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Variability of Soil Properties Across Planted Fallows under Earthworm Casts on an Alfisols in South Western Nigeria

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Abstract: An investigation was conducted on a ten year old fallowed plots consisting of two planted tree legumes (*Glyricidia* spp (GF) and *Leuecaena* spp (LF)) and grassland (GLF) on an Alfisol. The aim of the investigation was to assess the variability of soil properties under earthworm casts under each of these fallows, isolate soil factors that may contribute to the length and weights of two earthworm types (*Hyperiodrilus africanus* (Beddard) and *Eudrilus eugeniae* (Kinberg)). The degree of variability was evaluated using the coefficient of variation (CV), while the analysis of variance (ANOVA) was used to find the differences between soil properties under each of these fallowed plots. The stepwise multiple regression analysis (SMRA) was used to isolate soil properties that may contribute to the occurrence of earthworms types, lengths and weights. Results showed that the CV's of the soil properties varied widely and the most variable were: available P (GF/LF), MN, Fe, Cu and moisture contents (GF/GLF). Others were CEC (GF), Ca (LF) and Mg and Zn (GLF). Furthermore, results showed that the soil properties were sub-optimal under all the fallowed plots, but were significantly different ($p<0.05$) across ecosystems. Of all the soil properties considered, only the cation exchange capacity (CEC), total N, Cu and soil moisture content significantly ($p<0.05$) affected the types of earthworms, their lengths and weights with coefficient of determinations (R^2) of 0.40, 0.41 and 0.54 respectively.

Key words: Alfisol · Basement complex rocks · Earthworm · Variability · Vegetation

INTRODUCTION

Even on the same soil types with same vegetation, earthworms are much more frequent in some soils than in others. Close observation of such soils often do not show any visible difference in the nature of the soil. Earthworms are very important in soils and constitute a major component of many terrestrial ecosystems [1, 2] and usually dominate the biomass of soil invertebrates. They function as ecosystem engineers by structuring the environment of the soil community in non-acidic soils [3, 4]. When earthworms burrows, they cast and mix litter of soil (bioturbation) which influences soil aggregate stability, structure and improves the soil water infiltration rates, promotes the aeration of deeper soil layers and recycle soil nutrients [1, 2, 5, 7-9]. In addition, earthworms modulate soil physical and chemical properties and also affect biological processes such as organic matter mineralization [10-14].

Nutrient depletion of soil is a particular problem for small holder agriculture developing countries, where much grain-legume production occurs and many farmers cannot afford to use inorganic fertilizers. Sanchez [15, 16] reported that average annual nutrient depletion rates across African countries is about 22 kg N/ha, 2.5 kg P/ha and 15 kg K/ha. Sprent and Parsons [17] discussed the importance of woody tree legumes in forestry. In tree fallows, *Sesbania* spp., *Leucanea* spp., *Tephrosa* spp., *Crotolaria* spp., *Glyricidia* spp or *Cajanus* spp are usually inter-planted into arable crops (i.e. maize) and allowed to grow as dry season or longer-term fallows. The wood is harvested and the N-rich leaves, pods and green

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stem material are incorporated into the soil just before the rainy season [2, 5, 7, 8]. Several authors have reported that earthworms may affect soil fertility and plant growth in grassland [2, 5, 7, 8]. Furthermore, thier abundance can be affected by various soil properties [1]. There is sparse information on the assessment of the spatial variability of soils under earthworm casts on three contrasting ecosystems (or vegetal types): (grassland fallow (GLF), *Leuceanea* spp fallow (LF) and *Glyricidia* spp fallow (GF)) on an Alfisol in south Western Nigeria.

MATERIALS AND METHODS

Study Site: The investigation was conducted within the University of Ibadan (UI), Nigeria (Latitudes 7º15' and 7º30 and Longitudes 3º45' and 4º0'E) in the south western part of Nigeria. It is situated in the Humid Forest agro-ecological zone. Soils under this vegetation were reported to have developed from the Basement Complex Rocks [18] and classified as an Alfisol. Within UI, three ecosystems were chosen: (i) grassland fallow, (ii) Glyricidia spp and (iii) Leucanea spp fallows. The most common trees under the grassland fallows are *Ceiba petandra Linn.*, *Albizia adianthifolia Durazz.*, *Terminalia ivorensis A.chev., Bapphia nitida Lodd. and Elaeis guinensis L.* The grasses commonly seen are *Panicum maximum*, *Pennisetum sp* and *Imperata cylindrical*. The two tree legume fallow have been established for over 10 years. The mean climatic data for the UI between 1991 and 2001 is presented in Table 1.

Soil Sampling and Laboratory Analyses: From these three ecosystems, 36 mini-pits of dimension 70 cm x 70 cm in width and 70 cm depth were excavated: 12 (*Glyricidia* spp fallow (GF)), 13 (*Leucaena* spp fallow (LF)) and 11 (grassland fallow (GLF)). Soil samples were then collected from these pits at intervals of 0-15 cm; 15-30 cm and 30-70 cm, bagged, labeled and taken to the laboratory for analyses. Subsequently, they were later air-dried, crushed and passed through a 2mm sieve for routine physical and chemical analysis. (Soil samples were analyzed for the following variables: texture [19], pH (1: soil, water ratio), organic carbon [20], total N [21], available P [22]. Exchangeable bases (K, Ca and Mg) were extracted with 1N buffered NH_4OAc at pH 7. The K content was determined by flame emission spectroscopy, while Ca and Mg were determined by the atomic absorption spectroscopy [23]. The following micronutrients were determined after being extracted with 0.1 N HCl: Fe, Mn, Zn and Cu. At about 0630 hrs every morning, surface soils under each of these vegetations were neatly excavated using a shovel to a depth of 20 cm. Soils collected were placed on plastic trays where the earthworms were isolated, weighed, length determined and then subsequently identified.

Statistical Analysis: The following summary statistics were used: mean (x), standard deviation (*sd*) and standard errors (SE) were determined for each of the soil property under each of the vegetation types. The variability of each property was measured by coefficient of variation (CV) expressed as:

Table 1: Mean Climatic Data for the University of Ibadan, (1991-2001)

	Total rainfall(mm)	Total pan evaporation (mm)	Mean wind speed (km/hr)	Solar radiation (mJ/m2/day)	Temperature Min.	Temperature Max.	Temperature Mean	Relative humidity Min.	Relative humidity Max.	Relative humidity Mean	No. of rainy days
Jan	1.6	115.0	3.0	12.4	22.1	33.3	27.7	43	96	70	1
Feb	33.8	150.1	4.3	14.4	22.6	34.7	28.7	40	96	68	4
Mar	75.0	159.4	5.4	18.5	22.5	34.2	28.4	47	96	71	7
Apr	118.4	136.7	3.9	15.5	23.2	32.3	27.7	60	97	78	12
May	114.1	199.2	4.5	15.9	22.1	30.2	26.2	59	94	76	10
Jun	101.6	112.1	5.1	16.3	23.1	30.6	26.8	60	97	79	15
Jul	227.2	95.3	5.0	13.4	22.3	28.9	25.6	65	98	81	15
Aug	170.6	75.0	4.9	10.7	22.0	28.1	25.1	71	98	84	23
Sep	331.7	72.0	4.4	14.6	27.0	28.1	25.4	71	98	85	20
Oct	148.4	80.9	3.9	17.6	22.3	30.0	26.2	62	98	80	13
Nov	0.0	117.8	3.8	10.9	21.1	32.9	27.0	34	98	66	0
Dec	0.0	100.7	3.9	14.1	22.9	33.2	28.1	39	98	69	0
Total	1322.4	1414.42	4.34	14.5	22.477	31.37	26.9	54.3	97	76	120

$$CV = \frac{sd}{x}.100\%$$

The CV's were grouped into three least variable (<15%), moderately variable (15-35%) and extremely variable (>35%) [24]. Thus, the higher the CV, the more variable the soil property [25, 26]. Afterwards, data were subjected to the analysis of variance (ANOVA) using the general linear model procedure (PROC GLM) of the Statistical Analysis Systems [27]. The objective was to find out if there are significant differences between the soil chemical properties, soil moisture contents (MC), earthworm weights and lengths under each of these vegetation types. In order to isolate which of the above mentioned soil properties significantly relates to the types of earthworms occurrence, as well as weights and lengths of earthworms, the PROC STEPWISE procedure of the Statistical Analysis Systems [27] was used. Also, the data was subjected to the correlation procedure (PROC Corr) of the Statistical Analysis Systems [27].

RESULTS AND DISCUSSION

The texture of the soils varies between loamy sand (GF) and sand (LF and GLF) (Fig. 1). The mean separation of the differences between the soil properties across the three ecosystems are presented in Table 2. Though significant, the soil pH vary between 5.76 (GF) and 6.92 (LF). The contents of the soil organic carbon (OC), total N, available P (av.P), exchangeable cations (K, Ca, Mg and Na) were low across these ecosystems, though significant differences could be observed in some cases across these ecosystems (Table 2). The content of Fe was observed to be high but decreases generally with soil depth. It has been observed that the inherent fertility of most West African soils is closely related to the parent material [28-30]. Smyth and Montgomery [18] reported that the soils of south western Nigeria largely developed from the Basement Complex rocks of the Pre-Cambrian age; hence, such soils tend to be generally low in nutrients compared to those developed from the sedimentary rocks. Intensive leaching and weathering of these soils over the years have resulted in acidic reaction and low inherent fertility with regard to major and micro-nutrients [31]. It has been observed that the inherent fertility of most West African soils is closely related to the parent material [32, 33]. Smyth and Montgomery [18] reported that the soils of south western Nigeria largely developed from the Basement Complex rocks of the Pre-Cambrian age, hence, such soils tend to be generally low in nutrients compared to those developed from the sedimentary rocks. Intensive leaching and weathering of these soils over the years have resulted in acidic reaction and low inherent fertility with regard to major and micro-nutrients [32].

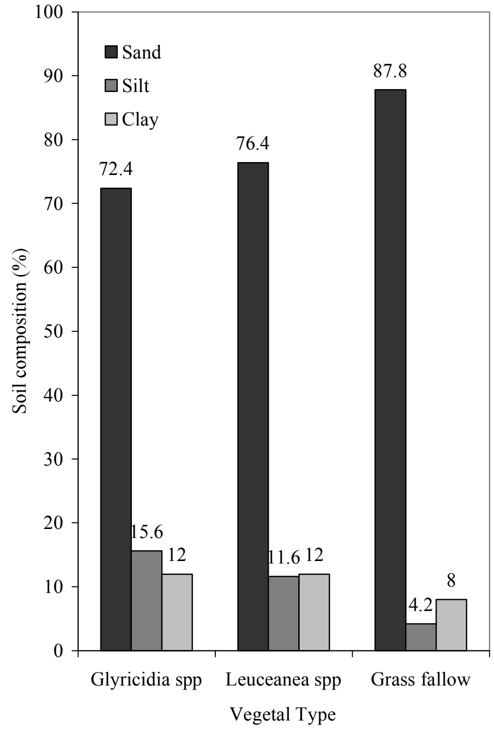

Fig. 1: Mean sand, silt and clay contents of the soils under the three fallow plots

Table 2: Characteristics of soils under different vegetation with earthworms

Soil characteristics	*Leuceanea spp*	Grassland	*Glyricidia spp*
pH (1:2, soil water ratio)	6.92a (0.11)†	6.23b(0.32)	5.76b(0.19)
Organic carbon (%)	1.89a(0.30)	1.37a(0.29)	1.42a(0.12)
Total N (%)	0.16a(0.10)	0.12a(0.03)	0.12a(0.07)
Moisture content (%)	6.63ab(0.91)	9.70a(1.44)	4.73b(0.60)
Exchangeable cations (cmol/kg)			
Ca	0.04a(0.01)	0.05a(0.004)	0.04a(0.001)
Mg	0.19a(0.01)	0.16a(0.02)	0.11b(0.005)
Na	0.04a(0.002)	0.05a(0.01)	0.04a(0.002)
K	0.05a(0.002)	0.05a(0.01)	0.03b(0.001)
CEC	0.48a0.02(0.90)	0.40a(0.04)	0.38a(0.03)
Exchangeable acidity	0.13a(0.0)	0.08a(0.001)	0.13a(0.03)
Extractable micronutrients			
Mn	109a(5.70)	63b(8.29)	38c(3.68)
Fe	230b(20.59)	341a(53.28)	242b(26.68)
Cu	1.52b(0.05)	1.90ab(0.22)	2.14a(0.16)
Zn	25.78a(1.13)	28.60a(7.76)	20.99a(0.86)
Base saturation (%)	79.00a(1.28)	75.90a(3.09)	65.87b(4.54)

†means with same letter are not significantly different at 5% Duncan multiple range test (DMRT); Numbers in parenthesis are the standard errors

Table 2: The coefficient of variation of soil properties under different vegetal cover

Vegetal types	Least variable <15%	Moderately variable 15-35%	Extremely variable >35%
Glyricidia spp	pH, Ca, Mg, Na, Zn	K, total N	Av.P, Exh. Acidity (EA), Mn, Fe, Cu, CEC, Moisture content (MC), Base saturation (B.sat)
Leuceanea spp	pH, Na, Cu, B.sat	Na, Mn, Zn, Mg, K, Fe, CEC, total N	OC, Av.P, Ca, MC
Grassland	EA, B.sat,	pH, Ca, Na, K, CEC, total N	OC, Av.P, Mg, Mn, Fe, Cu, Zn, MC

Table 3: Results of stepwise multiple regression analysis of soil chemical properties and types of earthworm under three vegetation types, in Nigeria

Source of variation	DF	Sum of squares	Mean square	R^2=0.40 F Value	C(p)=-5.2658† Pr>F
Model	2	3.57424	1.78712	10.93	0.0002
Error	33	5.39798	0.16358		
Corrected Total	35	8.97222			

Variable	Parameter estimate	Standard error	Type II sum of square	F value	Pr>F
Intercept	2.95230	0.31238	14.61110	89.32	<0.0001
Cu	-0.25557	0.12376	0.69752	4.26	0.0469*
CEC	-2.40671	0.71351	1.86110	11.38	0.0019**

† C(p)= mallows, *= significant at 5% and **=, significant at 1%.

Table 4: Results of stepwise multiple regression analysis of soil chemical properties and weight of earthworm under three vegetation types, in Nigeria

Source of variation	DF	Sum of squares	Mean square	R^2=0.41 F Value	C(p)=-5.076† Pr>F
Model	2	348.9578	174.47879	11.49	0.0002
Error	33	501.06798	15.18388		
Corrected Total	35	850.02556			

Variable	Parameter estimate	Standard error	Type II sum of square	F value	Pr>F
Intercept	-3.39815	3.00961	19.35746	1.27	0.2670
Cu	2.30333	1.19241	56.65603	3.73	0.0620^{ns}
CEC	24.73558	6.87434	196.59183	12.95	0.0010**

† C(p)= mallows, ns= not significant at 5% and **=, significant at 1%.

In terms of the variability in the soil properties, results showed that from the three ecosystems, the least variable soil properties were pH, Na, Zn and the Base saturation (Bsat). In addition to these, other least variable soil properties were Ca, Mg and K (GF), Mn, Cu and Zn (LF) and exchangeable acidity (GFL) (Table 2). There is a very wide range in the degree of variability of soil properties across these ecosystems, thus the assumption that soils within a farmland are of uniform properties could be misleading. Thus, in a landscape, there is the natural variation, which is often compounded by additional impositions by man, through various forms of use and/or management practices. These have implications for crop production, since soil variability will lead to variability in crop performance and yield. When the classification of Wilding and Dress [26] and Akinbola *et al*. [23] were used, the least variable soil properties were pH and Na (GF and LF), Ca, Mg, Zn (GF), base saturation (LF and GLF), Cu (LF) and exchangeable acidity (EA) (GLF) (Table 2). These results are in agreement with the observations of Fragoso *et al*. [33]. It is also interesting to observe that under the three fallows total N and exchangeable K were moderately variable, while the soil moisture contents, organic carbon (OC) and available P (avP) were extremely variable (Table 2).

The two species of earthworms identified in these ecosystems were *Hyperiodrilus africanus* (Beddard) and *Eudrilus eugeniae* (Kinberg) and this was in agreement with the findings of 34 and 35. The weights and lengths of the earthworms under each ecosystem are presented in Fig. 2. Though within an ecosystem, there were no significant differences between the mean weights and lengths of earthworm, however, *Hyperiodrilus africanus* (Beddard) were heavier and longer than *Eudrilus eugeniae* (Kinberg) (Fig. 2). The results of multiple linear step-wise regressions are presented in Tables 3-5 on earthworm occurrence/types, weights and lengths. The coefficients of determinations (R2) were 0.40, 0.41

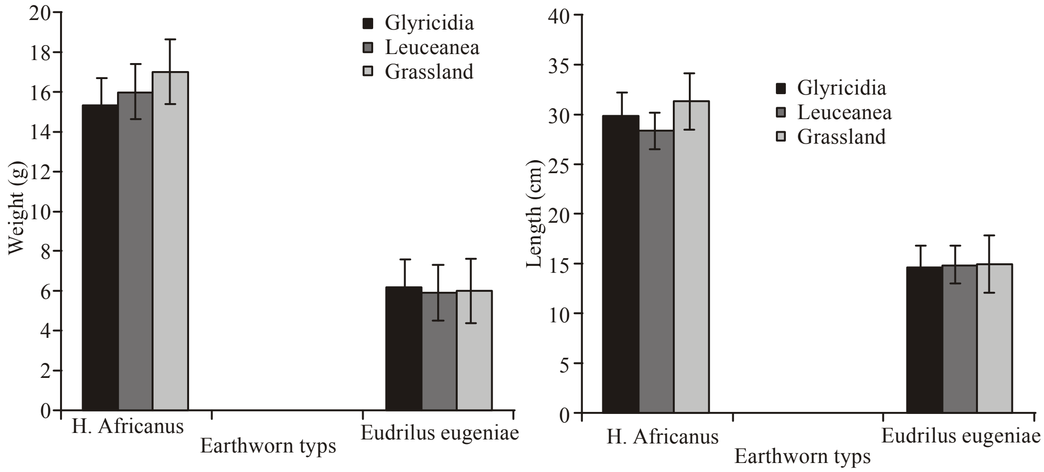

Fig. 2: Weight and length of two species of earthworms under three vegetal types in Nigeraia

Table 5: Results of stepwise multiple regression analysis of soil chemical properties and length of earthworm under three vegetation types, in Nigeria

				R^2=0.54	C(p)=-3.3732†
Source of variation	DF	Sum of squares	Mean square	F Value	Pr>F
Model	4	1167.19008	291.79752	8.95	<0.0001
Error	31	1010.86631	32.60859		
Corrected Total	35	2178.05639			
Variable	Parameter estimate	Standard error	Type II sum of square	F value	Pr>F
Intercept	-0.49788	4.51062	0.39730	0.01	0.9128
TN	-36.17740	14.99688	189.76009	5.82	0.0220*
Cu	4.68225	1.87447	203.46350	6.24	0.0180**
CEC	36.46345	10.19233	417.34986	12.80	0.0012**
MC	0.60937	0.28400	150.12553	4.60	0.0598*

† C(p)= mallows, *=significant at 5% and **=, significant at 1%

Table 6: Correlation coefficients between the soil properties and earthworm weights, lengths and types under three ecosystems

	Glyricidia spp			*Leucanea* spp			Grassland		
	Weight	Length	Type	Weight	Length	Type	Weight	Length	Type
pH	-0.706**	-0.704**	0.706**	ns	ns	ns	ns	ns	ns
OC	ns	ns§	ns	ns	ns	ns	ns	ns	ns
TN	ns	ns	ns	ns	ns	ns	ns	ns	ns
Av.P	ns	ns	ns	ns	ns	ns	ns	ns	ns
Ca	ns	ns	ns	ns	ns	ns	0.796**	0.775**	-0.776*
Mg	ns	ns	ns	ns	ns	ns	0.904**	0.905**	-0.900**
Na	ns	ns	ns	ns	ns	ns	0.722**	0.700**	-0.701**
K	ns	ns	ns	ns	ns	ns	0.799**	0.770**	-0.771**
EA				ns	ns	ns	ns	ns	ns
Mn	-0.579*†	-0.576*	0.574*	ns	ns	ns	ns	ns	ns
Fe	ns	ns	ns	ns	ns	ns	ns	ns	ns
Cu	-0.601*	0.599*	-0.602*	ns	ns	ns	ns	ns	ns
Zn	ns	ns	ns	ns	ns	ns	ns	ns	ns
CEC	0.632*	0.631*	-0.633*	ns	ns	ns	ns	ns	ns
MC	0.660**	0.661*	0.660	ns	ns	ns	ns	ns	ns
Bsat	-0.594*	-0.596*	0.596*	ns	ns	ns	ns	ns	ns

† * significant at 5%, **=significant at 1%.; ns=not significant

and 0.54, respectively. The following soil properties, extractable Cu, the cation exchange capacity (CEC), total N and the soil moisture contents (MC) were observed to be significantly related to the types/occurrence, weight and length of the two types of earthworms. This suggests that soil properties that may be controlling types of worms along with their weights and lengths may extractable Cu, cation exchange capacity (CEC), total N and the soil moisture contents. The results of the correlation coefficients between soil properties and each of these fallows- GF, LF and GLF- (Table 6) showed that significantly negative and positive associations were observed between the weight, length and types of earthworms and the following soil properties (pH, Mn, Cu, CEC and Bsat) under the GF. In addition, significant positive associations were also observed between the weight, length and types of earthworms and the soil moisture contents. However, under the GLF, significant positive associations were only observed between the afore variables and the exchangeable cations (K, CA, Mg, Na) and significant negative associations between types of earthworms and the soil exchangeable cations. It is interesting to observe that none of the soil properties had any associations with the weight, length and types of earthworms. Auerswald *et al.* [36] reported that of all the soil properties considered to influence the population and activity of geophagous earthworms, only the soil moisture content was found to be significantly correlated ($p<0.05$). This finding was in agreement with the results of the SMRA and the correlation analysis in this study. In addition, results showed that the soil acidity significantly affected the weights ($r=-0.706^{**}$) and lengths (-0.704^{**}) of the two species of earthworms in the GF fallow plot. Klok *et al*. [37] reported that the soil acidity significantly affected the population of epigeic earthworm's species- *Lumbricus rubellus* (Hoffm.) in temperate soils that have abundant grasslands.

CONCLUSIONS

The present study showed that the soil nutrient contents under the three fallowed plots were sub-optimal and there were significant differences in pH, soil moisture contents (MC), exchangeable K and extractable micronutrients (Fe, Mn and Cu). The occurrence, lengths and weights of two earthworms-*H. africanus* and *E. eugeniae* were significantly influenced by soil moisture contents (MC), extractable Cu, CEC and total N contents of the fallowing plots. Large variability in terms of CV's were observed for the following soil properties: MC, organic carbon and available Phosphorous (Av.P). In addition,

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