Abundance of earthworms in Nigerian ecological zones: implications for sustaining fertilizer-free soil fertility

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The abundance of earthworms in the ecological zones in Nigeria has been determined and the possibility of earthworm functions replacing both mechanized land preparation and organic fertilizers discussed. The most abundant earthworms, comprising 62 % of the population, were the advantageous solid-wormcast makers. Mixed Leguminous Wooded Savanna had the highest earthworm density (1.50 million worms/ha), while Wooded Savanna had the lowest (0.23 million worms/ha). Coastal Forest and Mangrove (0.51 t/ha) had the highest earthworm biomass and *Afziela* Savanna/Semi-Deciduous Forest (0.03 t/ha) had the least. A new soil impact index (SIINDEX) is introduced, which simultaneously incorporates both earthworm biomass and density. The highest SIINDEX was from Mixed Leguminous Wooded Savanna (0.72) and the lowest from *Afziella* Savanna/Semi-Deciduous Forest (0.11). Forests with SIINDEX less than 0.2 should be regarded as endangered, because their earthworm functions are too low to accomplish significant leaf-litter breakdown and recycling. We suggest that if the illegal annual bush burning is prevented, the soil surface will be naturally mulched, earthworms protected, and by their function in the soil, the need for soil mechanization and fertilization could be replaced by earthworms to produce natural foods.

Key words: Annelida, Oligochaeta, leaf litter breakdown, soil fauna, SIINDEX.

INTRODUCTION

It is now universally accepted that earthworms are important in the soil. Yet their abundance and distribution in Nigeria are little known. The few publications related to this subject have been based on local, or at best, a few regional surveys, (Nye 1955; Madge 1966, 1969). These authors studied earthworms around Ibadan (southeastern Nigeria). Hauser (1994), in field experimental studies at the International Institute for Tropical Agriculture (IITA), Ibadan, Nigeria, discussed the role of earthworms under alley farming. (Alley farming involves planting leguminous shrubs along hedgerows of a farm as protection against strong winds and heavy raindrops. During the next planting season, the shrubs are ploughed into the soil, thus supplying more nutrients into the soil.) Tian *et al.* (1992, 1993, 1995), also from IITA, Ibadan, studied the biological effects, decomposition and nutrient release of plant residues with contrasting chemical compositions under humid tropical conditions. They also studied the effects of earthworms and millipedes in these processes. None of these studies has, however, shown the pattern of distribution of earthworms in the very diverse ecological zones of Nigeria.

Eighteen ecological zones are recognized in Nigeria (Areola 1982) (Fig. 1). Among them are Coastal Forest and Mangrove, Deltaic Swamp Forest, Swamp Forest/Wooded Savanna, Secondary Forest, Mixed Leguminous Wooded Savanna, *Isoberlina* Savanna, *Afziela* Savanna/Semi-Deciduous Forest, Plateau Grass Savanna, Wooded Savanna, Mixed and Wooded Savanna (Areola 1982). These are diverse in their rainfall regime, soil moisture regime and dominant vegetation that ultimately produces organic material for earthworms. The type of dominant vegetation of an ecological zone is important to earthworm survival and performance, as is the variety of the food material available. Thus, where the available vegetation is readily digestible and available, earthworms are expected to thrive. Ultimate interest lies not so much in the earthworm abundance *per se,* but especially in the role earthworms play in affecting soil fertility.

Because of the agricultural implications of earthworm abundance in any ecological zone, it is

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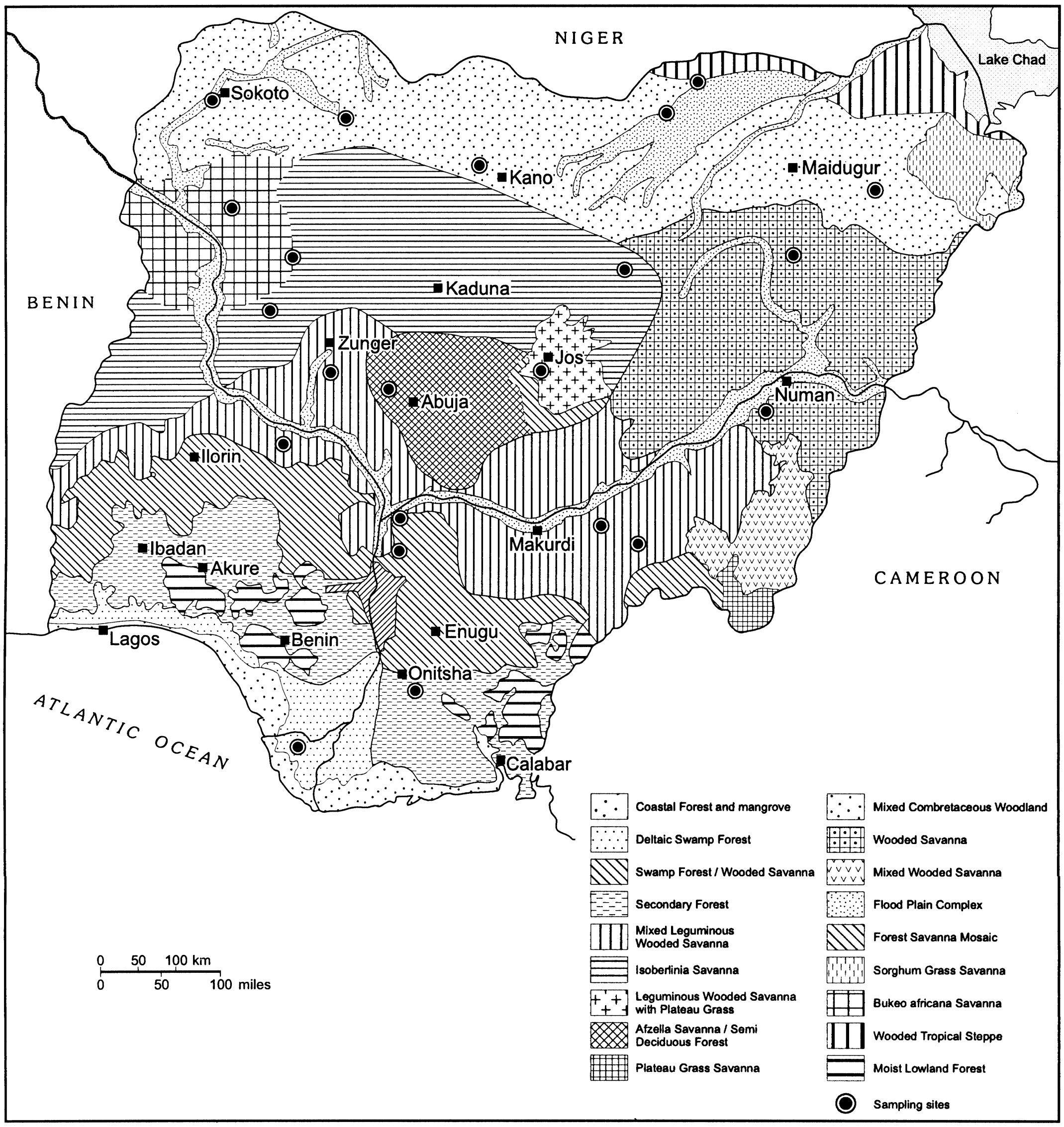

Fig. 1. Map of Nigeria showing the ecological zones and a few of the sampling locations. Adapted from Areola (1982).

important to have an estimate of their population sizes. This in turn indicates the level of an earthworm workforce available to work the soil. Today, there is a growing evidence that xenobiotics introduced into the soil in the form of, for example, fertilizers, insecticides, herbicides are harmful to soil productivity and non-target organisms (Efroymson *et al.* 1997a,b). Because medical experts warn against consumption and bioaccummulation of agrocides and other agrochemicals in humans, agricultural experts are daily exploring alternatives for sustaining soil fertility without the use of inorganic fertilizers. Withdrawal of inorganic fertilizers means higher dependence on the role of soil animals to sustain soil fertility. Earthworms are of prime importance among such soil animals.

These considerations necessitate the need to have an estimate of earthworm abundance in the soil. The objective of our study was to determine population density and biomass of earthworms in the major ecological zones in Nigeria so that in the future such information could be used in conservation and production strategies.

MATERIALS & METHODS

Eighty-two locations covering the major ecological zones in the country were sampled for earthworms (Fig. 1). Because of the desire to create a database of earthworms based on sampling locations that do not exceed 100 km direct distance from one another, the number of sampling locations was not equal for all the ecological zones. Information on the geographical and climatic character of the zones have been published by many authors and organizations, for example Barbour *et al.* (1982) and the Federal Department of Surveys (1978).

Ten replicate quadrats, 0.5 × 0.5 m each, and about 0.5 km apart, were dug to 30 cm depth around each sampling location. The earthworms from each quadrat, collected by digging and hand-sorting, were stored in a separate container, killed and preserved in formo-acetic alcohol (F.A.A.). They were identified using the original descriptions (Kinberg 1867; Beddard 1890, 1891, 1897; Michaelsen 1891, 1892, 1902, 1913, 1915, 1937; Clausen 1963, 1965, 1967; Sims 1965, 1971, 1987; Segun 1976a,b, 1977, 1978, 1980; Segun & Owa 1990; Owa 1992, 1994). Their wet masses were recorded to 1 decimal place on a toploading Mettler balance. Statistical analyses were done using the computer software Statistical Package for Social Sciences (SPSS v.10.0.1; SPSS Inc., 1999). Differences in the abundance of the earthworms in the different zones were subjected to analysis of variance (ANOVA). Separation of means was by the Duncan multiple-range tests.

It is a common observation that there is very wide variation in size and relative density among the earthworm species. There is also a concomitant observation that larger earthworms have lower densities and vice versa. Furthermore larger earthworms burrow deeper and transport nutrients deeper into the soil, while smaller earthworms, living closer to the surface, are better at leaf litter breakdown. For these reasons, using either of earthworm density or biomass separately as an indicator of their impact on the soil does not allow for valid comparisons of different habitats. A more robust and pertinent index of impact was therefore developed and is hereby proposed, called the earthworm soil impact index (SIINDEX), which is a function of both earthworm biomass and density, SIINDEX = f(biomass, density). By induction SIINDEX is hereby defined as the square root of the product of the earthworm density (in million worms/ha) and earthworm biomass (in t/ha). That is,

$$\text{SIINDEX} = \sqrt{\text{density} \times \text{biomass}}.$$

This means that by its nature SIINDEX incorporates the effects of both biomass and density of earthworms on the soil. For SIINDEX, it is preferable to measure density in million worms/ha since earthworm population sizes in the soil are commonly in that order of magnitude. Measuring biomass in t/ha allows comparison of earthworm impact with that of the inorganic fertilizers that also are commonly applied to the soil in t/ha. SIINDEX was calculated for the earthworms, in addition to regular densities and biomass.

RESULTS

The earthworms and their frequencies of occurrence in the ecological zones are shown in Table 1. The most frequent earthworms in the ecological zones were *Ephyriodrilus afroccidentalis,* (29 records) *Eudrilus eugeniae* (29) and *Hyperiodrilus africanus* (28). The least frequent were *Parapolytoreutus obiensis,* (1 record), *Eminoscolex steindachneri,* (1) and *Libyodrilus mekoensis* (2). The ecological zones with the highest earthworm species diversity were the Secondary Forest (with 17 spp.), Swamp Forest/Wooded Savanna (13 spp.) and the Mixed Leguminous Wooded Savanna (12 spp.)

Mixed Leguminous Wooded Savanna had the highest earthworm density (1.50 million worms/ha), followed by *Isoberlina* Savanna (1.46 million worms/ha) and Coastal Forest and Mangrove (0.96 million worms/ha) (Table 2). The lowest values were from Wooded Savanna (0.23 million worms/ha), Plateau Grass Savanna (0.41 million worms/ha) and Deltaic Swamp Forest (0.44 million worms/ha) (Table 2). The overall average earthworm density for the ecological zones was 0.85 million worms/ha.

Earthworm biomass was highest in Coastal Forest and Mangrove (0.51 t/ha), Mixed Leguminous Wooded Savanna (0.38 t/ha) and Deltaic Swamp Forest (0.29 t/ha), respectively. The lowest biomass values were recorded for *Afziela* Savanna/Semi-Deciduous Forest (0.03 t/ha), Swamp Forest/Wooded Savanna (0.09 t/ha) and Mixed Wooded Savanna (0.10 t/ha). The overall average earthworm biomass for all the zones was 0.21 t/ha.

The highest SIINDEX were those of Mixed Leguminous Wooded Savanna (0.72), Coastal Forest and Mangrove (0.65) and *Isoberlina* Savanna (0.56). The lowest SIINDEX were those of *Afziela* Savanna/Semi-Deciduous Forest (0.11), Wooded

Table 1. Earthworm species composition in the ecological zones and their collection frequencies.

	Earthworm species found and frequencies of collection*																				
	E. steindachneri	*E. afroccidentalis*	*E. eugeniae*	*E. abinsianus*	*H. lagosensis*	*H. africanus*	*H. oshogboensis*	*I. wurae*	*I. preussi*	*I. roseus*	*I. tonyii*	*I. vomiensis*	*K. nigeriensis*	*K. penetrabilis*	*K. proxipora*	*K. variabilis*	*L. mekoensis*	*L. violaceus*	*P. obiensis*	*V. prima*	No. of different spp.
Coastal Forest and Mangrove			3		2	3	1				1						1	1			7
Deltaic Swamp Forest		5	5		6	5	4	4	1	1					1				1		10
Swamp Forest/Wooded Savanna		5	9	2	4	5	8	6	1	2	4			1	4			2			13
Secondary Forest		8	8	1	6	8	2	1	2	3	1	1	1	2	3		1	2			17
Mixed Leguminous Wooded		3	1	4		5			3	4	2	1	2	2		1				1	12
Savannal soberlina Savanna		4	2	2		1				2								1			6
Leguminous Wooded Savanna with Plateau Area	1	1																			2
Afziela Savanna/Semi-Deciduous Forest		2																			1
Plateau Grass Savanna				1									3								2
Wooded Savanna			1	5					1							1					4
Mixed Wooded Savanna									1			1				1				2	4
Flood Plain Complex		1				1			1											1	3
Total number of records of each species	1	29	29	15	18	28	15	11	10	12	8	3	6	5	8	3	2	6	1	4	220

*The earthworm names abbreviated above are, in sequence, *Eminoscolex steindachneri, Ephyriodrilus afroccidentalis, Eudrilus eugeniae, Eutoreutus abinsianus, Heliodrilus lagosensis, Hyperiodrilus africanus, Hyperiodrilus oshogboensis, Ikennodrilus wurae, Iridodrilus preussi, Iridodrilus roseus, Iridodrilus tonyii, Iridodrilus vomiensis, Keffia nigeriensis, Keffia penetrabilis, Keffia proxipora, Keffia variabilis, Libyodrilus mekoensis, Libyodrilus violaceus, Parapolytoreutus obiensis,* and *Vomia prima.*

Table 2. Earthworm density, biomass and SIINDEX (in descending order for each parameter) in Nigerian ecological zones.

	*n**	Mean ± S.D.	Minimum	Maximum
Density (million/ha)				
Mixed Leguminous Wooded Savanna	9	1.50 ± 1.26	0.21	4.28
Isoberlina Savanna	5	1.46 ± 1.34	0.13	3.39
Coastal Forest and Mangrove	5	0.96 ± 0.54	0.28	1.66
Swamp Forest/Wooded Savanna	16	0.90 ± 0.41	0.21	1.84
Secondary Forest	19	0.88 ± 0.86	0.03	2.96
Mixed Wooded Savanna	2	0.80 ± 0.11	0.72	0.87
Afziela Savanna/Semi-Deciduous Forest	2	0.49 ± 0.00	0.49	0.49
Deltaic Swamp Forest	12	0.44 ± 0.27	0.06	0.92
Plateau Grass Savanna	4	0.41 ± 0.28	0.08	0.7
Wooded Savanna	6	0.23 ± 0.15	0.03	0.47
Total	80	0.85 ± 0.79	0.03	4.28
Biomass (t/ha)				
Coastal Forest and Mangrove	5	0.51 ± 0.57	0.02	1.4
Mixed Leguminous Wooded Savanna	9	0.38 ± 0.21	0.07	0.61
Deltaic Swamp Forest	12	0.29 ± 0.49	0.01	1.77
Wooded Savanna	6	0.24 ± 0.32	0.03	0.8
Secondary Forest	19	0.16 ± 0.25	0.01	1.14
Isoberlina Savanna	5	0.15 ± 0.13	0.01	0.29
Plateau Grass Savanna	4	0.11 ± 0.10	0.04	0.26
Mixed Wooded Savanna	2	0.10 ± 0.06	0.05	0.14
Swamp Forest/Wooded Savanna	16	0.09 ± 0.05	0.02	0.18
Afziela Savanna/Semi-Deciduous Forest	2	0.03 ± 0.01	0.02	0.03
Total	80	0.21 ± 0.30	0.01	1.77
Soil impact index				
Mixed Leguminous Wooded Savanna	9	0.72 ± 0.45	0.12	1.62
Coastal Forest and Mangrove	5	0.65 ± 0.51	0.07	1.21
Isoberlina Savanna	4	0.56 ± 0.39	0.05	0.99
Secondary Forest	19	0.29 ± 0.22	0.02	0.71
Swamp Forest/Wooded Savanna	16	0.28 ± 0.13	0.08	0.53
Mixed Wooded Savanna	2	0.27 ± 0.11	0.19	0.35
Deltaic Swamp Forest	12	0.27 ± 0.18	0.02	0.63
Plateau Grass Savanna	4	0.19 ± 0.10	0.06	0.27
Wooded Savanna	6	0.16 ± 0.09	0.06	0.32
Afziela Savanna/Semi-Deciduous Forest	2	0.11 ± 0.02	0.1	0.12
Total	79	0.35 ± 0.30	0.02	1.62

*n = number of locations sampled within the ecological zone. At each sampling location, ten replicate quadrats were dug up at a distance of about 0.5 km apart.

Savanna (0.16) and Plateau Grass Savanna (0.19), respectively. The overall average SIINDEX was 0.35.

Statistical tests (Table 3) show that the differences in the earthworm density among the ecological zones were significant. (P = 0.025) but the differences in biomass were not ($P > 0.05$). Differences in SIINDEX were significant, ($P < 0.0001$). This again illustrates the superiority of the soil impact index over either biomass or density. For example, if the impact of earthworms on the soil is based on biomass only we would falsely concluded that there is no significant difference in the impact of earthworms on the soils of the different ecological zones in this study.

Duncan multiple-range test (Table 4) recognized four subsets among the ecological zones. But their intra-subset homogeneity and inter-subset differences were not statistically significant. This means that there were no groups of zones that were uniquely different from all others, in terms of their earthworm abundance and earthworm soil impact.

Table 3. ANOVA table showing significance of differences in earthworm density, biomass and SIINDEX among the ecological zones.

		Sum of squares	d.f.	Mean square	*F*	*P*
Density (million/ha)	Between groups	11.271	9	1.25	2.30	0.025
	Within groups	38.065	70	0.54		
	Total	49.337	79			
Biomass (tons/ha)	Between groups	1.217	9	0.14	1.55	0.148
	Within groups	6.108	70	0.09		
	Total	7.325	79			
Soil impact index (SIINDEX)	Between groups	2.533	9	0.28	4.17	<0.0001
	Within groups	4.660	69	0.07		
	Total	7.193	78			

The geographical and edaphic factors related to the ecological zones are shown in Tables 5 and 6. Mean annual rainfall is highest in the Coastal Forest and Mangrove (2182 mm), Deltaic Swamp Forest (2024 mm) and Swamp Forest/wooded Savanna (1732 mm). The number of rainy days are highest in these zones in the same order. The mean annual temperature is warm (above 25 °C) and of low range (23.5–27.1 °C). Thus temperature may not be a very important factor determining the distribution of the earthworms. The soils are slightly acidic ranging between pH 5.28 to 6.78. The organic matter in the soils have a rather wide range (1.27–4.88 %). The largest value is associated with the Mixed Leguminous Wooded Savanna. Calcium ranges between 4.25 ppm in the *Isoberlina* Savanna and 21.16 ppm in the Wooded Savanna. Cation exchange capacity (C.E.C) ranges between 6.94 in the Savanna/Semi-Deciduous Forest to 11.4 in the *Isoberlina* Savanna.

DISCUSSION

All congeners of the two most frequent earthworms genera (*Ephyriodrilus afroccidentalis, Hyperiodrilus africanus, H. malakai* and *H. oshogboensis)* are among the 'solid-casters', (i.e. those that make worm casts that are solid and finger-shaped). Member of the two other solid-casting genera are *Heliodrilus lagosensis, Iridodrilus preussi, I. roseus, I. tonyii* and *I. vomiensis.* The other earthworms are 'granule-casters', that make granule-type casts. Solid casts have two advantages over the granule type in the soil. First, while granule casts are readily erodible by rain run-off, the solid casts are not that readily eroded (Stewart *et al.* 1988). Second, the solid casts act as time-released nutrient capsules over the soil (Lake & Supak 1996). The solid casters comprise about 62 % of the total records of the earthworms; granule-casters comprise about 38 % (Table 1).

The overall average earthworm density (0.85

Table 4. Duncan homogeneity test of soil impact index.

Ecological zone	*n*	Subset for α = 0.05: 1	2	3	4
Afziela Savanna/Semi-Deciduous Forest	2	0.1101			
Wooded Savanna	6	0.1559			
Plateau Grass Savanna	4	0.1862	0.1862		
Deltaic Swamp Forest	12	0.2652	0.2652	0.2652	
Mixed Wooded Savanna	2	0.2694	0.2694	0.2694	
Swamp Forest/Wooded Savanna	16	0.2798	0.2798	0.2798	
Secondary Forest	19	0.2924	0.2924	0.2924	
Isoberlina Savanna	4		0.5640	0.5640	0.5640
Coastal Forest and Mangrove	5			0.6484	0.6484
Mixed Leguminous Wooded Savanna	9				0.7174
P		0.369	0.056	0.052	0.405

Table 5. Geographic and edaphic factors of the ecological zones. All values are given as mean ± S.D.

Ecological zone	Mean annual rainfall (mm)	Number of rainy days	Mean annual temperature (°C)	pH	Organic matter (%)	Calcium (meq/100g soil)	Cation exchange capacity (meq/100g soil)
Coastal Forest and Mangrove	2162 ± 315	146.67 ± 46.33	26.33 ± 0.52	6.07 ± 0.32	1.21 ± 0.75	14.60 ± 6.76	12.50 (SM)[1]
Deltaic Swamp Forest	2024 ± 453	122.50 ± 34.16	26.38 ± 0.50	5.66 ± 0.86	3.18 ± 0.46	7.44 ± 5.99	142.49 ± 405.94
Swamp Forest/Wooded Savanna	1732 ± 489	113.64 ± 21.94	26.18 ± 0.39	6.03 ± 0.61	2.00 ± 1.38	11.82 ± 7.09	8.16 ± 4.72
Secondary Forest	1442 ± 301	93.81± 13.59	26.43 ± 0.51	5.85 ± 0.91	2.37 ± 1.30	7.29 ± 8.43	7.60 ± 2.71
Mixed Leguminous Wooded Savanna	1270 ± 205	90.00 ± 17.89	27.09 ± 0.30	6.32 ± 1.14	4.88 ± 5.59	13.85 ± 10.19	8.46 ± 1.66
Isoberlina Savanna	1185 ± 104	90.00 ± 0	25.67 ± 1.21	6.48 ± 1.30	2.99 ± 1.72	4.25 ± 7.35	11.40 ± 3.47
Leguminous Wooded Savanna with Plateau Area	635 ± 0	50.00 ± 0	26.50 ± 0.71	6.15 ± 1.06	2.99 ± 2.04	19.80 ± 0.71	NA[2]
Afziela Savanna/Semi-Deciduous Forest	889 ± 0	80.00 ± 14.14	27.00 ± 0	6.75 ± 1.48	1.47 ± 1.31	0.15 ± 0.07	6.94 ± 0.98
Plateau Grass Savanna	916 ± 418	64.29 ± 15.12	26.29 ± 0.49	5.78 ± 0.33	1.54 ± 0.40	19.67 ± 2.69	NA
Wooded Savanna	889 ± 0	70.00 ± 12.65	26.83 ± 0.41	6.52 ± 0.26	2.19 ± 1.32	21.16 ± 3.08	NA
Mixed Wooded Savanna	1588 ± 270	100.00 ± 42.43	23.50 ± 2.12	6.00 ± 0.42	1.75 ± 0.37	18.85 ± 0.35	NA
Flood Plain Complex	1524 ± 221	116.67 ± 11.55	27.00 (SM)	7.70 (SM)	1.82 (SM)	0.10 (SM)	10.38 (SM)

[1]SM = single measurement. [2]NA = not available.

million worms/ha) is very low compared to the temperate region of Europe from where Lavelle (1978a) reported 2.5–9.5 million worms/ha. For western Africa he reported 0.1–4.0 million worm/ha. Since earthworms are very important in the breakdown and recycling of leaf litter, their low density in Nigerian soils is likely to be an impediment to agricultural policy that seeks to minimize the application of inorganic fertilizer in favour of the role of soil animals in sustainable soil fertility. It is therefore important to devise means of conserving and multiplying the earthworms in Nigeria.

The solid casters, where they exist in large numbers, cause the soil surface to be covered by solid cast aggregates (Van de Westeringh 1972; Lavelle 1978b). Such a feature has many advantages, e.g. the surface area of the soil is increased for gaseous exchange (Curry & Good 1992; Joschko *et al.* 1989), Since casts are made of fine soils the adsorptive surface for water retention capacity may also be increased.

In Nigeria the important role of earthworms in soil litter breakdown and recycling is often negatively affected by illegal annual bush burning during the dry season that destroys the litter. It is therefore important that there should be enough earthworms in the soils during the rainy season so that a good percentage of the litter could be broken down and taken deep into the soil before the remaining litter is destroyed by bush burning (Knollenberg *et al.* 1985).

While, in general, the national average earthworm abundance is low, there is need to pay particular attention to *Afziela* Savanna/Semi-Deciduous Forest, Wooded Savanna and Plateau Grass Savanna where earthworm abundance is very low. Ironically, these regions, because of their dominant grass vegetation, provide ready fuel for bush burning to the detriment of the earthworms. Moreover, after the grass has been flared off, the soil becomes exposed to wind erosion that transports the inorganic residues of the burnt grass elsewhere over hundreds and thousands of kilometres distant (Barbour *et* al. 1982). Over many years, this leads to depletion of soil nutrients, especially at the surface and root level (Areola 1982). Unfortunately, the earthworms required to move nutrients up from deeper in the soil to the root levels have also been destroyed. Thus, it is obvious that illegal bush burning does damage to the soil in many ways, not only by wasting the litter but by making recovery difficult.

Application of inorganic fertilizers can be mini-

Table 6. ANOVA table showing significance of differences in ecological factors between the ecological zones.

		Sum of squares	d.f.	Mean square	*F*	*P*
Mean annual rainfall (mm)	Between groups	16612856.257	11	1510259.660	9.936	<0.001
	Within groups	13983642.964	92	151996.119		
	Total	30596499.221	103			
Number of raindays	Between Groups	48585.781	11	4416.889	8.180	<0.001
	Within groups	49675.758	92	539.954		
	Total	98261.538	103			
Mean annual temperature (°C)	Between groups	29.372	11	2.670	8.470	<0.001
	Within groups	29.003	92	0.315		
	Total	58.375	103			
pH	Between groups	14.147	11	1.286	0.950	0.502
	Within groups	71.754	53	1.354		
	Total	85.900	64			
Organic matter (%)	Between groups	60.635	11	5.512	0.625	0.799
	Within groups	467.091	53	8.813		
	Total	527.726	64			
Calcium	Between groups	2124.531	11	193.139	3.834	<0.001
	Within groups	2770.529	55	50.373		
	Total	4895.060	66			
Cation exchange capacity	Between groups	79.034	11	11.291	1.103	0.387
	Within groups	296.853	25	10.236		
	Total	375.887	36			

mized if the soil nutrients harvested in fruit and leafy vegetables are replaced by recycling the vegetable litter and by upward movement of nutrients that are located deeper in the soil (Tomlin *et al.* 1995). If these two processes are effective, soil fertility should be sustained. Earthworms are involved in both processes (Lavelle *et al.* 1997). The involvement of earthworms at leaf litter breakdown and re-injection into the soil is a function of many factors, including the earthworm biomass and density (SIINDEX), the amount of litter available for breakdown, the duration of rainfall (which affects the wetness of the leaves), and the palatability of the of the leaves. As there is very little research on these aspects of earthworms in the zones under consideration, it will probably take a long time to acquire sufficient data to manipulate all the variables. Some of the factors cannot be controlled, for example, the duration and amount of rainfall. Some can be controlled, for example, the abundance of earthworms, which can be promoted by human efforts. The most passive way to promote earthworm abundance is to protect the soil from bush burning. Another is the adoption of minimum tillage farming practice which tends to preserve soil structure, unlike mechanized ploughing and harrowing which destroys soil structure and earthworms. There is need for a comparative study between mechanized land preparation and minimum tillage with respect to gains and losses in terms of (a) soil structure, (b) leaf litter re-injection and recycling and (c) vertical movement of soil inorganic nutrients.

When land preparation is mechanized, soil structure is lost as it becomes more loose (Werner 1990). Although a mechanized soil may appear at first to be better aerated and more yielding it is more prone to erosion and faster loss of nutrients. (Slater & Hopp 1947; Aina 1984; Bostro 1986; Werner 1990). In mechanized soil preparation, leaf litter is buried thereby their soil surface mulching function is lost. Earthworms are destroyed en masse in the process (Mackay & Kladivko 1985). Soil nutrients are brought to the exposed surface and are briefly available before being washed away in the rain runoff. By contrast, with minimum tillage the soil firmness is preserved and soil nutrients are conserved (Mackay & Kladivko 1985). Aeration of the soil, upward movement of soil nutrients, leaf-litter re-injection and recycling are all largely influenced by soil animals (Madge 1966, 1969). It would be interesting to estimate how many earthworms will produce an equivalent effect and yield as a well-defined mechanized soil preparation, or a well-defined fertilizer application regime. When these are estimated, it would be possible to plan for earthworm breeding and production to meet the needs of different soils and ecological zones.

This is the first nationwide study of earthworm abundance in Nigeria and many more are encouraged until a large database can be created, allowing a management plan to be generated with the view to facilitate earthworm-assisted soil fertility.

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