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Impact of Collembola and Enchytraeidae on soil surface roughness and properties

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Abstract The aim of the study was to quantify the alteration of soil surface roughness caused by the casting activity of mesofauna. Undisturbed soil monoliths with a surface area of 5000 mm^2 were taken from the upper 4 cm of the Ap-horizon in agricultural land. Two tillage systems were studied: conventional tillage (CT) and conservation tillage (CS). The sampling plots were mechanically compacted by wheeling with graded loads. Sampling occurred in spring after compaction and before seeding. The soil monoliths were defaunated before inoculating one half of the monoliths with 150 individuals of Collembola (*Folsomia candida*) and the other half with 100 individuals of Enchytraeidae (90% *Enchytraeus minutus* and 10% *E. lacteus*). Soil surface roughness was measured using a noncontact laser scanner: before inoculation and 6 months later. Photographs show the soil surface covered with casts. Results from laser scanning show that in most cases the surface roughness increased due to mesofaunal activity. However, roughness decreased when cracks were filled with casts. The casting activity and surface roughness changes are highest in uncompacted soil. A high degree of soil compaction significantly reduced the activity at the surface. In most cases the soil surface is more altered in CT than in CS. When the content of carbon and nitrogen were determined, both elements were accumulated in the casts but more by Collembola than Enchytraeidae. The results are discussed in the context of the hemiedaphic (*F. candida*) and the euedaphic (*Enchytraeus* spp.) mode of living.

Key words Collembola · Enchytraeidae · Casts · Soil surface roughness · Soil tillage

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Introduction

The increasing weight of agricultural machinery has been recognized as a growing problem for the structure of arable soils, influencing soil fertility and soil health. This involves ecological as well as economical aspects, e.g. soil degradation, erosion, soil loss, reduced yields, and growing costs for fertilizers and energy input. Ehlers and Claupein (1994) show possibilities to minimize these problems by using conservation tillage (CS) instead of conventional tillage (CT).

Severely reduced soil pore space and destroyed pore geometry have negative impacts on biological processes due to reduced transport of gases, water and nutrients. Moreover, the destruction of the soil pore system hampers the growth of fine roots because of raised penetration resistance, limitations in the “habitable pore space” for soil organisms and changes of the microbial activity from aerobic to anaerobic mode (Brussaard and van Faassen 1994; Whalley et al. 1995). The mesofauna, especially Collembola (springtails) and enchytraeids (potworms), are of great importance for soil properties because they occupy key links within the food web in the soil promoting decomposition processes (Hendrix et al. 1986). However, their influence on soil structure has largely been neglected until now.

Didden and Marinissen (1994) proposed enchytraeids had comparable effects as earthworms on soil structural formation, but on a smaller scale. Dawod and FitzPatrick (1993) emphasized the increased importance of enchytraeids at low soil pH levels. Few data are available on the enchytraeids’ influence on soil porosity and their gut transit of soil material (Didden 1990; van Vliet et al. 1993, 1995). Van Vliet et al. (1995) concluded from their results that enchytraeids have a larger influence on soil structure in agricultural fields than in forested areas.

During a microcosm experiment Heisler et al. (1996) observed an accumulation of mesofaunal casts at the soil surface, increasing roughness, but they could not measure this effect. Didden (1987) showed that increased soil bulk density hampers the migration of Collembola into the soil, resulting in an avoidance of compacted soil. He stated that the available space for microarthropods is determined by animal size and the amount of accessible space, the size distribution of pores and their interconnection and the proportion of air-filled pores.

The aim of our investigation was to quantify the change in soil surface roughness caused by the activity of Collembola and Enchytraeids, and from this to gain insight into the impact of mesofauna on soil structure, an aspect underestimated up to now. This paper reports on geometrical data on soil surface roughness created by mesofauna under different tillage systems (CT and CS) and different grades of mechanical soil compaction. Furthermore, chemical data on the roughness-forming cast aggregates are presented.

Materials and methods

The investigation site is located near Relliehausen in the Northeast of the Solling area (Lower Saxony, Germany). The soil is characterized as a Pseudogley-Parabraunerde (FAO: Haplic Luvisol) derived from loess with a texture of loamy silt. At the investigation site conventional tillage (CT: ploughing to a depth of 300 mm) and conservation tillage (CS: incorporating straw mulch with a rotary harrow to a depth of 120 mm) have been practised for many years. Parts of the site of each tillage system were mechanically compacted by wheeling with graded loads: 0 tonnes; 2×2.5 tonnes; 6×5.0 tonnes (wheeling frequency × wheel load). Undisturbed soil monoliths were taken from each compacted plot of both tillage systems. They included the upper 40 mm of the soil and covered a surface area of 5000 mm^2. Samples were taken in spring after compaction and before seeding.

The soil monoliths were then enclosed in short acrylate tubes and defaunated in sets of three monoliths for 3 min at 750 W in a microwave oven. After cooling, the soil surface was rewetted by spraying with water. Two monoliths from each plot were inoculated with 150 individuals of Collembola (*Folsomia candida*), which corresponds to 30 000 individuals/m^2 and two with 100 individuals of Enchytraeidae (90% *Enchytraeus minutus* and 10% *E. lacteus*) which corresponds to 20 000 individuals/m^2. The numbers were derived from abundances in arable land (Tischler 1965; Didden 1993). Afterwards, the monoliths were covered with laboratory film and kept in a dark room at 20°C. No food was added. Six months later, the monoliths were defaunated again following the same procedure as mentioned above.

Before and after mesofaunal activity the roughness of the soil surface was determined using a laser relief meter. A central area of 1200 mm^2 within the surface of the monolith was scanned with a grid distance of 0.3 mm resulting in 13 225 height values for the 1200 mm^2 area. Vertical resolution of the laser scanner was 0.2 mm. From the digital elevation maps obtained three indices were calculated in order to characterize the surface roughness of each monolith. First, the specific surface area (SSA), which is the total surface area with reference to the map area of 1200 mm^2, was calculated. Secondly, the random roughness coefficient (RRC) as defined by Currence and Lovely (1970) was calculated. The RRC is taken as the standard deviation of smoothed elevation points. It is a frequently used index to describe soil surface roughness statistically. Lastly, the maximum difference in height (Δh) was determined. This is the difference between the highest and the lowest elevation point of the surface. As a measurement of the mesofaunal activity the relative difference in SSA before animal inoculation and 6 months later (ΔSSA, as a percentage) was calculated. For more details on the parameters SSA, RRC and Δh see Helming et al. (1993).

After the roughness measurements the surfaces of the monoliths were air-dried to prepare them for cast collection. The casts were carefully sucked up from the soil surface using a pipette connected with a water jet pump. Then the total carbon content (C_t) and the total nitrogen content (N_t) of the casts were determined in triplicate with a macro-elementanalyser LECO CHN-1000 (Leco, Kirchheim, Germany).

Results

Over the incubation period of 6 months, the soil surfaces of the monoliths were covered by casts of Collembola or Enchytraeidae, resulting in a change in surface roughness due to mesofaunal activity. Figure 1 (b, c, e, f) shows examples of this activity for CS monoliths in comparison with the soil surface of the monoliths before mesofaunal inoculation (Fig. 1a, d). The microstructure influenced by Enchytraeidae became coarser (Fig. 1b, e) than that influenced by Collembola (Fig. 1c, f). Furthermore, the development of soil surface roughness caused by casting activity depended on soil compaction. Surface roughness was less pronounced with increasing wheel loads.

Tables 1 and 2 contain the indices (arithmetic means) that were calculated from the laser data characterizing the soil surface roughness of two monoliths from each treatment. Figures 2 and 3 show changes in the index specific surface area (ΔSSA). The changes of the soil surface occurred in both directions, increasing (+ΔSSA) and decreasing (–ΔSSA) surface roughness.

The surface roughness increased for both tillage systems and both mesofaunal groups only in case of the 0 t wheel load. The difference in SSA for the collembolan monoliths was 3.10% (CT) and 6.25% (CS) and for the enchytraeid monoliths 10.75% (CT) and 5.20% (CS). By contrast, the RRC index decreased. Also, Δh decreased or remained unchanged in CT enchytraeid monoliths. Since the indices Δh and RRC express the range of elevation heights and their standard deviations, whereas SSA refers to the spatial distribution of elevations, one can conclude that mesofaunal activity levelled off the differences in surface elevation while creating a pronounced surface microstructure at the same time.

For the less compacted plots (2×2.5 tonnes) of the CT treatment, all three roughness indices indicated a smoothening effect of mesofaunal activity. This effect was more pronounced for enchytraeid (ΔSSA –7.05%) than for collembolan activity (ΔSSA –3.60%). In addition, Δh decreased by about 36–37%, which indicates the filling-up of soil cracks with casts. The RRC index decreased by 32% for Collembola and 40% for Enchytraeidae. However, the CS treatment with low compacted soil resulted in an increase in surface roughness.

The Collembola in the CT monoliths of the highly compacted plots (6×5.0 tonnes) caused an increase of soil surface roughness of 7.40%, but had no impact on the total elevation range. The RRC increased in CT whereas it decreased in the CS monoliths. Here, the soil surface became less rough (–1.4%) and Δh decreased by about 25%. For the Enchytraeidae with CS treatment the SSA as well as Δh remained almost constant. The RRC decreased by 25%. The CT monoliths showed almost no alteration of the SSA and the RRC index but Δh decreased by 25%.

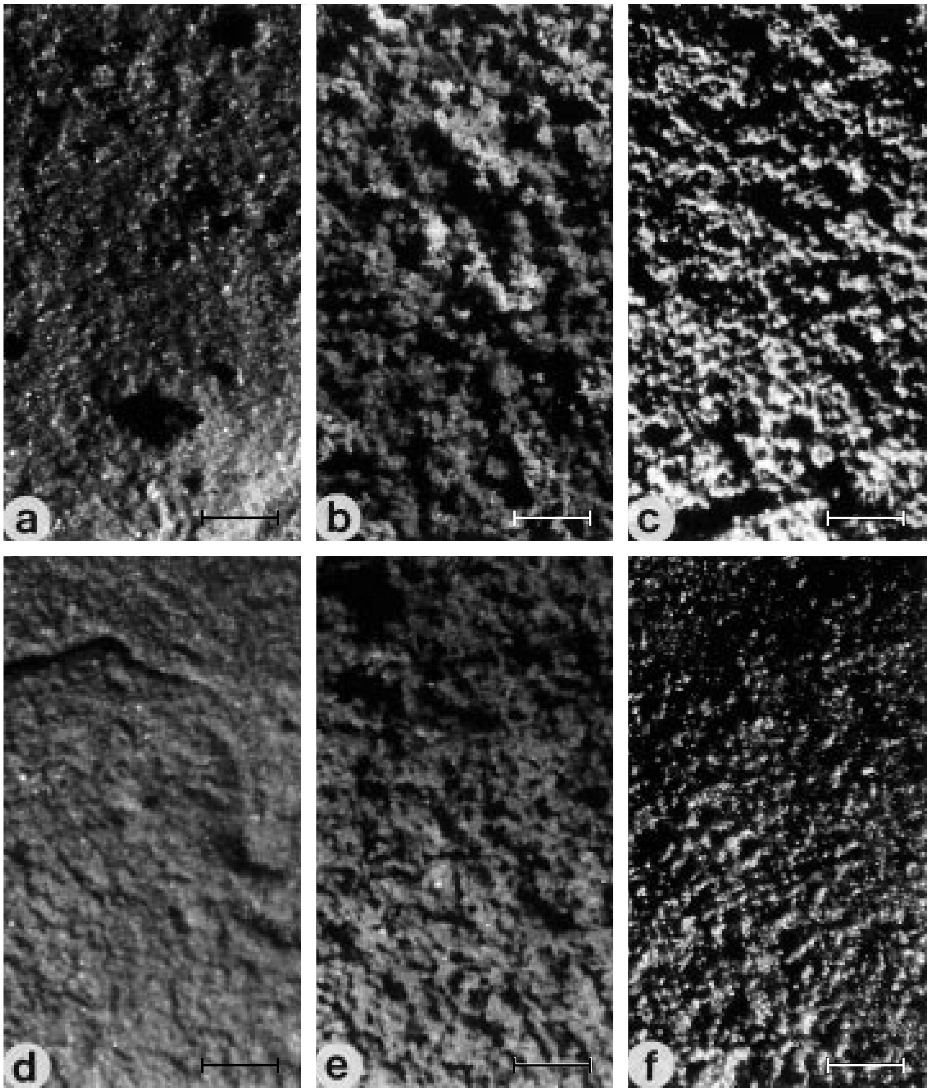

Fig. 1 **a–f** Microrelief of the soil surface from conservation tillage. **a–c** 0 t treatment. **d–f** 6×5.0 t treatment (wheeling frequency × wheel load). **a, d** Before mesofaunal activity; **b, e** after enchytraeid activity for 6 months; **c, f** after collembolan activity for 6 months. *Scale bars*: 1 mm

Table 1 Results of noncontact laser scanning of the soil surface before and after collembolan activity. (*SSA* specific surface area, *RRC* random roughness coefficient, Δh maximum difference in height in millimetres)

Tillage system Wheel load in tonnes	Soil surface at start			Soil surface after 6 months		
	SSA	RRC	Δh (mm)	SSA	RRC	Δh (mm)
Conventional						
0	1.13	0.40	6.5	1.17	0.37	5.5
2×2.5	1.35	1.38	11.0	1.30	0.94	7.0
6×5.0	1.15	0.38	6.5	1.23	0.41	6.5
Conservation						
0	1.13	0.35	7.5	1.20	0.30	6.0
2×2.5	1.12	0.24	4.0	1.16	0.26	4.5
6×5.0	1.39	0.94	12.0	1.38	0.83	9.0

In general, the range of structural alterations was most pronounced on the soil surfaces of the Enchytraeid monoliths. Roughness effects decreased in enchytraeid monoliths with increasing wheel load for both tillage systems, while such effects were observed for collembolan monoliths only in the case of CS.

The results of the chemical analyses show an increase of C_t and N_t at the soil surface caused by mesofaunal activity (Table 3). In general, the contents of C_t and N_t were higher in soil and casts of the CS plots than of the CT plots. Collembolan casts were more enriched with C_t and N_t than were those of Enchytraeidae. In collembolan casts the C_t content increased twofold and the N_t increased threefold. In the case of enchytraeid casts, C_t remained almost the same in CT and increased in CS by about 10%. For N_t, an increase of about 50% was found in enchy-

Table 2 Results of noncontact laser scanning of the soil surface before and after enchytraeid activity (*SSA* specific surface area, *RRC* random roughness coefficient, Δh maximum difference in height in millimetres)

Tillage system Wheel load in tonnes	Soil surface at start			Soil surface after 6 months		
	SSA	RRC	Δh (mm)	SSA	RRC	Δh (mm)
Conventional						
0	1.12	0.41	3.5	1.24	0.35	3.5
2×2.5	1.48	1.90	13.5	1.34	1.15	8.5
6×5.0	1.39	1.05	12.0	1.38	1.07	9.0
Conservation						
0	1.15	0.50	7.0	1.21	0.46	6.5
2×2.5	1.29	0.82	8.5	1.36	0.79	9.5
6×5.0	1.46	1.21	10.0	1.44	0.95	10.5

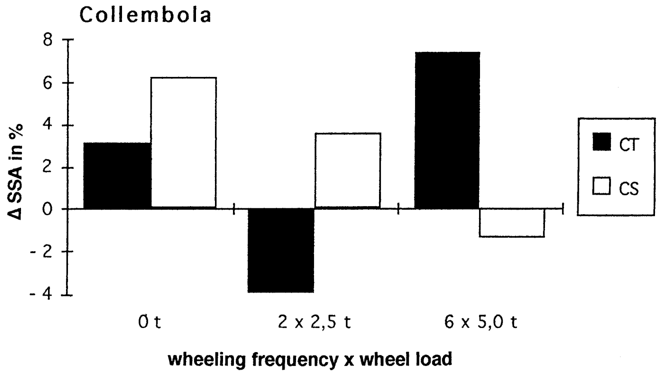

Fig. 2 Differences in specific surface area before and after collembolan activity (ΔSSA) in relation to wheel load and conventional tillage (*CT*) and conservation tillage (*CS*)

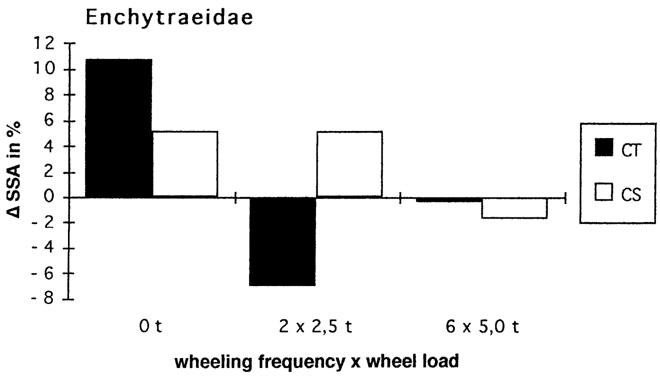

Fig. 3 Differences in specific surface area before and after enchytraeid activity (ΔSSA) in relation to wheel load and conventional tillage (*CT*) and conservation tillage (*CS*)

traeid casts. The C/N ratio became narrower as a result of mesofaunal activity. This effect was more pronounced in collembolan than in enchytraeid casts.

Discussion

Our study shows soil mesofauna creating a fine-structured soil surface by casting. Mesofaunal activity resulted mostly in increased soil surface roughness. In some cases

Table 3 Total carbon (C_t) and nitrogen (N_t) contents as arithmetic means for $n=3$ and C/N ratios of the soil and the mesofaunal casts

Tillage system Sample	C_t (%)	N_t (%)	C/N
Conventional			
Soil	0.96	0.108	8.9
Collembola casts	1.76	0.328	5.4
Enchytraeid casts	0.91	0.165	5.5
Conservation			
Soil	1.40	0.154	9.1
Collembola casts	2.95	0.519	5.7
Enchytraeid casts	1.58	0.239	6.6

surface roughness decreased when cracks were filled with casts which flattened and homogenized the coarse surface structure. However, an enhanced fine structure on the soil surface has both positive and negative aspects. The positive effect arises from the fact that the organic substances which cement small aggregates are more resistant to microbial attack than are those of larger aggregates (Haider 1996), resulting in increased aggregate stability. The negative aspect relates to the fact that the finer the surface structure formed the more sealing occurs and hence surface runoff increase (Rudolph et al. 1994).

However, an increase as well as a decrease in soil surface roughness represent a proportion of mesofaunal activity on the soil surface. In relation to soil compaction, the results showed depression of surface casting activity at low soil compaction (2×2.5 tonnes) while the activity decreased at high compaction (6×5.0 tonnes). These results fit in with the abundances of Collembola and enchytraeids determined on the same plots of the investigation site (Langmaack et al. 1996; Kracht and Schrader 1997).

The greatest increase in soil surface roughness for the collembolan monoliths was determined from the 6×5.0 tonnes monoliths in CT. This result can be explained by the hemiedaphic mode of living of *F. candida* in contrast to the euedaphic enchytraeids. Hemiedaphic animals live not only in the soil but also on the surface, while euedaphic animals live within the soil. Thus, it appears that *F. candida* was unable to penetrate the compacted soil. Its activities were confined to the surface.

Differences in the mode of living between the mesofaunal groups are also responsible for differences in the chemical composition of their casts. The euedaphic *Enchytraeus* spp. feed on the soil matrix to a greater extent than does *F. candida*. In addition, *F. candida* uses not only the organic resources in the soil but also those from the surface. From this point of view it is evident why the casts of *F. candida* were more enriched in carbon and nitrogen with a narrower C/N ratio than those of the enchytraeids. Differences between the tillage systems can be related to the high organic matter content in the surface CS soil caused by mulching.

The increase in carbon contributes to the water stability of soil aggregates influenced by Collembola (Heisler et al. 1996) as well as enchytraeids (Didden 1990; Chan and Heenan 1995). Furthermore, mesofaunal activity causes an accumulation of nutrients at the soil surface with high availability because of favourable, i.e. wide, surface/volume ratio of these fine cast aggregates (diameter <0.5 mm). On the scale of a microstructure built up with mesofaunal casts, aeration is improved and this enhances aerobic microbial processes and organic matter dynamics. The microscopical observations of Chan and Heenan (1995) revealed that enchytraeid casts were much more porous than aggregates from bulk soil. In addition, a soil rich in fine aggregates may be penetrated more easily by fine roots.

Considering their high abundance, high reproductive rates and short generation period, the impact of Collembola and enchytraeids on the structure formation in arable soils is likely to be great, especially under CS conditions where the use of heavy machinery is avoided.

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