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Chemical Properties of Soils under Oil Palm Plantation and Fallow in Ekpoma, Edo State Nigeria

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Abstract

Due to the importance of oil palm, it has become one of the most rapidly expanding foods in Ekpoma, Edo State. One of the major constraints to oil palm plantation is the fertility of the soil and soil nutrient distribution. Thus, this study identifies and compares the various chemical properties of soils under oil palm plantation and fallow lands in Ekpoma. The study investigates the key issues of soil chemical properties for sustainable agricultural development in Ekpoma, Edo State. Soil samples were collected from both sites based on slopes (upper, middle, and lower) at 0-15 cm. Soil samples were analyzed in the laboratory for chemical properties and texture. Results showed that for oil palm plantation, the mean soil pH was 5.3, organic carbon (OC) 8.88g/kg, total N 2.10g/kg, available P 1.63mg/kg, Ca 1.47cmol/kg, Mg 0.55cmol/kg, K 0.04 cmol/kg, Na 0.89 cmol/kg, effective cation exchange capacity (ECEC) 3.16cmol/kg, clay 9.47%, silt 4.07% and sand 86.47%. For fallow land, the mean pH was 5.38, OC 23.00g/kg, total N 5.60g/kg, available P 1.14mg/kg, Ca 1.93cmol/kg, Mg 0.93cmol/kg, K 0.08 cmol/kg, Na 0.95 cmol/kg, ECEC 4.10 cmol/kg, clay 10.8%, silt 9.4% and sand 79.8%. Available P, Ca, K, Mg, and clay contents were very low in both soils. Organic carbon, ECEC, Ca, Mg, K, and N was significantly higher in an unfallow land than in a plantation. The decay of the above-ground and root biomass of fallow vegetation and the presence of native leguminous species among the vegetation have been attributed to increases in soil chemical properties to manage soils for sustainable agricultural development.

Keywords: fallow soils, lower slope, middle slope, soil nutrient, upper slope

Introduction

Oil palm *(Elaeis guinensis)* has become one of the utmost, rapidly expanding equatorial foods (USDA, 2011). One of the major constraints to oil palm plantation is the lack of information on soil fertility status and soil management factors (Georges, 2020). Due to the combined effect of physical, chemical, or biological processes that operate with different intensities and at different scales, soils are characterized by a high degree of spatial variability (Priyabrata *et al.,* 2008).

Soil fertility under plantation crops is lower than that under most forest soils. However, the decline rate under plantation cropping is often much lower than annual cropping because of the higher rates of nutrient inputs and possibly because of lower losses compared with annual crop (Hartemink, 2003). Variation in soil properties has also been found to influence soil management and crop production (Fasina, 2005). Variability can also occur due to the type of land use and management (Shittu *et al.,* 2006). Basaran *et al*. (2006) observed that most physical and chemical soil properties show spatial variation by changing the parent material and topographic position.

The decline in soil nutrients under oil palm plantations is mainly due to leaching losses, nutrient immobilization, nutrient loss from plantation via harvested palm fruits, and a destabilization of the oil palm plantation's nutrient cycle result of the loss of biodiversity. Ovie *et al*. (2013) reported slightly acidic pH, increased soil total N, and available phosphorus under oil palm plantation compared to grass vegetation and built-up areas. In oil palm plantation of one to three years old and matured oil palm plantation was previously a secondary, tropical, and peat swamp forest. Seca *et al*. (2014) reported that the soil pH, total N, total K were significantly different, but CEC, P, organic matter, and total carbon showed no significant difference between the three areas. Ufot *et al.* (2016) observed that organic carbon (OC) was significantly affected by land use. Ahukaemere *et al.* (2012) recorded higher OC in fallow and oil palm plantation soils than continuously cultivated soil. However,

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Onyekwere *et al*. (2003) pointed out that low-level organic carbon in a cassava plot reflects continuous cultivation and pedogenic processes.

Okon *et al*. (2017) found that the pH (6.61), organic carbon (43.94g/kg), and total N content (3.26) in oil palm plantation established in 1978 were significantly higher ($p \leq 0.05$) than plantation of 1990 and 2005. Furthermore, available phosphorus (5.14mg/kg) and potassium (0.306cmol/kg) in the plantation of 1990 were significantly higher than those from fallow land. Ogeh and Osiomwan (2012) found that oil palm plantation significantly influenced soil chemical properties due to high-level variation in organic carbon content, total nitrogen, available phosphorus, calcium, magnesium, and potassium compared to the control. Akinola and Olubanjo (2017) reported that the soil pH of cultivated tomato in Akure, Southwestern Nigeria was significantly higher ($P \leq 0.05$) than that of bare soil, which also was significantly higher ($P \leq 0.05$) than that of cultivated oil palm. Olojugba and Fatubarin (2015) found that soil organic matter was highest (2.21%) in soil cultivated with tomato and lowest (1.34%) in soil cultivated with oil palm. Castrignano *et al*. (1998) describe that soil properties' spatial characterization becomes essential when carefully managed for sustainable agricultural development. Therefore, this study aimed to determine and compare soils' properties under oil palm plantation and fallow in Ambrose Alli University Teaching and Research Farm, Main Campus, Ekpoma, Edo State, Nigeria.

Materials and Methods

The study area was in oil palm plantation of Ambrose Alli University Teaching and Research farm, Main Campus Ekpoma, Edo State. Ekpoma lies within latitude 06^0 45'N and longitude 06^0 08'E. The town is a transition zone between the rainforest zone and the savannah zone. It is situated at 332 m above sea level, with its average annual rainfall is about 1500 to 2000 mm with a bimodal rainfall pattern. The rainy season lasts between March and October, with a peak in July and a break in August, and the dry season is between November and March.

The temperature of the area is moderately high throughout the year. There are slight variations in the average daily temperature (ADT). A temperature range of 28°C to 30°C is usually experienced, but the mean annual air temperature of the area is about 28°C. It is also an agricultural town (EADP, 1995).

Soil Sample Collection

Soil samples were collected from a toposequence within the plantation and fallow land; the upper, middle, and lower slopes at a depth of 0 – 15 cm with a probe auger. The samples were thoroughly mixed to obtain a composite sample, after which it was air-dried at room temperature, sieved using a 2mm mesh sieve, and bagged into polyethylene bag in readiness for laboratory analysis.

Laboratory Studies

Soil pH was measured in a 1:1 (soil-water mixture) by glass electrode pH meter (MaClean, 1982); organic carbon was done by wet dichromate acid oxidation method (Nelson and Sommers, 1992), total nitrogen was determined by the micro Kjeldahl method (Bremner, 1982). Available phosphorus was extracted with a Bray II solution and determined by the molybdenum blue method on the technician auto-analyzer as modified by Olsen and Sommers (1990). Potassium and sodium were determined with a flame emission photometer, while calcium and magnesium were determined with an automatic adsorption spectrophotometer (Anderson and Ingram, 1993). ECEC was calculated by the summation of exchangeable base and exchangeable acidity (Anderson and Ingram, 1993).

Data obtained were analyzed statistically using a t-test to test the differences between means at 5% probability level. The variability of soil properties within the profiles' horizons was measured by estimating variability (CV).

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Results and Discussion

The soil chemical properties of the oil palm plantation and fallow land are presented in Tables 1 and 2.

Soil reaction (pH)

The soil pH of the oil palm plantation ranged from 5.27 to 5.33 with a mean of 5.30 (Table 1), while for the fallow land, it ranged from 5.31 to 5.48 with a mean 5.38 (Table 2). The range indicates a strongly acidic reaction for both soils. Soil pH of both oil palm plantation and fallow land was slightly variable (%CV = 0.57 and 1.69). Soil pH was not significantly different between both soils (Table 3).

Organic carbon, Total Nitrogen, and Available phosphorus

Organic carbon ranged from 5.23 to 13.48 g/kg and with a mean of 8.88 g/kg in oil palm plantation (Table 1) and 11.0 to 39.5g/kg with a mean of 23.00 g/kg in fallow land (Table 2). Organic carbon was higher in fallow compared to oil palm plantation. Based on the mean values, organic carbon was above the critical level of 10 g/kg in fallow land but was deficient in oil palm plantation. Organic carbon was highly (62.00%) and moderately (42.29%) variable in fallow and oil palm plantation. This result was accounted for by higher organic carbon in the fallow middle slope and lower plantation slope.

Total nitrogen of oil palm plantation ranged from 1.26 to 3.22 g/kg with a mean of 2.10 g/kg (Table 1), while fallow land ranged from 2.66 to 9.45 g/kg with a mean 5.60 g/kg (Table 2). In line with OC, a higher total N was recorded in the lower slope of oil palm plantation and middle slope of fallow. Total N was highly and moderately variable in fallow and oil palm plantation. The variability was similar to that of organic carbon. Total N of both soils was above the critical level of 1.5 g/kg and therefore classified as sufficient for crop production.

The soil available P of oil palm plantation and fallow ranged from 0.63 to 1.46 mg/kg and 0.69 to 3.07 with mean values of 1.14 and 1.63 mg/kg (Tables 1 and 2). Generally, available P recorded in both soils was very low and, therefore, deficient compared to the critical level of 15 mg/kg for soils in cretaceous sandstones. The very low variability also suggests the very low concentration of available P in both soils.

Organic carbon, N, and P were significantly higher in soils of fallow land compared to oil palm plantation (Table 3).

Exchangeable Cations and ECEC

In oil palm plantation basic cations (calcium, magnesium, sodium and potassium) of the soils ranged from 1.16 to 2.01, 0.46 to 0.71, 0.84 to 0.97 and 0.04 to 0.05 cmol/kg with means of 1.47, 0.55, 0.89 and 0.04 cmol/kg (Table 1). In soils of fallow Ca, Mg, Na and K ranged from 1.67 to 2.32, 0.78 to 1.01, 0.87 to 1.02 and 0.07cmol/kg to 0.09 cmol/kg and mean values of 1.93, 0.93, 0.95 and 0.08 cmol/kg (Table 2). Higher Ca, Mg, and K was recorded in the lower slope of oil palm plantation soils while Na was in the upper slope. But for fallow soils, higher Na, K, and Ca were recorded in the lower slope and Mg in the middle slope. Calcium, Mg, K, and Na were higher significantly in fallow land than oil palm plantation (Table 3). The coefficient of variability reveals that Ca and Mg were low (31.95% and 25.45%), while Na and K were very low (7.86% and 2.250%) in oil palm plantation (Table 1). The fallow soils coefficient of variability of the basic cations was also very low (Table 2). Based on mean basic cations values and established critical levels of 3.8, 1.9, and 0.24 cmol/kg for Ca, Mg and K, the soils are deficient in these elements.

Effective cation exchangeable capacity (ECEC) for oil palm soils ranged from 2.65 to 3.97 cmol/kg with a mean of 3.16 cmol/kg, and for fallow, it ranged from 3.75 to 4.67 cmol/kg with a mean value of 4.1 cmol/kg (Tables 1 and 2) respectively. ECEC was higher in the lower slope in both soils, but the highest and significant ECEC was recorded in fallow compared to oil palm plantation (Table 3). The upper slope to the lower slope of the oil palm plantation soil, the texture ranged from sandy loam to loamy sand, but in fallow land, it ranged from loamy sand to sandy loam (Tables 1 and 2) respectively.

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Table 1. Physicochemical properties of soils in an oil palm plantation in Ekpoma.

Landscape	pH	OC	N	P	Ca	Mg	K	Na	ECEC	Texture
		← g/kg	→	mg/kg	←		cmol/kg		→	
Upper slope	5.53	7.98	1.96	1.15	1.25	0.47	0.04	0.97	2.88	sandy loam
Middle slope	5.30	5.23	1.26	0.69	1.16	0.46	0.04	0.84	2.65	loamy sand
Lower slope	5.27	13.48	3.22	3.07	2.01	0.71	0.05	0.88	3.97	loamy sand
Mean	5.30	8.88	0.21	1.63	1.47	0.55	0.04	0.89	3.16	
SD	0.03	0.42	0.09	1.26	0.47	0.14	0.01	0.07	0.71	
%CV	0.65	47.29	42.85	0.77	31.95	25.45	2.25	7.86	22.46	

SD: Standard deviation
%CV: % Coefficient of variation

Table 2. Physicochemical properties of soils in fallow land Ekpoma.

Landscape	pH	OC	N	P	Ca	Mg	K	Na	ECEC	Texture
		← g/kg	→	mg/kg	←		cmol/kg		→	
Upper slope	5.48	11.00	2.66	1.33	1.78	0.78	0.07	0.87	3.75	Loamy sand
Middle slope	5.34	39.05	9.45	1.46	1.67	1.01	0.08	0.97	3.89	sandy loam
Lower slope	5.31	19.00	4.62	0.63	2.32	1.00	0.09	1.02	4.67	sandy loam
Mean	5.38	23.00	5.60	1.14	1.93	0.93	0.08	0.95	4.1	
SD	0.09	1.44	0.35	0.45	0.35	0.13	0.01	0.07	0.49	
%CV	1.69	62.83	62.40	39.16	17.96	13.94	9.92	7.67	12.09	

SD: Standard deviation
%CV: Coefficient of variation

Table 3. Comparison of soil chemical properties in soils of oil palm plantation and fallow land in Ekpoma.

Landscape	**pH**	**OC**	**N**	**P**	**Ca**	**Mg**	**K**	**Na**	**ECEC**
		←g/kg	**→**	**mg/kg**	**←**		**cmol/kg**		**→**
Fallow (mean)	5.38	23.00	5.60	1.14	1.93	0.93	0.08	0.95	4.1
Oil palm (mean)	5.30	8.88	0.21	1.63	1.47	0.55	0.04	0.89	3.16
T-test	**NS**	*	*	*	*	*	*	*	*

NS: Not significant
*: Significant ($P<0.05$)

Correlation of Soil Properties

In soils of oil palm plantation, significant positive correlations between OC and N (*r = 1.000**), P and CEC (*r = 1.000**), Ca and CEC(*r = 0.998**), Mg and K (*r = 0.999**) were observed (Table 4). Non-significant negative correlations between pH and OC, N, P, exchangeable bases, and CEC were observed and between Na and exchangeable bases (K, Ca, and Mg). Non –significant correlation between P and exchangeable bases, CEC, and N and exchangeable bases and P were observed. In soils of fallow land, significant positive correlations between OC and N (*r = 1.000***), P, and Ca (*r = 1.000***) were observed (Table 5). Non-significant negative correlations of pH with OC, N, P, exchangeable bases, and CEC were observed. Phosphorus negatively correlated with exchangeable bases (Na, Mg, and K) and CEC. Non – significant correlation between P and exchangeable bases and CEC also existed. Organic carbon correlated positively with P and Mg, K, and Na but negatively affected CEC and Ca.

Exchangeable cations and ECEC of both soils were very low and below established critical levels. The low cations and ECEC values of soils obtained across both landscape agree with the works of Ogeh and Ukodo (2012). They noted that low and variable character of cation exchange capacity (CEC) within humid forest zone could be as a result of the domination of low activity components such as kaolinite, Fe, and Al (hydroxides) as a result of the higher degree of weathering of the parent

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rock. Ovie *et al*. (2013) reported slightly acidic pH, increased soil total N, and available P under oil palm plantation in Edo State. The findings are still at variance with this present study due to low P and strongly acidic pH. Compared to palm plantation, the higher organic carbon in the fallow agreed with Ufot *et al*. (2016). They observed that organic carbon was significantly affected by land-use type with fallow land (10.30 g/kg) being the highest followed by oil palm plantation (10.10 g/kg). Agboola *et al*. (2017) reported that the conversion of natural forest into monoculture plantations of cocoa and oil palm resulted in a decline (27.3% and 0.9%) of soil organic carbon. Michel *et al*. (2010) reported a significant reduction in organic carbon in plantations and mixed crop fields than natural forests. They attributed this to a lack of understory vegetation associated with agricultural lands.

Higher organic carbon content in fallow land was probably due to the accumulation of organic matter over the soil surface years. Total nitrogen followed a similar trend with organic carbon. A similar result was observed by Okon *et al*. (2014), who recorded increases in total nitrogen with an associated increase in organic carbon. However, organic carbon and total N in oil palm plantation soils were not similarly high.

Table 4. Matrix of Correlations for soil properties in oil palm plantation.

Soil Parameters	OC	N	P	Ca	Mg	K	Na	EC EC
pH	-.291	-.266	-.431	-.508	-.560	-.589	.917	-.449
OC		1.000*	.989	.972	.956	.945	.115	.986
N			.984	.965	.948	.936	.141	.981
P				.996	.989	.983	-.035	1.000*
Ca					.998*	.995	-.122	.998*
Mg						.999*	-.182	.992
K							-.217	.987
Na								-.055

*: Significant (P<0.05)

Table 5. Matrix of Correlations for soil properties in fallow land Ekpoma.

Soil Parameter	OC	N	P	Ca	Mg	K	Na	ECEC
pH	-.596	-.599	.517	-.506	-.979	-.937	-.986	-.739
OC		1.000**	.379	-.391	.746	.277	.453	-.101
N			.376	-.388	.749	.280	.457	-.098
P				-1.000**	-.333	-.784	-.653	-.959
Ca					.321	.776	.643	.955
Mg						.846	.932	.587
K							.982	.928
Na								.841

*: Significant (P<0.01)

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Conclusion

Fallowing brings about restoration of soil fertility and soil properties improvement, especially to soil nutrients such as organic matter and total N. The decay of above-ground and root biomass of fallow vegetation and the presence of native leguminous species among the vegetation have been attributed to these increases.

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