

EVALUATION OF NUTRIENT STOCKS AND SOME SOIL INDICES OF AGRO-ECOSYSTEM AS AFFECTED BY LONG-TERM MONOCROPPING SYSTEM

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ABSTRACT

Objectives: This study investigates nutrients stock and some soil indices of agro-ecosystem soil as affected by monoculture cropping system (cacao plantation). This was with a view to provide comprehensive understanding of soil nutrient dynamics in the ecosystems due to their different management practices.

Methods: The study was carried out in 0.063 ha sample plots, three each in natural forests and cacao plantations adjacent to each other. In each plot, five core soil samples were randomly collected at two depths (0–15 and 15–30 cm), bulked according to depth, air-dried, sieved through 2 mm sieve, and analyzed for soil physicochemical properties using standard methods. One-way analysis of variance was used to test significant mean differences of the soil properties among cacao plantation and natural forest at probability level ($p \leq 0.05$) at different soil depth.

Results: The results showed that soil physical properties such as particle size distribution, moisture contents, and bulk density; chemical properties such as pH, exchangeable cation, organic carbon, organic matter, phosphorus, and sulfur from natural forest were higher than the soil properties in cacao plantation for both top and subsoil. Soil indices such as soil structural stability index, base saturation percentage, and sodium adsorption ratio were higher in natural forest ecosystem than the soil indices of cacao plantation.

Conclusion: From this study, it can be concluded that long-term monoculture cropping system had significant effect on nutrients stock and soil indices. This subsequently might result in permanent soil degradation and productivity.

Keywords: Cacao, Land use, Plantations, Topsoil, Subsoil.

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INTRODUCTION

Monoculture cropping system is an agro-ecosystem commonly practice and developed in the southwestern region of Nigeria in which trees and shrubs are established and occurs from year to year. Long-term cropping often results in differences in physical, chemical, and biological properties of soil which, in turn, might lead to changes in the functional quality of soil [1,2]. Inappropriate long-term land use and cultivation pattern may result in the depletion of soil organic matter, organic carbon (OC), and subsequently to soil erosion, which might result in permanent soil gradation and productivity decreases [3,4]. Consequently, long-term cropping might also improve soil quality with good management systems [4,5].

Many researchers [3,6-8] have also reported that long-term cropping system can play an important role in improving organic matter stock and maintaining soil nutrients such as total nitrogen (TN) stock which are important for both plants and microorganisms. According to Negasa *et al.* [9], the increase in yields in the past half-century is due to the intensification of soil long-term cultivation practices. From existing literatures, there is, therefore, a need to understand the impacts of long-term cropping system on soil quality to take appropriate measures that can enhance sustainable crop production. Hence, the hereby study investigates variations in nutrients stock and some soil indices of agro-ecosystem soil as affected by long-term monoculture cultivation practices.

METHODS

Study area

The study area is located at the agricultural farm of Ile-Oluji/Okeigbo local government area of Ondo State in Southwest Nigeria. It is situated approximately between latitude 5° 15' and 8° 15' N and longitudes 4° 31' and 6° 00' E. This area lies within the rainforest vegetation zone of Nigeria. In the study catchment, mean annual temperature ranges between 21°C and 29°C and rainfall of 2000 mm was reported using Ondo State Ministry of Environment (2017) meteorological data. During the rainy season, however, the relative humidity of the air is high of about 87% and may be as low as 67%. Monoculture cropping system is commonly practiced and is the dominant farming system for farmers' livelihoods. Cacao plantations are dominated over other land use types in the study catchment. This study catchment was selected as it represents agro-ecosystem conditions having a monocropping land use systems with practices such as diversified soil management practices and non-irrigated fields.

Identification of long-term cropping land use systems

Formal and informal discussions with farmers in the catchment area were used to identify the long-term cropping and their specific soil management practices. On the basis of the farmers' views in the discussion final consensus, long-term cacao dominant cropping was identified and described all their corresponding management practices. Continuous cacao crop (monocropped) has been grown for more than 20 years.

Soil sampling procedure and analysis

Three sample plots, 25 m×25 m each, were established in three different natural forests and three different cacao plantations in the study area. Soil samples were collected in May 2015 in the sampling units at two depths of 0–15 cm and 15–30 cm using soil auger and replicated 5 times. The sampling depth was selected as occurred due to long-term cropping systems, land use types. Considering statistical representativeness and costs of soil analysis, a total of 27 composite soil samples from the sample plots were collected.

The analysis of the soil samples was carried out following the standard laboratory procedures of AACCS. Soil texture was determined using the Bouyoucos hydrometer method [10] and soil dry bulk density by the core method [11]. Soil pH was determined using pH meter combined glass electrode [12], electrical conductivity (EC) using conductivity meter [13], soil OC by the Walkley-Black method [14], available phosphorus by Olsen method [15], and TN by Kjeldahl digestion method followed by distillation and titration [16].

Mineral elements (Ca²⁺, Mg²⁺, K⁺, and Na⁺) were analyzed after extracted in a 1:10 soil/solution ratio using 1 M ammonium acetate at pH 7.0. Ca²⁺ and Mg²⁺ in the extracts were analyzed using atomic absorption spectrophotometer, whereas Na⁺ and K⁺ were determined by flame photometry [17].

Soil indices

Soil structural stability index (SSSI)

SSSI of the cacao plantation and natural forest was estimated using the formula stated by Pieri [18] and Serme *et al.* [19] as follows;

$$SSSI = \frac{1.724 \times \%OC}{\%Clay + \%Silt} \times 100 \quad (1)$$

Base saturation percentage (BSP)

This was determined by the formula stated by Seilsepou and Rashidi [20] as follows;

$$BSP = \frac{Ca^{2+} + Mg^{2+} + Na^{+}}{CEC} \times 100\% \quad (2)$$

Sodium adsorption ratio (SAR)

SAR was determined using the formula stated by Elbasher *et al.* [21] as follows;

$$SAR = Na^{+} / \sqrt{Ca^{2+} + Mg^{2+} / 2} \quad (3)$$

Statistical analysis

Data were analyzed using statistical analytical software package (SAS) version 9.2. One-way analysis of variance was used to test significant mean differences of the soil properties among cacao plantation and natural forest at probability level ($p \leq 0.05$) at different soil depth. Mean values were separated using Duncan multiple range test.

RESULTS AND DISCUSSION

Physical properties of the topsoil (0–15 cm) as affected by long-term monoculture cropping system

There was variability in the soil physical properties at fixed depth of 0–15 cm (topsoil) of the agro ecosystems. Percentage clay, silt, and bulk density of the natural forest were higher than cacao plantation. Percentage sand of natural forest was lower than cacao plantation (Table 1). The variability in the soil physical properties may be attributed to continuous process of clearing, disposing, burning, and leveling of farming fields. These processes, in turn, promote weathering of native rocks, thereby leading to lower SSSI of the topsoil in the cacao (long-term plantation) compared to natural forest.

Mineral nutrients of the topsoil (0–15 cm) as affected by long-term monoculture cropping system

The Ca²⁺, Mg²⁺, K⁺, Na⁺, and Mn²⁺ contents in the topsoil of the agro-ecosystems were highest in natural forest and lowest in the cacao

plantation. There was a significant difference in the Ca²⁺, Mg²⁺, K⁺, and Na⁺ contents of the topsoil among agro-ecosystems (Table 2). Long-term land use and poor agronomic practices have been reported to deplete soil Ca²⁺, Mg²⁺, K⁺, Na⁺, and Mn²⁺ contents, thereby lowering soil productivity. These, therefore, accounted for lower Ca²⁺, Mg²⁺, K⁺, Na⁺, and Mn²⁺ in cacao plantation than in the natural forest.

Soil nutrients of the topsoil (0–15 cm) as affected by long-term monoculture cropping system

The soil pH varied significantly among the agro-ecosystems from 6.93 to 7.03 with the highest in natural forest and lowest in the cacao plantation. The highest percentage of OC and matter was found to be highest in natural forest and lowest in the cacao plantation (Table 3). Available phosphorus, moisture content, and TN were highest in natural forest and lowest in the cacao plantation. Furthermore, EC of the topsoil was highest in natural forest and lowest in the cacao plantation (Table 3). This happened because of intensive farming over a long period of years. This result is in line with the study of [22,23] who stated that land use changes alter percentage soil of OC and matter, available phosphorus, moisture content, and TN [24]. Furthermore, land use management has been among anthropogenic factors contributing depletion of OC and matter, available phosphorus, moisture content, and TN [25].

Soil indices of the topsoil (0–15 cm) as affected by long-term monoculture cropping system

SSSI, SAR, SSSI, and BSP were significantly varied among the agro-ecosystems. The highest SSSI and SAR were recorded from natural forest and the lowest from cacao plantation, while BSP of cacao plantation was higher than natural forest (Table 4). This could be attributed to the effects of long-term land usage leading to the depression and depletion of soil nutrients, thereby influencing SSSI and SAR.

Physical properties of the subsoil (15–30 cm) as affected by long-term monoculture cropping system

The lowest sand contents and bulk density were observed from cacao plantation whereas the highest were observed from the natural forest. The highest clay contents were observed in the cacao plantation and lowest in the natural forest. Both the cacao plantation and forest agro-ecosystems had the same percentage silt contents (Table 5). The percentage physical properties among agro-ecosystems were significant except for the percentage silt content which there was no significant differences among the agro-ecosystems. The highest clay content and lowest sand in cacao plantation may be attributed to

Table 1: Physical properties of the topsoil (0–15 cm) as affected by long-term monoculture cropping system

Physical properties	Cacao (long-term plantation)	Natural forest
Clay%	7.00 ^b	8.67 ^a
Sand%	74.33 ^a	72.00 ^b
Silt%	18.67 ^b	19.33 ^a
Bulk density	0.95 ^b	1.04 ^a

Means with the same letter long the same rows are not significantly different at $P \leq 0.05$

Table 2: Mineral elements of the topsoil (0–15 cm) as affected by long-term monoculture cropping system

Exchangeable bases	Cacao (long-term plantation)	Natural forest
Ca ²⁺	6.82 ^b	7.71 ^a
Mg ²⁺	0.95 ^b	1.09 ^a
K ⁺	0.84 ^b	0.96 ^a
Na ⁺	0.15 ^b	0.17 ^a
Mn ²⁺	0.01 ^b	0.02 ^a

Means with the same letter long the same rows are not significantly different at $P \leq 0.05$

Table 3: Soil nutrients of the topsoil (0–15 cm) as affected by long-term monoculture cropping system

Soil nutrients	Cacao (long-term plantation)	Natural forest
Soil pH	6.93 ^b	7.03 ^a
Organic carbon (%)	2.71 ^b	2.74 ^a
Organic matter	4.43 ^b	5.05 ^a
Electrical conductivity (ds m ⁻¹)	0.02 ^b	0.03 ^a
Available phosphorus	0.04 ^b	0.05 ^a
Moisture content	7.78 ^b	8.94 ^a
Total nitrogen	0.45 ^b	0.51 ^a

Means with the same letter long the same row are not significantly different at $P \leq 0.05$

Table 4: Soil indices of the topsoil (0–15 cm) as affected by long-term monoculture cropping system

Soil Indices	Cacao (long-term plantation)	Natural forest
Soil structural stability index	18.20 ^b	31.38 ^a
Base saturation percentage	43.80 ^a	33.10 ^b
Sodium adsorption ratio	0.10 ^b	0.11 ^a

Means with the same letter long the same rows are not significantly different at $P \leq 0.05$

Table 5: Physical properties of the subsoil (15–30 cm) as affected by long-term monoculture cropping system

Physical properties	Cacao (long-term plantation)	Natural forest
Clay%	27.00 ^a	23.00 ^b
Sand%	62.00 ^b	66.0 ^a
Silt%	11.00 ^a	11.00 ^a
Bulk density	0.85 ^b	0.96 ^a

Means with the same letter long the same rows are not significantly different at $P \leq 0.05$

repeated cultivation due to long-term organic fertilization usage in which such practices aggravate effect of erosion that erodes coarse soil particles and leaves fine soil particles. The variation in bulk density and SSSI among could be attributed to long duration of the cropping system and variability in management practices.

Mineral elements of the subsoil (15–30 cm) as affected by long-term monoculture cropping system

The soil Ca^{2+} , Mg^{2+} , K^+ , and Na^+ varied significantly between agro-ecosystems, with the highest values observed from natural forest and lowest from cacao plantation, respectively. Mn^{2+} content in both cacao plantation and natural forest was the same (Table 6). The significant lower content of Ca^{2+} , Mg^{2+} , K^+ , and Na^+ may be as a result of long-term cropping, type of vegetation, and cover with limited litter addition on soil surface, resulting into little addition of soil Ca^{2+} , Mg^{2+} , K^+ , and Na^+ , exchangeable bases of the subsoil (15–30 cm) as affected by long-term monoculture cropping system

Soil nutrients of the subsoil (15–30 cm) as affected by long-term monoculture cropping system

The soil pH varied significantly among agro-ecosystems from 5.47 to 5.70 with the highest in cacao plantation and lowest in natural forest. OC, available phosphorus, moisture content, and TN of natural forest were higher than that of cacao plantation. Organic matter was highest in cacao plantation and lowest in the natural forest. Both the cacao plantation and natural forest had the same EC. There were statistically significant differences in soil chemical properties among agro-ecosystems (Table 7). The higher pH in cacao plantation could be as a

Table 6: Mineral elements of the subsoil (15–30 cm) as affected by long-term monoculture cropping system

Exchangeable bases	Cacao (long-term plantation)	Natural forest
Ca^{2+}	4.39 ^b	4.88 ^a
Mg^{2+}	0.61 ^b	0.68 ^a
K^+	0.54 ^b	0.60 ^a
Na^+	0.09 ^b	0.11 ^a
Mn^{2+}	0.01 ^a	0.01 ^a

Means with the same letter long the same rows are not significantly different at $P \leq 0.05$

Table 7: Soil nutrients of the subsoil (15–30 cm) as affected by long-term monoculture cropping system

Soil nutrients	Cacao (long-term plantation)	Natural forest
Soil pH	5.70 ^a	5.47 ^b
Organic carbon (%)	1.98 ^b	2.20 ^a
Organic matter	3.40 ^a	3.37 ^b
Electrical conductivity (ds m ⁻¹)	0.02 ^a	0.02 ^a
Available phosphorus	0.026 ^b	0.029 ^a
Moisture content	8.82 ^b	10.19 ^a
Total nitrogen%	0.29 ^b	0.32 ^a

Means with the same letter long the same rows are not significantly different at $P \leq 0.05$

Table 8: Soil indices of the subsoil (15–30 cm) as affected by long-term monoculture cropping system

Soil indices	Cacao (long-term plantation)	Natural forest
Soil structural stability index	11.25 ^a	11.16 ^b
Base saturation percentage	28.15 ^a	20.90 ^b
Sodium adsorption ratio	0.08 ^b	0.09 ^a

Means with the same letter long the same rows are not significantly different at $P \leq 0.05$

result of low leaching of basic cations from topsoil to subsoil exchange complex. Lower OC, available phosphorus, moisture content, and TN of cacao plantation compared to the natural forest occur due to changes in the rates of accumulation of nutrients by the dominated crop, nutrients turnover, and decomposition in the cacao plantation [25,26].

Soil indices of the subsoil (15–30 cm) as affected by long-term monoculture cropping system

The highest SSSI and BSP of the subsoil (15–30 cm) were recorded from cacao plantation and the lowest from natural forest, whereas the lowest SAR was recorded in cacao plantation. However, there were significant differences in SSSI, BSP, and SAR among agro-. The observed higher SSSI and BSP of cacao plantation of the subsoil (15–30 cm) could be attributed to the differences in soil nutrients and exchangeable bases both at the top (0–15) and subsoil (15–30 cm) (Table 8).

CONCLUSION

This study revealed that soil properties, nutrient stocks, and soil indices were significantly varied across the agro-ecosystem. These variations found to be attributed mainly to the difference in nutrients turnover, duration of the cropping system, and variability in management practices.

Therefore, long-term monoculture cropping system had significant influence on nutrient stocks and soil indices by depleting mineral nutrients, soil organic matter, OC, moisture content, available phosphorus, TN, SSSI, BSP, and SAR at the topsoil and subsoil. This subsequently might result in permanent soil degradation and productivity.

CONFLICTS OF INTEREST STATEMENT

Authors declare no conflicts of interest.

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