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EARTHWORM CASTING: STABILIZATION OR DESTABILIZATION OF SOIL STRUCTURE?

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Summary—The aim of the study was to determine the effect of the gut passage through earthworms on the aggregate stability of soils varying in texture, carbonate and organic matter content. The soil material used originated from the Ap and B horizon of a loam soil (Gleyic Luvisol) and from the Ap and P horizon of a clay soil (Calcaric-Vertic Cambisol). Sieved aggregates of 1–2 mm size were filled into vessels and inoculated separately with two earthworm species: the anecic detritivorous *Lumbricus terrestris* and the endogeic geophagous *Aporrectodea caliginosa*. The casts of both species were collected for the determination of chemical (total carbon, organic carbon, $CaCO_3$, C-to-N ratio, pH) and physical factors (particle size distribution, water stable aggregation, tensile strength). These data were compared with those of natural and remoulded (physical data only) soil aggregates which were not influenced by earthworms. Remoulded aggregates were artificially formed simulating mechanical processes in the earthworm gut. Differences were detected between the earthworm species in the same soil as well as between casts of the same species but from different soils. The contribution of earthworm activity to the cast stability depends decisively on the original composition of the parent soil. The tensile strength of casts was positively correlated with the clay and carbonate content of the parent soil. For the water stable aggregation the correlation was inverse. Moulding processes in the earthworm gut destabilize the soil structure but at the same time biochemical processes act as an antagonistic stabilizing system. The more sensitive the parent soil is to physical disturbance the more effective is the casting for the water stable aggregation but less effective for the tensile strength. © 1997 Elsevier Science Ltd

INTRODUCTION

A major effect of the soil fauna on soil processes is the reorganization of soil structure by animals moving through the soil and particularly by feeding on soil material (Martin and Marinissen, 1993; Oades, 1993). In respect to soil turnover earthworms are one of the most important animals. They have to ingest and egest large amounts of soil because of their low assimilation efficiency. Since the time of Swaby (1949), earthworm casts have generally been assumed to be more stable than the parent soil aggregates. Shipitalo and Protz (1989) proposed an aggregation model for earthworm casts, suggesting that the bonds, which are responsible for aggregate stability, consist predominantly of clay-polyvalent cation-organic matter linkages. The conditions for such linkages are optimal in casts but, nevertheless, casts can be less stable than the bulk soil (Shipitalo and Protz, 1988) even after drying (Zhang and Schrader, 1993). An increase of stabilization was reported by Marinissen and Dexter (1990) when ageing was combined with fungal colonization. Recently, Gu and Doner (1993) concluded from their results that soil aggregate stabilization generally is only realized with the contribution of both organic substances and polyvalent cations such as Al, Fe, Ca and Mg. In relation to digestion processes of earthworms Ca is likely to be the most important cation. Ultrastructural studies on the calciferous glands of *L. terrestris* revealed that Ca is secreted as $CaCO_3$ by specialized gland cells in a cyclic fashion characterized by the processes of secretion and regeneration (Schrader, 1991). During digestion the original soil structure is destroyed by thorough kneading at low pressures (McKenzie and Dexter, 1987). Barois *et al.* (1993) showed by comparative electron microscopy a complete destruction and a restruction of ingested soil from *Pontoscolex corethrurus*. In a micromorphological study Schrader and Altemüller (1993) and Schrader *et al.* (1995) investigated the gut content of *A. caliginosa* by fluorescence microscopy. After counterstaining of the thin sections with berberine sulphate a fragmentary arrangement of clayey microaggregates of 2–6 μm size became evident. Presumably, the results are mainly influenced by soil type and species of worms. It appears that to give a general answer to the question whether newly-formed cast aggregates are more stable than the parent soil aggregates, one must take into account the relevant parent soil properties and earthworm species. Studies comparing the effects of different species to soils of different characters are still lacking.

From this point of view our study was initiated to compare the properties of casts produced by earthworms of different living and feeding habits and collected from different soils. As representatives of the detritivore and the geophagous type, casts of *Lumbricus terrestris* and *Aporrectodea caliginosa*, respectively were investigated. Soils were selected to give a range of contents of clay, organic carbon and calcium carbonate. These criteria we found fulfilled in the upper two horizons of soils from a loam and a clay site. The soil material of the horizons was offered to the earthworms separately to avoid a mixture of the horizons by bioturbation. It was not the aim to simulate a natural soil profile, but we followed up on the idea to compare cast attributes originating from different parent soil material separately. The experiment was carried out under laboratory conditions to enable a species-specific separation of the earthworm casts. Besides natural aggregates, aggregates of remoulded soil served as a second control for the physical measurements to simulate mechanical processes during the gut passage of soil. The comparision of the casts and the parent soil of natural and remoulded aggregates should elucidate the interaction between casting effects of earthworms on the stabilization of soil structure and the properties of parent soil such as clay, carbonate and organic matter content.

MATERIALS AND METHODS

Soils, earthworms and sample preparation

The soil material was collected from a loam and a clay site which were under intensive agricultural use (sugar beet). Both sites are part of the Krummbach research catchment (Lower Saxony, Germany) of the Special Collaborative Program 179 of the German Research Foundation (DFG). The soil type of the loam site was a Gleyic Luvisol, FAO (Ultic Hapludalf, coarse-silty, mixed, mesic; USDA) of loess loam, whereas the clay site was characterized as a Calcaric-Vertic Cambisol, FAO (Vertic Eutrochrept, fine, mesic; USDA) of clay. A more detailed site discription can be found in Othmer and Bork (1989). From both sites soil material of the Ap and the next horizon below was used: Bt horizon below 290 mm in the case of the loam site and P horizon below 220 mm in the case of the clay site. To improve the separation of earthworm casts from the bulk soil, the soil was dried and sieved to obtain 1–2 mm aggregates. Then the aggregates were sprayed with water to obtain a water content of 18% (w/w) and 21% (w/w) for the loam and the clay soil respectively. When the water potential was at equilibrium, the aggregates were packed to a mean bulk density of 1.25 Mgm^{-3} into microcosms to a depth of 400 mm. For more details about the experimental design see Zhang and Schrader (1993).

Two earthworm species were used in the experiment: the anecic *Lumbricus terrestris* L. 1758 and the endogeic *Aporrectodea caliginosa* (Sav. 1826). They were handsorted from arable land and were then adapted for 2 weeks in the soils as used during the experiment. Each microcosm, filled with aggregates of one soil, was inoculated with one species. The experiment took place in a dark room at 12°C (±1°C). According to the food preferences of the different ecological groups, optimal feeding conditions were created for the earthworms: The detritivore *L. terrestris* was fed with dried leaves of *Betula pubescens* (C-to-N ratio of 42.5), whereas the geophagous *A. caliginosa* was fed with dried pulverized cattle manure (C-to-N ratio of 20.7). Both food sources were supplied to the soil surface. After 6 weeks, casts were collected from the surface and from within the soil and air-dried. Differences between casts due to ageing (0–6 weeks) would be levelled out by the air-dry process. For each soil, cast material of 48 adult individuals were used for the chemical and physical measurements: 16 *L. terrestris* and 32 *A. caliginosa*.

The casts were broken into 1–2 mm aggregates for the physical measurements (Hartge and Horn, 1989). In the case of the chemical measurements, casts and control soil were each ground with a mortar and pestle. Two kinds of soil aggregates served as controls: (1) 1–2 mm natural aggregates as used as the substrate and (2) remoulded aggregates. The remoulded aggregates were formed by kneading the soil at a water content of about the liquid limit to simulate mechanical processes in the earthworm gut without considering the chemical and biological effects from feeding. The soil was air-dried and broken into 1–2 mm aggregates.

Chemical measurements

The total carbon content (C_t) of the bulk soil and the casts was determined by dry combustion in a furnace using a Leco IR 12 C system (Leco Corp., Michigan, U.S.A.). The organic carbon content (C_{org}) was determined in samples from which carbonate had been removed with 10% HCl before. For both the C_t and the C_{org} determination samples of 100 mg were used and were analyzed in triplicate. The carbonate content was calculated from the differences between C_t and C_{org} supposing that $CaCO_3$ was the main carbonate compound.

The total nitrogen content (N_t) was estimated in triplicate by the Kjeldahl method. Samples of 5.0 g air dried soil were boiled in a sulphuric acid solution (96–98%) with salicylic acid, 1 Kjeltab CT (code: AA 20, C. Gerhardt GmbH and Co. KG, Germany) and 1.0 g Na-thiosulphate × 5 H_2O. Then a steam distillation was carried out with a NaOH solution (32%) added in 50 ml boric acid (2%) and an indicator. Finally, N_t was measured by titration using 20 mM HCl.

The determination of the pH was done in triplicate using 10 mM $CaCl_2$ with a ratio of 1:2.5 (soil:$CaCl_2$).

Physical measurements

The texture of the control soil and the casts was analyzed in triplicate with the standard pipette method as described by Hartge and Horn (1989).

Aggregate water stability was determined by the method proposed by Kemper and Rosenau (1986). The measurement for soil and casts was repeated six times. Four grams of air-dry aggregates between 1 and 2 mm were poured on a sieve with 0.2 mm mesh and then wet-sieved for 3 min at 35 rev min^{-1}, with a stroke of 40 mm (Hartge and Horn, 1989). The aggregates remaining on the sieve were collected and oven-dried. After being weighed they were dispersed with 0.2 N $Na_4P_2O_7$ solution, wet-sieved and oven-dried again to get the weight of sand fraction > 0.2 mm. The water stable aggregation (WSA) was calculated from the following equation:

$$WSA\% = (W_1 - W_2)/(4.0 - W_2) \times 100\%, \quad (1)$$

where W_1 is the mass of soil (g) remaining on the sieve after wet-sieving, and W_2 is the mass of soil (g) on the sieve after dispersion.

The tensile strength of air-dry aggregates was measured by indirect tension with the compression test apparatus WF 10020 from Wykeham Farrance, England. The aggregates were placed between two metal plates and crushed with a velocity of 0.38 mm min^{-1}. The crushing forces were determined with an electrical balance as described by Dexter and Kroesbergen (1985). At least 50 aggregates were crushed for each treatment because of the stochastical nature of aggregate tensile strength. The tensile strength of individual aggregates was calculated after Dexter and Kroesbergen (1985):

$$\sigma_t = 0.576F/d^2, \quad (2)$$

where σ_t is the aggregate tensile strength in kPa, F the crushing force in N and d the aggregate diameter in m.

Statistical analysis was carried out with the statistical graphics system (Statgraphics, STSC Inc., U.S.A.). The 5% probability level was chosen as the level of minimum significance.

RESULTS

The results of the chemical measurements are presented in Table 1. More than 95% of the total carbon content of all samples were detected as organic except in the P horizon of the clay control soil (83%) which had a high carbonate content (3.08%). C_{org} in casts of both earthworm species was higher than in the control soils. This was most evident for the lower horizon of both soils. Casts of *L. terrestris* collected from the Bt horizon of the loam soil contained more than twice C_{org} compared to the control soil aggregates. For the control of both soils a higher C_{org} content was detected in the Ap horizon than in the lower horizon. This result was also obtained for the casts in the loam soil. But the data of cast samples from the clay soil showed an inverse result, i.e. C_{org} was higher in the lower horizon than in the Ap horizon. Generally, C_{org} increased more in casts of *L. terrestris* than in casts of *A. caliginosa*. This difference was more evident in the loam soil than in the clay soil.

The carbonate content in the lower horizon of both control soils was higher compared to the Ap horizon. In the loam soil there was only 32% more $CaCO_3$ in the Bt horizon, whereas in the clay soil a six-fold increase in carbonate content was detected for the lower horizon. The carbonate content of casts from the Ap horizon of both soils and from the Bt horizon of the loam soil increased. Casts of *A. caliginosa* collected from the loam soil showed more than twice (Ap) and three times (Bt) increase in $CaCO_3$ content compared to the control soil. On the other hand $CaCO_3$ decreased in casts from the P horizon of the clay soil. In the case of *A. caliginosa* the carbonate content decreased 65% from the

Table 1. Means (SD) of the chemical measurements of the parent soil aggregates (control) and the casts of *L. terrestris* and *A. caliginosa* from the horizons of the loam and the clay soil

Sample	Hor.	C_t (%)	C_{org} (%)	$CaCO_3$ (%)	C/N	pH
			Loam soil			
Control	Ap	1.38 (0.026)	1.35 (0.026)	0.25	10.5	7.02
	Bt	0.75 (0.035)	0.71 (0.020)	0.33	11.9	7.11
L. terrestris	Ap	1.77 (0.031)	1.72 (0.061)	0.42	13.2	6.94
	Bt	1.70 (0.017)	1.64 (0.081)	0.50	13.8	6.65
A. caliginosa	Ap	1.46 (0.051)	1.38 (0.040)	0.67	10.7	6.64
	Bt	1.14 (0.031)	1.01 (0.055)	1.08	11.8	7.27
			Clay soil			
Control	Ap	1.96 (0.032)	1.90 (0.015)	0.50	10.5	6.90
	P	2.19 (0.350)	1.82 (0.025)	3.08	11.7	7.04
L. terrestris	Ap	2.34 (0.015)	2.26 (0.066)	0.65	12.4	6.72
	P	2.68 (0.031)	2.42 (0.042)	2.17	12.0	6.75
A. caliginosa	Ap	2.15 (0.074)	1.99 (0.118)	1.33	10.6	6.73
	p	2.36 (0.104)	2.23 (0.180)	1.08	10.9	6.99

control soil, i.e. to 19% lower $CaCO_3$ than in casts from the Ap horizon. The $CaCO_3$ decline of casts from *L. terrestris* amounted to 30% in the P horizon. Nevertheless, this carbonate content was 3 times higher than that of casts from the Ap horizon of the clay soil. Comparing the earthworm species half as much $CaCO_3$ was detected in casts of *L. terrestris* except in the P horizon where the double quantity of $CaCO_3$ was found.

The C-to-N ratio was taken into account as an index to the organo-chemical quality of the aggregates. In the upper horizon the C-to-N ratio was more narrow than in the lower horizon in both control soils. Only in the case of casts from *A. caliginosa* in loam soil was this difference between the horizons the same because of nearly the same ratios. In all the other cases no C-to-N ratio difference between the horizons was calculated. With the exception of the P horizon of the clay soil casts of *L. terrestris* showed a wider C-to-N ratio than aggregates of the control soil. Only in casts of *A. caliginosa* collected from the P horizon of the clay soil did the C-to-N ratio become more narrow. For all cast samples of *L. terrestris* a wider C-to-N ratio was calculated compared to casts of *A. caliginosa*. In relation to the food, a wider C-to-N ratio was detected for the leaves, which were offered to *L. terrestris*, than the manure which was offered to *A. caliginosa*.

The pH of casts of both earthworm species remained nearly neutral as it was also measured for the control soils.

As shown in Table 2, in the casts the percentage of clay was generally higher, and percentage of sand was generally lower, than that in the control soils. These results were more evident in samples from the loam soil than the clay soil.

The results of the water stable aggregation (WSA) and the tensile strength are summarized in Table 3. Casts of both species showed generally a decrease in WSA compared with that of the natural soil aggregates. For casts of *A. caliginosa* the decrease was more evident. Except for casts of *L. terrestris* from loam soil this difference was significant. It can be seen that the WSA of casts of *L. terrestris* was higher than that of *A. caliginosa*. This result is consistent with a 9–62% higher content of C_{org} in casts of *L. terrestris* compared to *A. caliginosa* (Table 1) indicating a stabilizing effect.

Table 2. Particle size distribution of the parent soil aggregates (control) and the casts of *L. terrestris* and *A. caliginosa* from the horizons of the loam and the clay soil

Sample	Hor.	Clay (%)	Silt (%)	Sand (%)
		Loam soil		
Control	Ap	16.2	80.8	3.0
	Bt	19.3	77.6	3.1
L. terrestris	Ap	16.0	81.5	2.5
	Bt	22.5	75.4	2.1
A. caliginosa	Ap	18.5	79.5	2.0
	Bt	20.3	77.2	2.5
		Clay soil		
Control	Ap	32.3	65.0	2.7
	P	54.7	41.9	3.4
L. terrestris	Ap	34.8	62.6	2.7
	P	55.4	41.6	3.0
A. caliginosa	Ap	32.0	65.5	2.5
	P	54.9	41.0	4.1

Table 3. Water stable aggregation (WSA) and tensile strength of the control soil aggregates (natural and remoulded) and the casts of *L. terrestris* and *A. caliginosa* from the horizons of the loam and the clay soil. Data from the same column of the same soil type and horizon with different superscripts are significantly different ($P < 0.05$)

Hor.	Sample	WSA in %	Tensile strength in kPa
		Loam soil	
Ap	Control (nat.)	78.8^{cd}	473^{a}
	Control (rem.)	8.8^{a}	411^{a}
	L. terrestris	76.7^{c}	617^{b}
	A. caliginosa	72.7^{b}	663^{b}
Bt	Control (nat.)	77.9^{c}	540^{b}
	Control (rem.)	15.1^{a}	448^{a}
	L. terrestris	73.4^{c}	710^{d}
	A. calignosa	67.8^{b}	620^{c}
		Clay soil	
Ap	Control (nat.)	81.2^{d}	800^{c}
	Control (rem.)	11.6^{a}	518^{a}
	L. terrestris	67.8^{c}	794^{c}
	A. caliginosa	58.4^{b}	692^{b}
P	Control (nat.)	86.2^{c}	886^{b}
	Control (rem.)	22.5^{a}	649^{a}
	L. terrestris	59.7^{b}	842^{b}
	A. caliginosa	54.3^{b}	841^{b}

While the WSA is an index for the aggregate stability at wet conditions the tensile strength is an index for the aggregate stability at dry conditions. Earthworm casts of the loam soil were significantly more stable than the natural aggregates when the tensile strength was measured (Table 3). The tensile strength of casts from the clay soil decreased slightly but not significantly except casts of *A. caliginosa* in the Ap horizon. Comparing the two species, casts of *L. terrestris* were significantly more stable in the Bt of the loam soil and the Ap horizon of the clay soil.

Casts of both earthworm species showed a significant increase in stability compared to remoulded aggregates measured by both methods. Clay aggregates of the control soil were more stable than loam aggregates. For casts this result was only true at dry conditions while the result was inverse for WSA.

DISCUSSION

Analogous to the strength sensitivity used in soil mechanics (Mitchell, 1976) we can define the sensitivity of soil structure stability to physical disturbance. In our case WSA and tensile strength are used as measures for the soil structure stability which can be expressed as the sensitivity of the parent soils as

$$S_{WSA} = WSA_{nat}/WSA_{rem} \quad (3)$$

for wet conditions and

$$S_{\sigma t} = \sigma_{t(nat)}/\sigma_{t(rem)} \quad (4)$$

for dry conditions. Furthermore, the efficiency of earthworm digestion and casting for stabilization of soil structure can be defined as

$$E_{WSA} = WSA_{cast}/WSA_{rem} \quad (5)$$

and

$$E_{\sigma t} = \sigma_{t(cast)}/\sigma_{t(rem)} \quad (6)$$

In Fig. 1 the efficiency of earthworm casting E_{WSA} and $E_{\sigma t}$ is plotted against the sensitivity of the parent soils S_{WSA} and $S_{\sigma t}$, respectively. It can be seen for WSA that the more sensitive a soil is to physical disturbance, the more effective is the stabilization by earthworm activity. Conversely, the efficiency concerning tensile strength decreases with increasing sensitivity. These relationships are based on the stability of remoulded aggregates, i.e. young aggregates like the earthworm casts but of the same content of clay, $CaCO_3$ and C_{org} as the natural soil

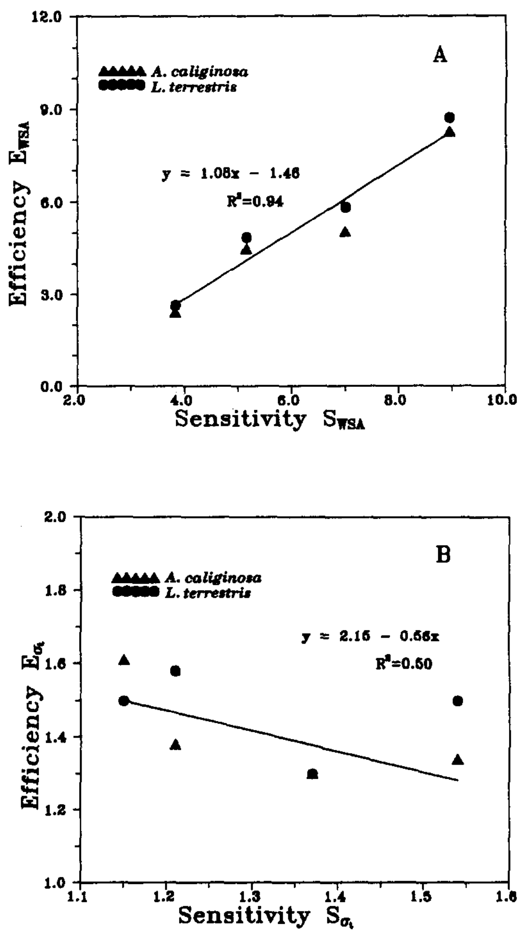

Fig. 1. Relations between the efficiency of earthworm casting (E_{WSA}, $E_{\sigma t}$) for soil structure stabilization and the sensitivity of the parent soils (S_{WSA}, $S_{\sigma t}$) to physical disturbance measured as water stable aggregation (A) and tensile strength (B). *** $P < 0.001$ and * $P < 0.05$.

aggregates. According to Dexter *et al.* (1988) natural aggregates obtain their high stability from numerous drying and rewetting cycles forming bonds of different natures between the contact points of soil particles over time. This process creates bonds which are generally more stable under wet conditions than are the fresh bonds in young earthworm casts. On the other hand, casts show characteristics which are derived from the biological moulding during soil digestion resulting in increased clay, $CaCO_3$ and C_{org} contents. These compounds form new linkages which cause increased cast stability compared with remoulded aggregates. From this it can be concluded that casting is a process which counteracts the destabilization caused by mechanical disturbance. Remarkable destabilization of soils by mechanical disturbance happens e.g. in agricultural practices during tillage like ploughing, especially when kneading processes occur in the top soil during wheeling at wet conditions (see overview in Blume, 1992, pp. 154–181 and 570–575). This conclusion appears to be valid for at least a variety of soils.

Zhang and Schrader (1993) reported for casts of three earthworm species from a silt loam soil a positive correlation between C_{org} and WSA as well as tensile strength. Furthermore, $CaCO_3$ was negatively correlated with tensile strength. In our study the earthworm casts originated from four different soil materials. Which role do the parent soil properties play in the stabilization of soil structure by earthworm casting? Figure 2 demonstrates the relationships between the clay content of parent soil and WSA as well as tensile strength of earthworm casts. With an increasing clay content, the WSA of casts decreases while the tensile strength increases. This indicates that casting, on one hand, is disrupting the bonds and making the clay dispersible, which was measured by wet-sieving: a high clay content leads to high dispersion and low WSA. On the other hand, through digestion processes, new bonds will be formed, from which clay–polyvalent cation–organic matter linkages are the most important ones (Shipitalo and Protz, 1989). However, the capacity to form new bonds is limited. The higher the clay content of the soil the larger will be the percentage of clay becoming unbonded. Its significance at dry conditions was measured by crushing: a high clay content, i.e. a high percentage of unbonded clay, caused a high tensile strength. The results show clay, besides C_{org} and $CaCO_3$ (Zhang and Schrader, 1993), to be most responsible for a decreasing WSA and increasing tensile strength in earthworm casts.

Figure 3 illustrates the relationships between the carbonate content of parent soil and WSA as well as tensile strength of earthworm casts. The WSA of the casts decreases with increasing carbonate content of the parent soils while the tensile strength

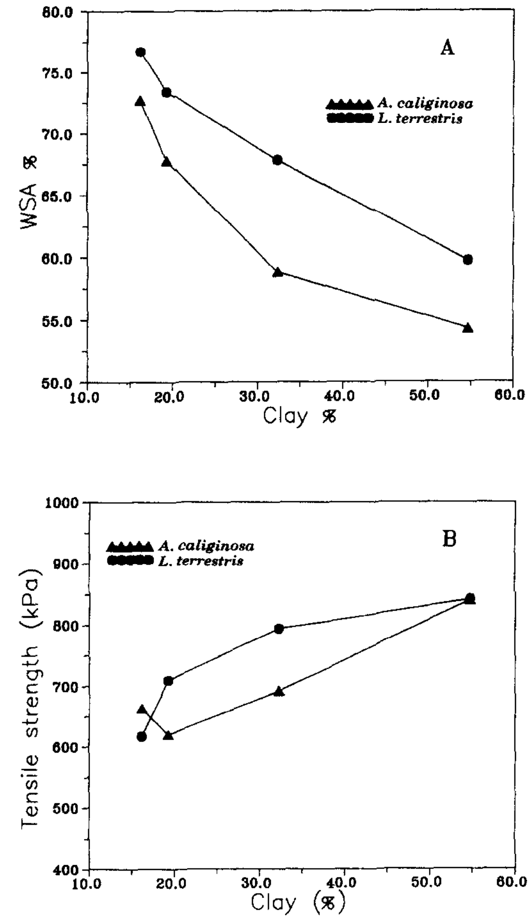

Fig. 2. Influence of the clay content of the parent soils on water stable aggregation (A) and tensile strength (B) of earthworm casts.

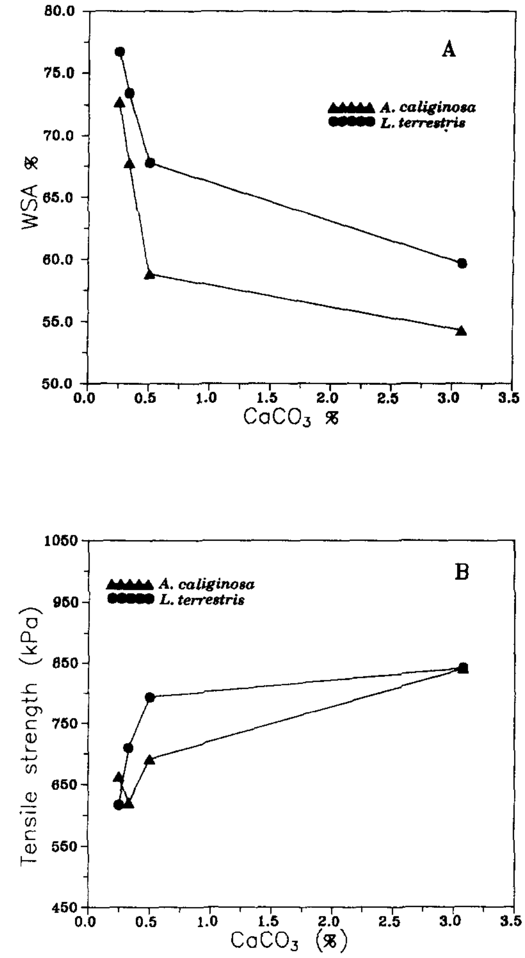

Fig. 3. Influence of the $CaCO_3$ content of the parent soils on water stable aggregation (A) and tensile strength (B) of earthworm casts.

increases. This can be a result of carbonate consumption and reaccumulation by digestion (Zhang and Schrader, 1993). Table 1 shows that the $CaCO_3$ content of the casts from the P horizon (>3% $CaCO_3$) decreased while from other soils (<1%$CaCO_3$) it increased. The change of the $CaCO_3$ content by digestion could be an index of the capacity of earthworm species to bond soil particles and to reform new stable aggregates. In relation to their aggregation model for earthworm casts Shipitalo and Protz (1989) assumed calcium to be the most involved cation in the clay–polyvalent cation–organic matter linkages.

The role of organic matter of the parent soils for the stability of earthworm casts is not clear. However, the tendency is similar to that of $CaCO_3$. To understand the role of the organic matter it would be desirable to clarify the chemical transformations by digestion. The C_{org} content in casts of *L. terrestris* was higher than in those of *A. caliginosa*. This result can be related to the nutrition habits of the earthworm species. Additionally, the C-to-N ratio of the food sources must be considered. The wider C-to-N ratio in casts of *L. terrestris* compared to those of *A. caliginosa* may be related to the wider C-to-N ratio of the offered leaves compared to the manure. The efficiency in consuming organic matter appears to be greater for the detritivorous *L. terrestris* than for the geophagous *A. caliginosa*. From this point of view it is clear that *L. terrestris* enriched C_{org} in casts to a greater extent.

Only small differences were measured in the texture between casts and parent soils. A significant selective particle ingestion by earthworms as observed by Lal and Akinremi (1983) appears to be confined to sandy soils.

Our conclusions are as follows: The C_{org} content of the earthworm casts is higher than the parent soils, and it increases more in loam soil than in clay soil. C_{org} increases more in casts of *L. terrestris* than *A. caliginosa*. The C-to-N ratio is nearly unchanged from the parent soil in casts of *A. caliginosa*, whereas it becomes wider in casts of *L. terrestris*.

At low carbonate contents of the parent soils ($< 1\%$) $CaCO_3$ increases in casts, more in casts of *A. caliginosa* than *L.terrestris*. The result is inverse at high carbonate contents before soil ingestion ($> 3\%$) where $CaCO_3$ decreases more in casts of *A. caliginosa* than *L. terrestris*.

Casts are less water-stable than natural soil aggregates but more water-stable than the artificially remoulded aggregates. The tensile strength of casts is higher than the remoulded aggregates and even higher than natural aggregates with low clay content.

The efficiency of casting for the stabilization of soil structure depends decisively on the sensitivity of a soil to physical disturbance: the more sensitive the soil the more effective is the casting for water stable aggregation and the less effective for tensile strength.

Water stable aggregation is negatively and tensile strength positively related to the clay and $CaCO_3$ content of parent soils.

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