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Physicochemical properties of earthworm casts and uningested parent soil from selected sites in southwestern Nigeria

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ABSTRACT

Earthworms modify both the physical and chemical properties of soils. In a study on the possible modification of soil properties by earthworms, earthworm casts and uningested A and B soil horizons from three sites in southwestern Nigeria were analysed for selected physical and chemical properties. The casts were derived from the earthworm species *Hyperiodrilus africanus*. Results were analysed by a combination of analysis of variance with comparison of means and correlation analysis. Earthworm casts were significantly enriched in exchangeable bases, organic matter, base saturation and cation exchange capacity (CEC). The light fraction organic matter (LFOM) (density $< 1.75\ \mathrm{g\,cm^{-3}}$) was more concentrated in the A horizon while the polysaccharides attached to heavy fraction (HFPS) (density $> 1.75\ \mathrm{g\,cm^{-3}}$), presumably composed mainly of the exudates of soil microorganisms, were significantly highest in the casts. The clay and sesquioxide contents differed significantly among the groups analysed in the order B horizon > casts > A horizon, while the sand content ranged in the order A horizon > casts > B horizon. However, the fine sand and silt soil fractions were significantly highest in the casts. The crystalline sesquioxide contents were highest in the B horizon, while the amorphous Fe and the sesquioxides associated with organic complexes were higher in casts. There was no significant difference in the soils' content of dispersible clay, while the wet stability of >250 μm aggregates from the B horizon was less than those from casts and the A horizon. Macroaggregate stability in casts was positively correlated with LFOM, amorphous Fe and Al, while microaggregate stability was positively correlated with HFPS. Meanwhile, microaggregate stability in the soil B horizon was mainly due to the crystalline forms of Al and Fe.

1. Introduction

The contribution of earthworms to soil development in the humid tropical regions cannot be ignored. Cast production at the rate of up to $50\ \mathrm{t\,ha^{-1}\,year^{-1}}$ has been reported for some species of earthworms (Rose, 1976). Management practices that result in modification of earthworm communities have been found to be reflected in the modification of soil physical properties (Blanchart et al., 1997). In Nigeria, Lal (1976) and Lal and Akinremi (1983) among others, documented the contributions of earthworms to the improvement of soil physical and chemical properties. In Ivory Coast, Blanchart (1992) also reported that earthworms were major factors responsible for soil structure formation within the upper 0–20 cm

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of soil. However, cast production was observed to be mainly restricted to the 9 months of rainy season by Nooren et al. (1995) who recorded an average of about 31 t of casts during a 9-month rainy season period in Ivory Coast. Earthworms are generally recognised to improve soil properties for agricultural use and increase crop productivity through their casting and burrowing activities during which they often mix soil materials with plant litter and animal waste to form nutrient – rich soils that are characterised by stable aggregates (Parmelee et al., 1990; Martin, 1991). This involves a process of ingestion of soil and litter, and egestion of aggregated soil in the form of casts which become more resistant to crushing on undergoing wetting/drying cycles (Marinissen et al., 1996). Shipitalo and Protz (1989) described how earthworms directly promote the formation of organic-cored microaggregates through the ingestion of soil and litter and how in the process, the pre-existing aggregates are completely destroyed by the peristalsis movement in the gut of earthworms with the formation of new microaggregates. The transit through the earthworm gut allows an intimate mixing of clay minerals and organic materials (from litter), which are encrusted with mucus to create new microaggregates (Shipitalo and Protz, 1989). The strengthening of bonds between organic materials, mucus and minerals for the stabilization of the new microaggregates is, however, achieved through the process of drying and ageing. Meanwhile, Pulleman et al. (2005a,b) established that earthworms contributed significantly to the formation of organic matter rich microaggregates and went further to demonstrate through a study of a thin section of soil aggregates of biogenic and physicogenic origin, that earthworms directly initiate the formation of microaggregates, thus confirming the earlier findings of Bossuyt et al. (2004). Protection of SOC by microaggregates within macroaggregates formed by earthworms was shown to be responsible for higher organic carbon contents of earthworm casts (Bossuyt et al., 2005). In elucidating the mechanisms for soil microaggregate stability, Six et al. (2004) suggested some mechanisms for explaining aggregate stability by earthworms. These include: (i) mechanical binding by muscular bundles from ingested plant materials or from fungal growth after excretion of the casts; (ii) the deposition within the casts of microbial-derived polysaccharides which strengthen bonds between organic and mineral components; (iii) the integration of the recalcitrant organic materials into compact structures as organo-mineral microaggregates; and (iv) cementing of soil particles in the worm's gut by calcium humate formed from decomposing organic material and calcite excreted by the worm's calciferous glands.

The structure of earthworm casts restricts air and water movement within them and thus protects organic matter within it from decomposition (Blanchart et al., 1993). Comparisons of the relative stability of casts over the parent materials have not been conclusive. Prior to the mid-1980s most studies suggested that freshly excreted earthworm casts were immediately more stable than uningested soil (Hopp and Hopkins, 1946; Dutt, 1948; Swaby, 1950; Teotia et al., 1950; Parle, 1963; Lal and de Vleeschauwer, 1981; Lal and Akinremi, 1983). Most recent studies however, indicate that fresh, moist casts are less water-stable than uningested soil because of the intense re-moulding that occurs during the passage through earthworms' gut (Shipitalo and Protz, 1988; Marinissen and Dexter, 1990; Schrader and Zhang, 1997; Decëans, 2000). Studies by Schrader and Zhang (1997) also indicated that cast stability was dependent mainly on the parent soil materials and the quality of organic matter available for casting. Earthworms have also been reported to be important players in bioturbation, whereby they bring up minerals and soil materials from the B horizon and depositing them on the soil surface as casts (Jordan et al., 1997). The extent of horizon mixed by earthworms is expected to be reflected in the chemical composition of casts and to a large extent in determining the physical stability of the casts.

The objective of this study was to compare the physicochemical properties of earthworm casts with the parent soils materials from A and B horizons in order to have a better understanding of the mechanism of aggregation in earthworm casts and factors responsible for differences in their structural stability between casts and uningested soil.

2. Materials and methods

Earthworm casts were collected from the soil surface at three different locations representing two different soil types in southwestern Nigeria in January 1996. The soils were identified as Egbeda and Owode series, which are classified, respectively, as Lixisol and Luvisol according to the FAO/UNESCO soil classification system (FAO, 1988). Owode soil was sampled at Ogere (soil 1) and Ikenne (soil 2), while Egbeda soil (soil 3) was sampled at Ibadan, all in southwestern Nigeria. The three locations were under 3-year bush fallow at sampling. The casts were produced by earthworm species *Hyperiodrilus africanus*. The *H. africanus* is referred to as a slightly pigmented epi-endogeic eudrilid species (Derouard et al., 1997). It lives in the upper 10–20 cm soil depth and feeds on a mixture of soil and above-ground litter (Tondoh, 1998). Bulk soil samples were collected from the A (0–15 cm) and B (50–100 cm) horizons of the soils. Samples were collected in replicates of three at each sampling site. The samples were air-dried and those meant for chemical and mechanical analyses were crushed and sieved with a 2 mm sieve. The samples were analysed for pH in 1:2.5 soil:water suspension and for organic carbon using the LECO induction furnace carbon analyser. The effective exchangeable bases were extracted with 1 M ammonium acetate (pH 7.0) and the exchangeable Na^+ and K^+ were determined from the extract by flame photometry, while Ca^{2+} and Mg^{2+} were determined by atomic absorption spectrometry. Extractable acidity was determined in nitrophenol-$Ca(OH)_2$ solution at pH 8.1. The soil effective CEC was determined as the sum of extractable bases plus exchangeable acidity. The crystalline forms of Al and Fe were extracted with sodium dithionate-citrate-carbonate system (Fe_{dc}, Al_{dc}) as described by Mehra and Johnson (1960), while the amorphous forms were extracted with 1 M ammonium oxalate (Fe_{ox}, Al_{ox}) as described by Schwertmann (1964). The organically bound forms of Fe and Al were extracted with sodium pyrophosphate (Fe_{py}, Al_{py}). The Fe and Al contents of the different extracts were determined using the Perkin-Elmer 3100 flame atomic absorption spectrophotometer.

The soils particle size distribution was determined using the pipette method after dispersion with calgon (Soil Survey