long-term cultivation and management. M. Sc Thesis Ahmadu Bello University, Zaria, Nigeria.1997;89.
36. Tisdall JM, Oades JM. Organic matter and water stable aggregates in soils. J Soil Sci. 1982;33(2):141-163.
37. Beare MH, Hendrix PF, Coleman DC. Water-stable aggregates and organic matter fractions in conventional- and no-tillage soils. Soil Sci Soc Am J. 1994;62(3):777-786.
38. Nyiraneza MH, N'Dayegamiye A, Laverdière MR, Dairy cattle manure improves soil productivity in low residue rotation systems. Agron J. 2009; 101(1):207-214.
39. Brady NC, Weil RR. The nature and properties of soils, 12th edition Prentice Hall. International Limited, London. 1999; 881.
40. Ahuja LR, Fiedler F, Dunn GH, Benjamin JG, Garrison A. Changes in soil water retention curve due to tillage and natural reconsolidation. Soil Sci Soc Am J. 1998;62:1228-1233.
41. Zhou H, Lu Y-Z, Yang Z-C, Li B-G. Influence of conservation tillage on soil aggregate features in North China plain. Agric. Sci. China. 2007;6(9):1099-1106.

Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/12797