IMPACTS OF EARTHWORMS ON SOIL AGGREGATE STABILITY

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INTRODUCTION

In agroecosystem studies we have experimentally measured the impacts of earthworms on aggregate stability in soils in several regions of the world. The following is a review of work recently finished and in progress at our laboratories in The Netherlands and in the USA.

Earthworm activities are known to affect soil physical properties. Burrowing produces channels which influence soil porosity and hydraulic conductivity. Casting activities, whether at the surface or below the surface, can either increase or decrease the abundances of water-stable soil aggregates Lavelle et al., 1987; Lee, 1985; Marinissen & Dexter, 1990; Shipitalo & Protz, 1988). In newly reclaimed polders, soils under grassland without earthworms may become compacted, with mostly horizontally oriented planar cracks, whereas in the presence of earthworms a porous structure is formed, with peds and pores of various sizes (Hoogerkamp et al., 1983; Marinissen & Bok, 1988).

Aggregation can be considered to consist of two phases: formation and stabilization (Allison, 1968). These processes usually occur simultaneously, and can be influenced by different physical, chemical (Boyle et al., 1989) and biological factors (Lavelle, 1988). The range and extent of involvement of complex polysaccharides, gums, etc., and fungal hyphae and roots in the aggregation process have been widely reviewed (e.g. Oades, 1984; Tisdall & Oades, 1982). We concentrate in this paper on some of the influences of earthworms in the process of soil aggregate stabilization.

In our recent studies in the Georgia Piedmont, we are concerned with the water-stability and persistence of soil aggregates. Earthworm casting activity may be important for maintenance of soil organic matter in the highly-weathered Ultisols typical of the southeastern USA, where coarse texture and predominance of kaolinitic clays impart dispersibility and instability to these soils (West et al., 1990). We present results of laboratory and field studies of water-stable aggregates with various experimental manipulations:

1) earthworm effects on water-stable size- distribution of sandy versus clayey textured Ultisols under varying conditions, and
2) relationships with bulk and micromorphic properties of field soils from different erosion classes and management practices.

In our recent studies in The Netherlands we are concerned with the effects of earthworms on the stability of aggregates in old (Late Weichselian) and young (Holocene) fluvial deposits of the river Rhine (Ochraqualfs and Haplaquepts, respectively). We present results of laboratory and field experiments of earthworm effects on water-stable aggregates.

METHODS

Laboratory study (earthworms, Georgia)

Soil from loamy sand and sandy clay loam surface horizons (Typic Kanhapludults) was crushed to pass a 2 mm sieve. 100 g soil was added to 120 cm^3 cups, with 0.5 g rye (*Secale cereale*) straw placed on the surface of the soil. The soils were then wetted to water-holding capacity. One earthworm (*Lumbricus rubellus* L.) was added to each cup and the units were incubated for 42 days with regular watering, to maintain the water contents at moisture-holding capacity. Water-stable aggregate-size distribution was then determined by wet sieving.

Field study (earthworms, Georgia)

Three cropping systems, in prevalent usage on the Georgia Piedmont were studied. These were: conventional-tilled soybean, conventional-tilled grain sorghum, and no-till grain sorghum. There were three levels of previous erosion as indicated by depth to the B_t horizon: slight, moderate, and severe. At the end of the 5 year study, the following analyses were conducted:

1) water-stable aggregates from 0-8 cm depth,
2) earthworm numbers, determined by hand-sorting of 10 cm dia x 15 cm deep core samples, and
3) infiltration, expressed as percentage of sprinkler infiltrometer-applied rainfall over a one hr period (West et al., 1990).

Laboratory studies (earthworms, fluvial soil, The Netherlands)

The old Late Weichselian topsoil (0-20 cm; clay loam) contained 1.3% C, the subsoil (40-80 cm; sandy clay loam) 0.7% C. The young Holocene topsoil (loam) contained 3.9% C and showed more biological activity; the subsoil contained 3.5% C. Peds less than 8 mm in diameter were collected by sieving the soil, without using pressure. Experimental vessels measuring 13 cm in diameter and 25 cm in height were filled by compressing the sieved soil in three phases to densities comparable to the field (Miedema, 1987). Per vessel five mature individuals of the epigeic earthworm *Lumbricus rubellus* and five of the endogeic *Aporrectodea caliginosa* were added. Highly palatable *Alnus* leaves were supplied on the surface. The vessels were incubated for 9 months. Water-stable aggregate-size distribution of the top 5 cm of soil was then determined by wet sieving.

RESULTS

Laboratory study (earthworms, Georgia)

Earthworm activity increased mean diameter of water-stable aggregates (Table 1). Note that the effect was greater in sandy than in clayey soil, and had the greatest impact in the > 2000 μm sizze-class. Coarser aggregates were predominantly fragments of soil surrounding earthworm channels (data not shown). It is hypothesized that these aggregates are bound by organic materials, derived, in part, from the applied rye litter (OM). Additional studies (West et al., 1990) found that earthworm castings incorporated all grain sizes, with bridges of organic matter and fine mineral particles binding coarser grains together.

Field study (earthworms, Georgia)

Earthworm numbers were significantly greater in moderately and severely-eroded field plots, possibly due to lower sand content, higher water holding capacity and higher organic matter content of these soils. Water-stable aggregates were greater in the severely-eroded plots (Table 2). Channels with dimensions similar to those made by the earthworms in laboratory soils were common in thin sections from the surface of the field plots (West et al., 1990).

The NT grain sorghum treatment had higher earthworms numbers and biomass, aggregation and infiltration than the CT treatments.

Laboratory study (earthworms, The Netherlands)

After nine months of incubation the earthworms had formed a 1 cm thick layer of casts on the surface of the soil column. The rest of the soil remained relatively unaffected, the influence of earthworms being confined to the channels formed and their direct vicinity. Still, earthworm activity correlates with a consistent increase in percentage of water-stable aggregates in the top 5 cm layer (Table 3 (A), Wilcoxon's paired signed-ranks test, P = 0.068). From the data in table 3 (B) it seems that there is a shift from the size class 2000-8000 μm to the size class 300-2000 μm in the earthworm as compared to the non-earthworm treatments, while there was hardly an effect on the class less than 300 μm.

CONCLUSIONS AND DISCUSSION

Organic matter added to the Piedmont soil under the NT, double cropped treatment induced greater earthworm abundance (P = 0.067), than that under CT winter fallow. We suggest that corresponding increased aggregation and infiltration is due, at least partially, to the increased earthworm activity. Higher abundance of earthworms and water-stable aggregates in more eroded soils, may be a result of higher clay content (slight = 5.7%; moderate = 10.7%; severe = 19.0% (1-3 cm depth), and SOM (0.73, 1.28, and 1.30 for slightly, moderate and severe, respectively) (R.R. Bruce, pers. comm., 1989) than in the very sandy uneroded soil. Channels produced by earthworms tend to increase the rate of saturated water movement through the soil horizons. However, particle reorientation parallel to channel walls, compaction of soil adjacent to the channels, and organic lining of channels may limit movement of water from the channels into the bulk soil (West et al., 1990).

In the Dutch fluvial soil increased aggregation was found in the class 300-2000 μm and decreased aggregation in the class 2000-8000 μm, which is contrary to the Georgia results. This may be largely due to the different pre-treatments of the soil (sieving over 2 mm before the start of the Georgia experiment and over 8 mm in the Dutch experiment; no dry sieving into size classes before determining the water-stability of aggregates in the Georgian study, which was done in the Dutch study), and/or to the one species extra (*Aporrectodea caliginosa*) in the Dutch study. Hence, while it is clear that earthworm activity causes increased aggregation of soil in certain size classes under a wide range of soil conditions, caution is needed in the generalization of results of individual studies.

The longer-term impacts of earthworm activities on bacteria (e.g. Lavelle et al., 1987) need to be carefully considered in basic studies of soil ecology. We suggest that research into several-year long dynamics of labelled organic matter, under realistic field conditions, such as is being conducted at several sites, including those of ours in The Netherlands and the USA, will be very informative for further understanding the interplays between physics, chemistry and biology of agroecosystems.

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Table 1. Mean water-stable aggregate size distribution from laboratory incubated treatments (% of dry weight)*

Treatment	Size Fraction (μm) > 2000	2000-250	250-160	< 53
Sand + OM + worm	20 (1.9)	65 (1.4)	14 (1.1)	1 (0.1)
Sand + OM	6 (0.9)	79 (0.6)	14 (0.5)	1 (0.2)
Sand	3 (0.4)	80 (0.9)	16 (0.5)	1 (0.1)
Clay + OM + worm	33 (5.3)	48 (6.3)	18 (2.7)	1 (0.2)
Clay + OM	24 (4.9)	57 (1.8)	18 (2.9)	1 (0.3)
Clay	13 (2.8)	61 (1.5)	23 (1.7)	2 (0.1)

* Percentages not corrected for primary particles; standard error in parentheses.
Soil + OM + worm N = 10; all others N = 3.

Table 2. Earthworm numbers, water-stable aggregates, and relative infiltration for erosion levels and cropping systems in Georgia Piedmont agroecosystems (from West et al., 1990).

	Earthworms ($\#/m^2$)	Water-stable aggregates (% > 0.25 mm)	Infiltration (% of rainfall)
Erosion levels			
Sligh	60 a*	53 a	84 a
Moderate	301 b	57 a	73 b
Severe	255 b	66 b	79 ab
Cropping System**			
CT Soybean	127 a	50 a	69 a
CT Sorghum	180 a	50 a	66 a
NT Sorghum	307 b***	76 b	100 b

* Means followed by the same letter are not significantly different at P = 0.05.
** CT winter bare fallow; NT double cropped with crimson clover
*** Significantly different at P = 0.067.

Table 3. Water-stable aggregate size distribution in laboratory incubated Dutch fluvial soil.

A. Dry weight of water-stable aggregates as a percentage of total dry weight of the 0-5 cm layer of soil.

B. Dry weight of water-stable aggregates of a certain size-class as a percentage of total dry weight of water-stable aggregates from a certain treatment.

Treatment		A	B		
			Size Fraction (μm)		
			8000-2000	2000-300	< 300
Old Topsoil	+ worms	63.6	77.5	22.1	0.4
	- worms	60.6	84.7	14.9	0.4
Young Topsoil	+ worms	90.4	79.4	20.5	0.1
	- worms	86.8	81.2	18.8	0.0
Old Subsoil	+ worms	19.8	56.3	43.5	1.2
	- worms	16.1	60.7	36.8	2.5
Young Subsoil	+ worms	85.7	73.7	26.2	0.1
	- worms	78.9	76.8	23.2	0.0