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Assessment of soil characteristics under four cropping and land management systems in south west Nigeria

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Soil degradation and desertification pose a major threat to agricultural production in sub-Saharan Africa. The influence of cropping systems which had been established on selected physical and chemical properties of soil were investigated in Akinyode-Okinni community in Egbedore Local Government Area (LGA) of Osun State, Nigeria. The cropping systems included agri-silviculture (SCM), silvi-pasture (SPC), agri-horti-silviculture (PAH) and agroforestry (AFT) selected from existing farms in the community. The selected plots had cocoa (*Theobroma cacao*), oil palm (*Elais guineensis*) and kola-nut (*Kola nitida*) as permanent crops; coco-yam (*Coco nucifera*), guinea grass (*Panicum maximum*), plantain (*Musa spp*), maize (*Zea mays*), and cassava (*Manihot utilissima*) were the annual crops. The experiment was carried out for two cropping seasons. Results showed that in the AFT system, bulk density (BD) decreased slightly from 1.22 to 1.16 g/cm^3 in the top soil and from 1.18 to 1.09 g/cm^3 in the subsoil after two cropping seasons. The pH varied between 6.40 and 7.05 in the first season and between 7.05 and 7.29 after two seasons. On average, the topsoil contained more organic carbon (OC) in SPC (38 g kg^{-1}) and SCM (36 g kg^{-1}) systems than in the PAH and AFT systems. Similarly, the total phosphorus content was higher in the topsoil of SPC and SCM systems than in the other systems. There was a slight reduction in soil acidity and no significant changes occurred in the concentrations of exchangeable bases after two cropping seasons. Conclusively, these cropping systems have the potential to reduce soil deterioration and thus; further studies to develop appropriate management strategies are necessary.

Key words: Cropping systems, exchangeable bases, organic carbon, silviculture, soil degradation.

INTRODUCTION

The influence of soil management practices on sustainable agricultural production could be related to the readiness of farmers to adopt improved agricultural practices. One of the goals of effective soil management practices is to create farming systems that mitigate environmental degradation associated with inappropriate

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activities of man (Sustainable Agriculture, 2001). Sustainable agriculture is part of a larger movement toward sustainable developmental processes, which recognize natural resources as being finite; it acknowledges limits on economic growth, and encourages equity in distribution of resources (Horrigan et al., 2002). The adoption of certain agricultural technologies which are believed to be yield-enhancing and development oriented can bring ecological, socio-economic, and cultural benefits if based on a holistic scientific approach (Madden and Chaplowe, 1997). Potential sustainable agricultural practices that may have impact on some developmental processes on soil management include organic farming, crop rotation, planting of cover crops, conservation tillage, integrated soil fertility cum nutrient management, enhancement and conservation of bio-diversity, integrated pest management, rotational grazing, and agro-forestry (Factsheet of Tropical Forages, 2015; Lamidi, 2013; Michel, 2010; Alabadan et al., 2009; Sustainable Agriculture, 2001; Allan, 1996).

This study focused on four soil management systems which are considered important in the quest to develop sustainable agricultural production systems. These systems include agri-silviculture, agri-silvipasture, agri-horti-silviculture, and agroforestry. In agri-silviculture farmers in dryland grow field crops in combination with forest trees; the silvi-pastoral system involves raising grasses instead of field crops in the spaces between forest trees (Balasubramaniyan and Palaniappan, 2005). Agri-silvipasture is the combination of agri-silviculture and silvi-pastoral systems whereas agri-horti-silviculture is a system where fruit trees are grown along with crops and multipurpose tree species. Agri-horti-silviculture is highly diverse in vegetation and its productive capacity is expected to be relatively high. For example, crops such as rice, mustard, soybean and/ or vegetables may be grown in between banana or guava (Balasubramaniyan and Palaniappan, 2005). The general assumption is that these agricultural systems have the capacity to restore and balance ecosystems naturally (Factsheet of Tropical Forages, 2015; Ifeanyi et al., 2013).

Thus, it was hypothesized that farmers' adoption of developmental soil management practices could have an impact on the physical and chemical properties of the soil. Therefore, this study examined the influence of four cropping and land management systems on selected physical and chemical properties of the soil after two cropping seasons in South West Nigeria.

MATERIALS AND METHODS

The study was conducted at Oluyeyin Akinode-Oke Farm (5.56°N, 4.56°E) in Okinni village located at Egbedore Local Government Area of Osun State, Nigeria. The soil is well drained and sandy loam in texture. The mean annual rainfall is between 300 and 350 mm. The area is prone to soil erosion. Four agricultural systems which had been established by farmers were selected for the study. These systems were agri-silviculture, silvi-pastural, agri-horti-silviculture, and agroforestry.

Agri-silviculture is a system of agriculture where the land is used to produce both forest trees and agricultural crops either simultaneously or alternately (Balasubramaniyan and Palaniappan, 2005). Silvi-pastural system is where trees are planted for wood production as well as fodder for feeding domestic animals. Agri-horti-silviculture is a system of agriculture where annual crops, fruit trees and multipurpose tree species are planted on a piece of land simultaneously or alternately. The agroforestry system was taken as a system having tree species as a major feature or a combination of all the other systems already described. The size of each of the selected cropping systems was 1 ha which was divided into four segments to serve as replicates.

The agri-silviculture system had three-year old cocoa trees which served as forest tree crop and plantain at the commencement of the study; maize (*Zea mays*) was grown in between the rows for two cropping seasons and the system was tagged SCM. The silvi-pastural system also had three-year old cocoa trees with guinea grass (*Panicum maximum*) grown between the rows and was tagged SPC; grazing was discouraged during the period of the experiment. The agri-horti-silviculture system, tagged PAH, had oil palm (*Elais guineensis*) and cocoa trees; maize was grown in the rows of the tree crops. In PAH system, cocoa served as a fruit tree crop, oil palm as a multipurpose tree species, and maize as a field crop. The agro-forestry system tagged AFT, had fully grown kola-nut (*Kola nitida*) trees which were regarded as forest tree species. A nearby field (same neighbourhood, of similar size) with secondary regrowth of vegetation (bush fallow) was selected as the control plot.

Soil samples were taken from each plot at two depths, 0 to 15 and 15 to 30 cm, prior to commencement of the study and after two cropping seasons. Soil samples were also taken from the control field for comparison. The samples were air-dried, sieved (2 mm) and analysed for physical and chemical characteristics. The parameters measured included particle size fractions, pH, total P, organic carbon, total N and exchangeable cations (Essington, 2004; Davidson and Ackerman, 1993; IITA, 1982). Core soil samples were also taken for determination of bulk density (BD) (Hamza and Anderson, 2005; Hakansson and Lipiec, 2000). The data obtained were subjected to One-way analysis of variance (ANOVA), the treatment means of the data were separated with least significant difference (LSD).

RESULTS AND DISCUSSION

Physical properties (bulk density (BD) and particle size fractions)

Generally the influence of the cropping systems on BD of the topsoil was not visible during the experimental period as shown in Table 1. However, when considered on absolute terms, a slight decrease was observed in some systems. For example, in the topsoil of the AFT system BD decreased from 1.22 to 1.16 g/cm^3. Similarly the BD of the subsoil tended to decrease slightly in PAH (1.22 to 1.06 g cm^{-3}) and SCM (1.21 to 1.17 g cm^{-3}) systems.

The relatively low BD values after two seasons suggest

Table 1. The bulk density (BD) and pH of the soil samples at different depths before and after two cropping seasons

Treatment	Depth	Initial		Final after two seasons	
		BD (g cm^{-3})	pH (in H_2O)	BD (g cm^{-3})	pH (in H_2O)
SCM	Topsoil	1.23	7.00	1.22	7.05
	Subsoil	1.21	6.80	1.17	7.30
SPC	Topsoil	1.28	7.01	1.20	7.29
	Subsoil	1.20	6.70	1.18	7.29
PAH	Topsoil	1.24	7.00	1.22	7.19
	Subsoil	1.22	6.40	1.06	7.05
AFT	Topsoil	1.22	6.95	1.16	7.27
	Subsoil	1.18	6.80	1.09	7.22
Control	Topsoil	1.18	7.00	1.16	7.12
	Subsoil	1.20	7.05	1.18	7.07

some improvement in this soil property which apparently, would have influenced some other properties of the soil. The slight decrease in BD could be attributed to the no-till strategy adopted for cropping systems with permanent crops. The absence of trampling by grazing animals may have contributed to the slight reduction in BD since grazing was discouraged in the experimental fields during the period of the study. In essence, the agricultural development systems used for this study could be described as being environmentally friendly because of their perceived lowering effect on BD which translates to occurrence of little or no soil compaction. It is common knowledge that soil compaction causes physical impedance of roots and thus limits access to water and nutrients by reducing the volume of soil exploited by plant roots.

This attribute is particularly important since compaction destroys the structural units of the soil and, thus alters the pore spaces which invariably affect aeration and water infiltration negatively (Taylor and Brar, 1991). Moreover, when BD is high (≥ 1.5 g cm^{-3}) root growth and development can be depressed (Hassan et al., 2007).

Data on particle size fractions of the surface and subsurface layers are given in Table 2. At the commencement of the experiment, the amount of sand particles varied from 704 to 760 g kg^{-1} in the top soil while the silt particles ranged from 123 to 182 g kg^{-1}. In the subsoil, the sand fraction varied from 694 to 762 g kg^{-1} whereas the silt fraction varied from 113 to 192 g kg^{-1}. The quantity of the clay fraction was, on average, 114 g after two cropping seasons were, more or less, similar to the initial values (data not shown) indicating little or no kg^{-1} for the topsoil and 122 g kg^{-1} for the subsoil. The soils in

Table 2. Distribution of particle size fractions in the top- (0-15 cm) and sub-soil (15-30 cm) layers.

Treatment	Depth	Sand	Silt	Clay
			g kg^{-1}	
SCM	Topsoil	722.3	167.2	110.5
	Subsoil	713.4	161.4	125.2
SPC	Topsoil	722.3	174.2	103.5
	Subsoil	704.3	167.2	128.5
PAH	Topsoil	713.0	157.4	129.6
	Subsoil	704.3	171.2	124.5
AFT	Topsoil	704.5	182.4	113.1
	Subsoil	694.8	192.0	113.2
Control	Topsoil	760.0	123.0	117.0
	Subsoil	762.0	113.0	125.0

(sandy loam). The particle size fractions measured change during the period of study. In general, there was no evidence of change in their distribution after two cropping seasons.

This observation is encouraging since the cropping systems were established by farmers to reduce erosion conserve to the soil. As the cropping systems contained plant species which shed some of their the various cropping systems had same textural class leaves regularly, the resulting litter may have reduced surface

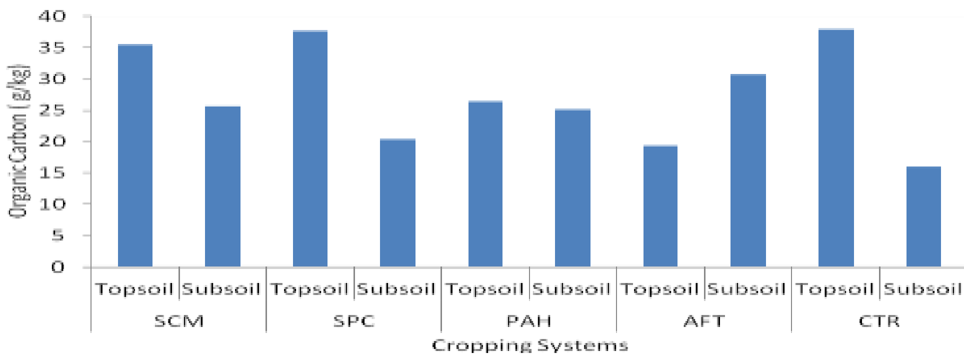

Figure 1. The amount of organic carbon (OC) in the topsoil (0-15 cm) and subsoil (15-30 cm) as influenced by the cropping systems.

runoff and prevented dislodgement and removal of fine soil particles. In addition, the no-till strategy adopted may have contributed in preserving the soil.

Chemical properties (organic carbon, pH, exchangeable bases, total phosphorus, and total nitrogen)

The organic carbon content of the topsoil of the SPC or SCM system was similar to the control which had secondary vegetation that remained untouched during the experimental period but higher than that of the PAH or AFT system (Figure 1). More organic carbon was measured in the topsoil than in the subsoil in all the cropping systems except AFT whose topsoil contained the lowest amount.

The value of organic carbon is an indication of the soil organic matter (SOM) content in agricultural soils (Obigbesan, 2000). The observed organic carbon content suggests that SOM was not negatively affected by the activities conducted in these cropping systems. Both SPC and SCM systems had 3-year old cocoa trees at the beginning of the experiment which may have contributed to the replenishment or maintenance of the organic carbon content through its litter. The reason for the relatively low amount of organic carbon measured in the topsoil of the AFT system is unclear since it contained kola nut trees that would shed its leaves and contribute to SOM upon decomposition; the amount of litter in each of the cropping systems was, however, not quantified in this study.

It was observed that the pH the topsoil at the commencement of the study was either slightly acidic or nearly neutral in all the cropping systems while that of the subsoil of all the systems varied from neutral to slightly alkaline except the control field which had a near neutral pH (Table 2). However, results showed that after the two cropping seasons, the pH of the subsoils of all the cropping systems had become neutral or slightly alkaline. Although it has been reported that agricultural practices such as zero tillage which contribute to SOM build up also promote soil acidity (Adepetu et al., 2014), the no-till strategy adopted in this study did not reduce the pH of the soil. For example, in the systems (SPC and SCM) where the amount of organic carbon in the topsoil was relatively high and comparable to the control, and given that zero tillage was employed, the soil did not become acidic. This assertion is supported by the pH (measured in water) of the soil which ranged between slightly acid to neutral before cropping and ranged between neutral to slightly alkaline after cropping.

Data on exchangeable bases and acidity measured on samples taken just before the commencement of the experiment are shown in Table 3. In the topsoil, exchangeable Ca varied from 4.5 to 12 Cmol kg^{-1} among the cropping systems whereas the variation in quantity of exchangeable Mg was not wide. The cropping systems also had similar amounts of exchangeable K and Na in the topsoil. The amounts of these nutrients in the cropping systems did not change appreciably after two cropping seasons (Table 4). Thus, the concentrations of these nutrient elements were somewhat stable during the study period probably due to addition of organic matter to the soil through fallen leaves and dead roots. However, the concentrations of most of the measured cations generally fall within the low range (Adepetu et al., 2014) except those of the SPC (topsoil) and AFT (subsoil) cropping systems that were within the medium class. Considering the critical limits of soil nutrients reported by Aderonke and Gbadegesin (2013), the amount of exchangeable K was generally in the medium range. Nevertheless, the low levels of exchangeable cations indicate the need for adequate soil management in all the cropping systems to boost the productive capacity of the soil. Cation exchange is important in soil as it controls

Table 3. Levels of exchangeable cations and acidity in the top-soil (0 - 15 cm) and sub-soil (15 - 30 cm) layers before the experiment.

Treatment	Depth	Ca	Mg	K	Na	Acidity
		Cmolc kg^{-1}				
SCM	Topsoil	8.38	1.20	0.38	1.20	0.38
	Subsoil	6.28	1.20	0.30	1.30	0.80
SPC	Topsoil	12.2	1.19	0.48	1.48	0.95
	Subsoil	3.20	0.90	0.20	1.20	0.71
PAH	Topsoil	6.80	1.10	0.42	1.60	0.70
	Subsoil	6.61	1.80	0.92	1.51	0.32
AFT	Topsoil	4.56	1.82	0.50	1.40	0.32
	Subsoil	10.62	3.18	0.60	0.90	0.35
Control	Topsoil	10.00	0.98	0.42	1.36	1.20
	Subsoil	10.10	1.06	0.42	1.36	1.20

Table 4. Levels of exchangeable cations and acidity in the top-soil (0 -15 cm) and sub-soil (15-30 cm) layers after the two seasons.

Treatment	Depth	Ca	Mg	K	Na	Acidity
		Cmolc kg^{-1}				
SCM	Topsoil	8.41	1.17	0.42	1.31	0.40
	Subsoil	6.34	1.18	0.23	1.48	0.30
SPC	Topsoil	13.07	1.21	0.52	1.62	0.60
	Subsoil	3.18	0.81	0.18	1.10	0.60
PAH	Topsoil	6.89	1.13	0.46	1.54	0.60
	Subsoil	6.66	1.93	0.85	1.54	0.30
AFT	Topsoil	4.52	1.93	0.46	1.38	0.40
	Subsoil	11.65	3.13	0.63	0.84	0.34
Control	Topsoil	10.10	1.12	0.54	1.42	1.16
	Subsoil	9.89	1.24	0.44	1.44	1.20

availability of nutrients to plants, prevents leaching of the nutrients, and ensures their release for plant uptake; low levels of exchangeable cations are usually attributed to leaching and soil erosion (Negassa, 2001). But in this study, soil erosion was minimal as there was no significant redistribution of particle size fractions.

The topsoil of the SPC and SCM systems contained more total P than the topsoil of the other systems as well as the control (Figure 2). The amount of total P in the subsoil was generally lower than in the topsoil in all the cropping systems except AFT. The results indicated that total P varied between 0.068 to 0.273% (mean = 0.184%) in the topsoil and between 0.095 to 0.147% (mean = 0.118%) in the subsoil. These mean values could translate to 1.84 g kg^{-1} for the topsoil and 1.18 g kg^{-1} for the subsoil. The amounts of total P in the topsoil of the

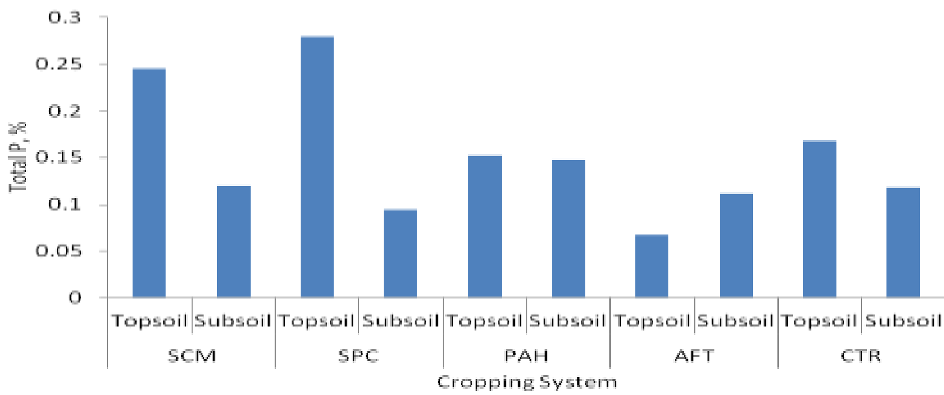

Figure 2. The amount of total P in the topsoil (0-15 cm) and subsoil (15-30 cm) as influenced by the cropping systems.

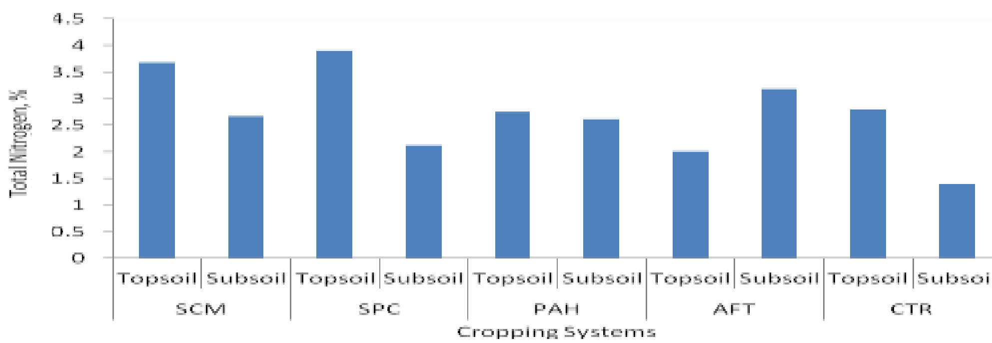

Figure 3. The amount of total nitrogen in the topsoil (0-15 cm) and subsoil (15-30 cm) as influenced by the cropping systems.

studied cropping systems are relatively high when compared with other soils. For example, the amount of total P in the top layer of some soils in the study region has been reported to vary from 90 to 198 mg kg^{-1} (Nwoke et al., 2004). The relatively high total P content observed in this study might be due to organic matter input from the associated trees and could buffer P in soil solution for uptake by growing crops.

The concentration of total N in the topsoil of the cropping systems varied from 0.201 to 0.390% while 0.212 to 0.319% in the subsoil (Figure 3). The trend was similar to that of total P; similar amounts were measured in the topsoil of the SPC and SCM systems and these were higher than the amount measured in the other systems. The results indicated that soil nitrogen is relatively high in these cropping systems based on a scale for maize production reported by Aderonke and Gbadegesin (2013). The authors had classified soil nitrogen > 0.15% as high, and the total N content of the topsoil in the present study was greater than this even in the control treatment probably due to addition of organic matter (that is plant litter).

Conclusion

Data on soil nutrient concentrations and the apparent stable particle size fractions after two cropping seasons suggest that, these cropping systems have the potential to minimise erosion and reduce soil deterioration. However, the differences in the total N and P, and organic C contents among the cropping systems necessitate further studies to develop appropriate management strategies to optimise the benefits that might be derived from the cropping systems.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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