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Selected physical properties and microbial activity of earthworm casts and non-ingested soil aggregates

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A b s t r a c t. Some physical properties and microbial activity of the casts of the earthworm *Aporrectodea caliginosa* were investigated and compared with the properties of aggregates from the bulk soil of the Ap horizon (Orthic Luvisol, FAO) of silty loam texture. The water stability of 20-day-old 8-9 mm aggregates from casts, as determined by the drop impact method, was significantly increased compared with those of 3-day-old casts and natural aggregates. The rate of wetting of the natural aggregates was substantially greater than that for the cast aggregates. The values of the crushing strength of aggregates from casts and natural aggregates were not significantly different. The populations of bacteria, streptomyces and fungi in earthworm casts increased with the ageing of the casts. The increased water stability of cast deposits can be an important factor in reducing the high susceptibility to erosion of the soil studied.

K e y w o r d s: earthworm casts, soil aggregates, stability, wetting, microbial population

INTRODUCTION

By burrowing and leaving their casts, earthworms exert a great influence on the water infiltration and gas exchange in soils. The number of burrows can range from 10^6 ha^{-1} for *Lumbricus terrestris* (Edwards *et al*.,1988) to 10^{10}ha^{-1} for *Allobophora* spp. (Kretzschmar, 1987). The air porosity for the water-conducting pores made by earthworms in the silty loam subsoil was 0.328 and 0.168% at a depth of 0.24-0.34 m and 0.34-0.44 m, respectively (Lipiec *et al*., 1998). Water infiltration in soils with earthworms is, commonly, several times faster than in soils lacking in earthworms (Piekarz and Lipiec, 1996; Lee and Foster, 1991).

The quantity of earthworm casts left on the soil surface is between 2 and 50 t yr^{-1} depending on the type of soil and land use, whereas the total amount of earthworm casts on the surface, and below it, can exceed 1000 t yr^{-1} (Lee and Foster, 1991). Tomlin *et al*. (1995), in reviewing the subject, indicate that the stability of earthworm casts compared with bulk soil aggregates can be greater or similar depending on whether they are fresh or old. The stability of the casts is enhanced by bacteria in the soil increasing their secretion production of gums (McKenzie and Dexter, 1987; Haynes and Fraser, 1998) in passing through the gut or by the cementing effect of calcium (Lee and Foster, 1991). The increased stability of the cast and soil aggregates is the single most important soil property affecting soil erodibility (Horn *et al*., 1998; Reichert and Norton, 1994) through the influence of particle detachment due to water-drop impact, surface sealing and water infiltration.

We compared the structural stability in the fresh and old casts of *Aporrectodea caliginosa* and characterised by the crushing strength and the water stability, the rate of wetting and microbial activity, - with that of the non-ingested aggregates. We used silty loam soil regarded as being highly conducive to structural destabilisation and erosion.

MATERIALS AND METHODS

The soil was collected from the upper 30 cm of the profile from Orthic Luvisol developed from silty formations, non uniform, over limestone (Felin, Świdnicki Plateau) (Table 1). The soil was passed through a 5-mm sieve, and then stored in covered barrels, at 17°C, for up to 4 weeks before use. The sieved soil was compacted to a bulk density of 1.3 Mg m^{-3} in PVC cylinders of 15 cm diameter and 30 cm in height. Afterwards, 4 healthy earthworms (2 adult and 2 young per cylinder) were introduced into the soil. *Aporrectodea caliginosa* earthworms were used. They were collected from the topsoil of the same soil under grassland

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T a b l e 1. Some properties of the soil

Soil	Particle size (mm) distribution (%, w w^{-1})						Organic matter content (%, w w^{-1})
	1-0.1	0.1-0.05	0.05-0.02	0.02-0.006	0.006-0.002	<0.002	
Silty loam	20	6	42	23	3	6	1.48

and then placed in a Petri dish on wetted filter paper for 24 h. After 24 h, adult and young healthy earthworms were introduced to the soil.

While incubating, fresh earthworm casts were collected from the surface of the soil. Before analysis, the earthworm casts were incubated at 18°C and at a humidity of 60 % for 3 and 20 days and the soil aggregates for 20 days.

The water stability of 8-9 mm earthworm casts and non-ingested aggregates from bulk soil was measured using the drop impact method as described by Rząsa and Owczarzak (1983). They were placed on a 2 mm steel sieve and water droplets weighing 0.05 g were dropped on them from a height of 1 m, hitting them with an energy of 4.905×10^{-4}J. The number of drops falling was the measure of their stability and caused the commencement of half and then of their total breakdown (at the appearance of the first spread of the surface). The measurements were done in 6 replicates.

The rate of wetting was determined using a horizontal capillary tube with the sponge being in contact with the earthworm cast or soil aggregate (Leeds-Harrison *et al*., 1994).Wetting was measured over 5 min. The size of the casts and aggregates used, ranged from 16 to 20 mm and was associated with the method used. The measurements were done in 9 replicates.

The crushing strength of single air-dry casts and the diameter of the aggregates was determined using the method proposed by Dexter and Kroesbergen (1985). The diameter of an individual aggregate was estimated as a mean of different measurements taken along three axes of the aggregate: the longest, the intermediate, and the smallest. The mean diameter of the aggregates used, ranged from 8 to 9 mm. An aggregate was placed on a metal plate and crushed with another plate fixed to the stable tensometric head using a strength-testing device described by Pawłowski *et al.* (1996). The value of the crushing strength was calculated from the equation:

$$Q = 0.576\, F\, d^{-2}$$

where F is the polar force (N) at failure; d is the mean diameter (m) of the spherical aggregate. The measurements were done in 17 replicates.

The number of bacteria, streptomyces and fungi was measured by plate culture. A medium for the bacteria AMA (asparagin mannitol agar) was prepared according to Fred and Waksman (1928), (L-asparagin 0.5 g, Mannitol 1 g, K_2HPO_4 1 g, KNO_3 0.5 g, $Mg_5O_4 \cdot 7H_2O$ 0.2 g, NaCl 0.1 g, agar 16 g, H_2O destil. 1000 cm^3), the medium for streptomyces was SEA (soil extract agar) prepared according to the procedure proposed by Strzelczyk and Strzelczyk (1963) (K_2HPO_4 0.5 g, soil extract 1000 cm^3, agar 16 g), and for the fungi, according to the Martin method (1950) (glucose 10 g, peptone 5 g, KH_2PO_4 1 g, $MgSO_4 \cdot 7H_2O$ 0.5 g, rose bengal solution 10 cm^3, streptomycin solution 2 cm^3, H_2O dest. 1000 cm^3). The probes, the solution and the plate cultures were prepared according to the Grabińska-Łoniewska method (1996). Incubation was conducted at a temperature of 19-21°C, over 12 days for the bacteria, 14 for the streptomyces and 4 days for the fungi.

RESULTS AND DISCUSSION

Water stability and rate of wetting

Figure 1 shows that water stability, as determined by the drop impact method was markedly greater for 20-day-old earthworm casts than in the non-ingested soil aggregates and the 3-day-old earthworm casts. The differences between the 3-day old non-ingested soil aggregates were relatively small. The relative differences increased in successive stages of disintegration stages due mostly to the increased stability of 20-day-old-earthworm casts. The total breakdown of the 20-day-old casts was caused by 695 drops whereas that of the 3-day-old earthworm casts and non-ingested soil, - by 20 and 25, respectively. In their review, Whalley and Dexter (1994) indicate that old casts become stable aggregates and can make up the majority of structural aggregates in the upper soil. The stability of the earthworm casts can be enhanced by amending soil with plant material (Shreder and Zhang, 1997; Haynes and Fraser, 1998).

The wetting of the natural soil aggregates was faster than that of the 20-day old casts (Fig. 2). The relative differences increased with the increased time of wetting. After 5 min, the volumes of water entering earthworm casts and non-ingested aggregates were 310 and 910 mm^3, respectively. The reduced wetting rate in the old casts can contribute to increased water stability (Fig. 1). The lower wetting rate in the casts can be associated with the presence of hydrophobic parts (Tomlin *et al*., 1995).

The results presented in Figs 1 and 2 indicate that greater water stability of old cast aggregates compared to

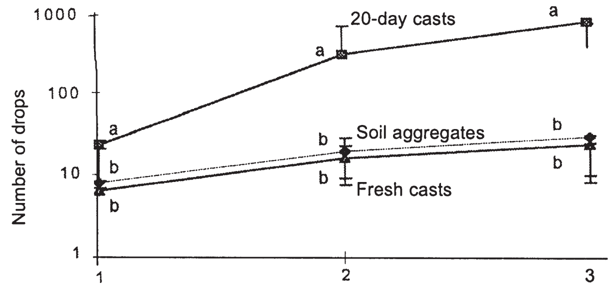

Fig. 1. The number of falling water drops causing the disintegration of earthworm casts and non-ingested soil aggregates. 1, 2, 3 are: beginning, half and total breakdown, respectively. Mean values of six repilicates and S.E. are shown. Note that the vertical axis is in a logarithmic scale. Means with the same letters within each disintegration stage are not significantly different at the 5% level by

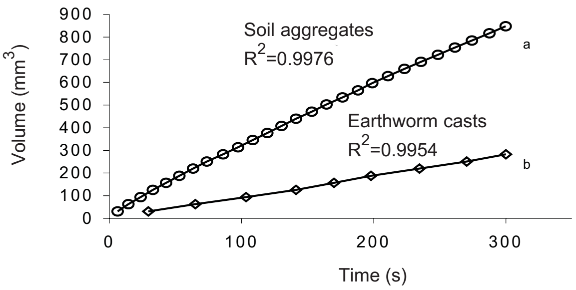

Fig. 2. The wetting rate of 20-day earthworm casts and non-ingested soil aggregates. Means with different letters are significantly different at the 5% level by the LSD test.

stability is similar to that of bulk soil aggregates. The results agree with the findings reported by Sharpley *et al.* (1979) and Lee (1992).

Crushing strength

The mean crushing strength of 8-9 mm aggregates from casts being 1.3±0.307 MPa was slightly reduced compared with that of non-ingested aggregates 1.57±0.23 MPa. In the study of McKenzie and Dexter (1987) who used 2 mm cast and non-ingested soil aggregates, the casts showed a substantially greater crushing strength. The lower crushing strength of the earthworm casts in our study can be associated with the greater size of the casts and non-ingested aggregates (8-9 mm) used and the related structure of the casts. As reported by Tomlin *et al.* (1995), the larger aggregates from earthworm casts consist of smaller aggregates (pellets). We observed that the measured crushing strength of the aggregates from the casts, mainly reflected the binding force between the pellets.

Microbial population

Table 2 shows that the colonisation of earthworm casts by bacteria, streptomyces and fungi increased on ageing. The population of Fungi of 3-day casts was significantly lower than that in 20-day casts and soil aggregates. This increase can also contribute to the increased stability of the old aggregates compared with the casts (Fig. 1). The results agree with the findings of Marinissen and Dexter (1990) showing that an increased population of fungi in the cast aggregates was an important factor in their stabilisation.

T a b l e 2. Numbers of microorganisms in earthworm casts

Object	Number of microorganisms (CFU g^{-1} dry soil)		
	Bacteria	Streptomyces	Fungi
3-day casts	11.08×10^5a	4.97×10^5a	0.74×10^4a
20-day casts	11.62×10^5a	6.47×10^5a	1.14×10^4b
Soil aggregates	9.54×10^5a	5.23×10^5a	1.02×10^4b

Means with the same letter in the column are not significantly different at the 5% level by the LSD test. CFU - Colony Forming Unit.

soil aggregates can be associated with a lower rate of wetting. This is a characteristic response of natural soil aggregates where an increased wetting rate results in a greater soaking due to the compression of the air trapped in the aggregate pores and micro-cracks by the invading water.

Increased water stability in old casts can contribute to an improvement in soil structure and can protect the soil against erosion. This is not true in respect of fresh aggregates whose

CONCLUSIONS

A comparison of physical properties and microbial activity of earthwarm casts with those of non-ingested soil aggregates allowes us to draw the following conclusions:

- Water stability and bacteria population, streptomyces and fungi were greater than those of 3-day old casts and non-ingested soil aggregates. The stability of 3-day old casts and soil aggregates was similar.

- Non-ingested aggregates when compared to earthworm casts were characterised by a slightly greater crushing strength. The rate of wetting was faster in soil aggregates than in earthworm casts.

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