

The impact of conventional and reduced tillage on the Enchytraeidae population in sandy soil and their correlation with plant residue and earthworms

Till Severon¹, Monika Joschko^{2*}, Dietmar Barkusky³, Ulfert Graefe⁴

¹ FH Eberswalde, Friedrich-Ebert-Straße 28, 16225 Eberswalde, Germany

² Leibniz-Zentrum für Agrarlandschaftsforschung (ZALF) e.V., Institut für Landschaftsbiogeochemie, Eberswalder Straße 84, 15374 Müncheberg, Germany

³ Leibniz-Zentrum für Agrarlandschaftsforschung (ZALF) e.V., Forschungsstation Landwirtschaft, Eberswalder Straße 84, 15374 Müncheberg, Germany

⁴ IFAB Institut für Angewandte Bodenbiologie GmbH, Sodenkamp 62, 22337 Hamburg, Germany

* Correspondence: e-mail: joschko@zalf.de; phone: +49 33432 82254; fax: +49 33432 82343

Abstract

Enchytraeids are a significant part of soil biota especially in arable land; it is therefore important to know their sensitivity to management. Reduced tillage (RT) is a cultivation method that benefits many groups of soil fauna, but the effects RT has on enchytraeids remains unclear. The aim of this study was to ascertain how the enchytraeid abundance at a research site on sandy soil in Northeast Brandenburg was affected by RT and conventional tillage (CT) during a ten year observation period and what reasons there may be for any observed effects of cultivation methods on enchytraeids. Works of several authors led to our hypothesis that a change in food availability and possible antagonistic relations to earthworms are likely to be the reasons for a negative effect of RT on enchytraeids abundance. Therefore, we examined the correlation between enchytraeids and plant residue as well as earthworms using Spearman's rank correlation coefficient. Our study showed that RT had a distinctly negative effect on the abundance of enchytraeids at our research site. The results of the study also showed that their abundance correlated significantly positive with plant residue under CT while under RT no correlation was ascertained. These findings support the thesis of Hendrix et al. (1986), which states that the bacteria-based food webs developing under CT favor organisms with high metabolic activity like enchytraeids, whilst the fungi-based food webs that occur under RT favor other soil animals such as earthworms. While earthworms were indeed favoured by reduced tillage at the experimental site, no clear relationship, neither positive nor negative, was found with respect to enchytraeid vs. earthworm abundances.

Keywords: Enchytraeidae; earthworms; conventional tillage; reduced tillage; plant residue

1. Introduction

Soil organisms are of great importance for agriculture. They affect soil structure and the breakdown of plant residue and therefore have a considerable impact on soil fertility (Whalley et al. 1995, Heisler 1998). In arable land soil organisms are more influenced by human activity than in any other ecosystem (Heisler 1998). For these reasons one aim of the German Federal Soil Protection Act is to improve the biological activity of arable soil by using site-specific management methods (BBodSchG 1998).

Reduced tillage (RT) is a management method that has positive effects on many groups of soil organisms (Didden et al. 1994, Kladvik 2001, Holland 2004, Joschko et al., 2009), in particular

earthworms, which belong to the most important biota in agricultural soils (Lee 1985). This study investigates the effects that conventional tillage (CT) and RT have on enchytraeids.

Enchytraeids are good indicators of biological activity in soil (Jänsch et al. 2005, Graefe & Beylich 2005) and have been the subject of many studies concerning arable land. They are also part of many processes which occur in arable soil and thus have an impact on the decomposition of plant residue (Golebiowska & Ryszkowski 1978, Hendrix et al. 1986) and on the soil structure (Didden 1990, Van Vliet et al 1995, Graefe & Beylich 2005). Hendrix et al. (1986), Golebiowska & Ryszkowski (1978) and Novak (2004) suggest that enchytraeids are

even of greater importance than earthworms where conventionally cultivated arable land is concerned because they are less sensitive to ploughing and more active metabolically.

The effect RT has on enchytraeids is not entirely clear. Some studies suggest that enchytraeids react negatively to the reduction of tillage (House & Parmelee 1985, Didden et al. 1994, Zwart et al. 1994), others suggest a positive reaction (Parmelee et al. 1990, Röhrig et al. 1998). One study found that the abundance of enchytraeids was higher under CT or under RT depending on the season of the year (van Vliet et al. 1995).

In this study the impact of CT and RT on the enchytraeid population of a research site on sandy soil in Northeast Brandenburg was investigated over a time span of ten years. Previous studies at this research site led to the hypothesis that enchytraeid abundance reacts negatively to reduced tillage. To find the reasons for the reaction of enchytraeids to RT we first examined the correlation between enchytraeids and plant residue. Plant residue and microorganisms decomposing plant residue are the main food source of enchytraeids (Whitfield 1977, Didden et al. 1994, Van Vliet et al. 1995). This led to the hypothesis that a change in food webs occurring under CT and RT would be visible in the relationship between enchytraeids and plant residue. Additionally we tested the hypothesis that enchytraeids and earthworms have an antagonistic relationship.

2. Material and methods

2.1. Study site experimental design

The study was carried out on a 74 ha heterogeneous field belonging to the Komturei Lietzen in the federal state of Brandenburg, Germany (Joschko et al. 2009). The dominating soil type is Luvisol (FAO/ISRIC/ISSS 1998; Seyfarth et al. 1999). The site is characterised by a 9.6 °C mean annual temperature and 472 mm of mean annual precipitation (1992–2004). The field was under conventional tillage until 1996. Following the harvest in September 1996, non-inverting, ploughless tillage was established in one half of the field, whilst the other half continued to be tilled conventionally. Residue cover at the time of sowing was <15% for both systems. The ploughless system is referred to as “reduced tillage” throughout this article because

the energy input and depth of the soil disturbance is reduced (Cannell 1985). The amount of fertiliser and pesticides used was the same in both tillage systems except in 1997 and 1998, when additional herbicides were applied to the reduced tillage system. Further details are found in Joschko et al. (2009).

42 monitoring plots (2m x 15m) on four transects were permanently installed in the field. The transects follow the main slope and tillage direction, with 21 plots for each tillage system. (Fig. 1). The distances between the 42 plots were irregular, with a mean distance of 70 m (Joschko et al., 2009).

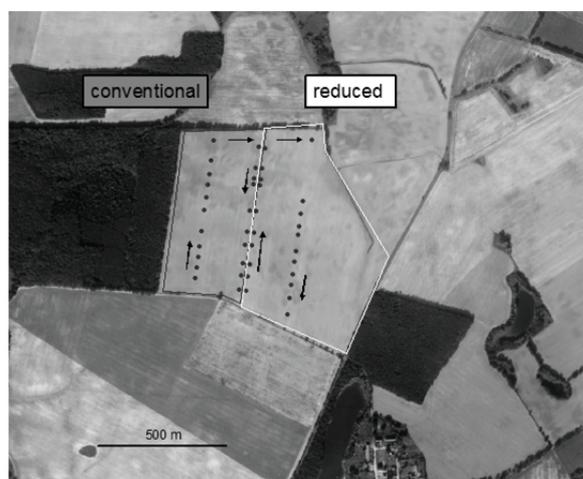


Fig. 1. Experimental design Lietzen: a 74 ha field under conventional and partly under reduced tillage with 21 plots each.

The crop rotation was as follows: winter wheat (1996), winter rye (1997, 1998), oilseed rape (1999), winter rye (2000, 2001, 2002), oilseed rape (2003), winter wheat (2004), grain maize (2005) and peas (2006).

2.2. Enchytraeid sampling and species identification

In September 1996 enchytraeids were sampled at each of the 42 plots prior to the installation of the two tillage variants and subsequently in spring (April, May) or autumn (August, September, October, November) of the following years up to 2006. In 1998, 2000, 2001 and 2006 sampling was carried out both in spring and autumn. Two soil cores with a 4.1 cm diameter were taken up to a depth of 20 cm from each plot. The soil cores were divided into four equal sections (0-5 cm, 5-10 cm, 10-15 cm, 15-20 cm).

In 2003 and 2004 only the top 15 cm of the soil were sampled.

Enchytraeids were extracted from soil using a modification of the wet-funnel method without heating (following Graefe 1984, as cited in Dunger & Fiedler 1997, p. 420). The soil sample was immersed in water by placing it into a sieve (mesh size 1.5 mm) in a water-filled bowl. After 2-3 days of extraction the sieve with the remaining soil was removed and most of the water in the bowl was emptied. The remaining water containing the enchytraeids was filtered through a fine sieve (mesh size 20 μm), and washed into a petri dish. Then the enchytraeids were counted using a binocular microscope. The total number of soil cores analysed for enchytraeid abundances was 1260 with a total of 4872 single samples.

Enchytraeid species identification was carried out at one soil core each (0-20 cm) from 5 plots sampled in November 2005 after maize (one under conventional tillage, 4 under reduced tillage) and at one soil core each (0-20 cm) from 8 plots sampled in September 2008 (four of each tillage variant). Species identification was based upon Nielsen & Christensen (1959), Schmelz (2003) and Schmelz & Collado (2010).

2.3. Earthworm sampling

Earthworms were also assessed at each of the 42 plots in September 1996 prior to the installation of the two tillage variants and subsequently in spring (April/May) of the following years up to 2006 (see Joschko et al. 2009). In 2000, 2003, 2005 and 2006 additional sampling was carried out in autumn (September, October, and November). Earthworms were collected at each of the 42 plots and were hand sorted from one 50 cm x 50 cm x 20 cm (w, l, depth) soil block immediately after sampling. Hand sorting has proved to be the optimal sampling method for the dry soils sampled at this location.

The earthworms were counted and identified to species level according to Sims & Gerard (1985) and Graff (1953).

2.4. Plant residue sampling

After extracting the enchytraeids the amount of coarse plant residue in the soil sample was

ascertained using a modified Fenwick-can (Dunger & Fiedler 1997). The air-dried soil was placed on the upper sieve (5 mm mesh size) of the Fenwick-can. With the water flow coming from below and above, the coarse organic material floated and was caught in a finely woven sieve (ca. 200 μm). Then the organic material was dried for two days at 60°C, sieved again (1 mm mesh size) and weighted to scientific precision.

Plant residues were collected from 0-20 cm; under conventional tillage plant residues were distributed to a depth of 25 cm however; this bias explains slightly lower values for plant residue amounts in 0-20 cm soil depth.

2.5. Statistical analysis

For data analysis we used the software StatSoft STATISTICA 7.1. With STATISTICA we tested for normal distribution using q-q plots and carried out correlation analysis. Because the data were not normally distributed we used Spearman's rank correlation coefficient. This correlation coefficient requires only ordinal data and can also be used for metric data which are not normally distributed (Rudolf & Kuhlisch 2008). The software automatically tested for significance ($p < 0.05$). When small amounts of data were concerned no automatic test for significance was conducted. We also used STATISTICA for the creation of graphics and Sigma Plot.

2. Results

3.1. Effects of tillage on enchytraeid abundance and species composition

The average abundance of enchytraeids collected at all 21 CT plots and 21 RT plots during the 10 year observation period indicate a strong positive effect of tillage on the enchytraeid population. The average enchytraeid abundance under CT was considerably higher with 22567 ind. m^{-2} . Under RT the enchytraeid abundance was lower with 12318 ind. m^{-2} .

The changes over the course of time in the average enchytraeid abundance under CT and RT (Fig. 2) indicate that the increase and decline of the enchytraeid abundance under both cultivation systems occurred mainly during the same years. It also shows that the enchytraeid

abundance was considerably higher under CT at most sampling dates. Enchytraeid abundances at single plots were not spatially autocorrelated (data not shown). While under conventional tillage enchytraeids were distributed evenly over the sampled soil depth of 0-20 cm, they concentrated in the upper soil (0-10 cm) in plots under reduced tillage. The enchytraeid species determination from soil samples in 2005 and 2008 yielded 15 species in 2005 (Tab. 1) and 9 species in 2008 (Tab. 2).

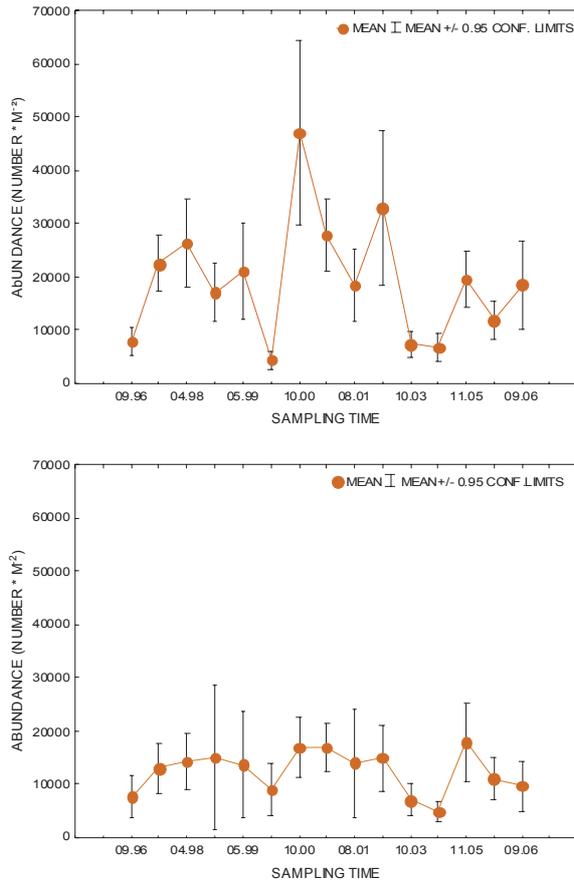


Fig. 2. Enchytraeidae abundance under conventional (above) and reduced (below) tillage over a ten year period.

Tab. 1. Enchytraeid species composition and abundance (ind. m⁻²) found in five plots under conventional (No. 10) and reduced (Nos. 29, 30, 31, 42) tillage in Lietzen in 2005.

Species \ Plot	10	29	30	31	42
Achaeta pannonica	1136	12498	31812	379	-
Buchholzia appendiculata	379	-	11361	-	-
Enchytraeus buchholzi agg.	-	379	-	-	-
Enchytraeus christenseni agg.	6059	757	3408	-	-
Fridericia bulboides	-	-	379	-	-
Fridericia christeri	1136	-	-	757	-
Fridericia galba	-	1136	-	-	-
Fridericia maculatiformis	-	2272	3408	3030	-
Fridericia sp. (trid)	-	757	-	-	-
Fridericia sp. juv.	1136	3030	2651	3030	-
Henlea jutlandica	1515	757	-	-	-
Henlea perusilla	-	-	-	-	379
Henlea ventriculosa	379	379	1136	-	-
Marionina communis	-	-	4166	379	-
Marionina minutissima	-	-	-	-	379
Oconnorella tubifera	-	-	5681	-	-
Total	11740	21965	64003	7574	757

Tab. 2. Enchytraeid species composition and abundance (ind. m⁻²) found in eight plots under conventional (Nos. 10, 19, 20, 21) and reduced (Nos. 29, 30, 31, 42) tillage in 2008.

Species \ Plot	10	19	20	21	29	30	31	42
Achaeta pannonica	757	1515	3787	757	2272	11361	-	-
Buchholzia appendiculata	-	-	-	-	-	1515	-	-
Enchytraeus buchholzi agg.	-	-	757	757	1515	5302	1515	-
Enchytraeus christenseni agg.	-	-	5302	1515	3030	15906	6059	12119
Fridericia bulboides	-	-	-	-	757	-	-	-
Fridericia christeri	-	757	-	-	-	-	-	-
Fridericia maculatiformis	-	-	757	-	1515	2272	-	-
Fridericia singula	-	757	-	-	-	-	-	-
Fridericia sp. juv.	757	1515	2272	-	2272	1515	2272	-
Henlea ventriculosa	-	-	-	-	1515	-	757	-
Total	1515	4545	12876	3030	12876	37871	10604	12119

3.2. Plant residue and its correlation with enchytraeid abundance

The average amount of plant residue in the upper 20 cm of soil was considerably higher under RT and a distinct accumulation in the upper 5 cm could be seen. Under CT the plant residue was evenly distributed over the sampled depth.

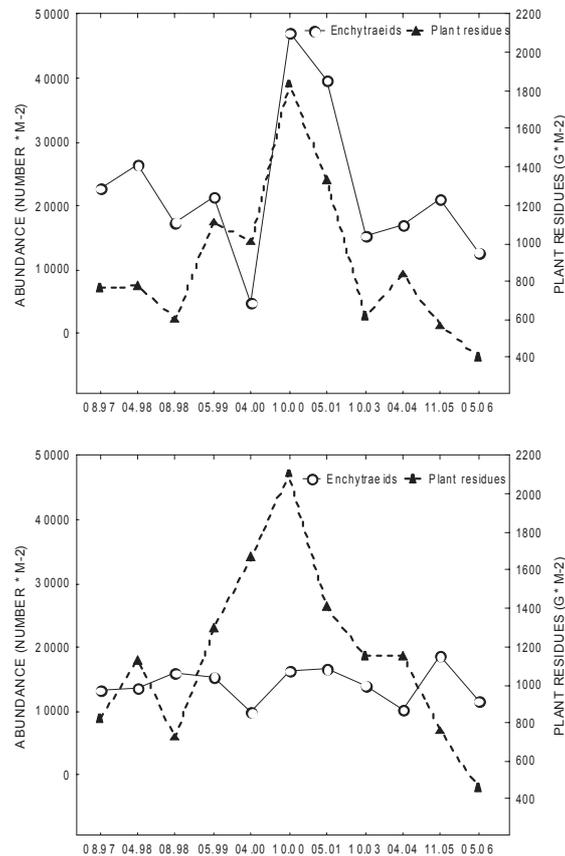


Fig. 3. Relationship between Enchytraeidae and plant residue during the observation period. Above: conventional tillage; below: reduced tillage.

The relationship between the total amount of enchytraeids and plant residue sampled each year, showed considerable differences between CT and RT on the 21 plots per cultivation system (Fig. 3). The relationship was markedly closer under conventional tillage. Under CT, the correlation was positive at 10 out of 11 sampling

campaigns; four of these correlations were statistically significant (Tab. 3). Under reduced tillage, in contrast, the correlation coefficient did not indicate any positive or negative trend and was never significant.

Tab. 3. Rank correlation coefficient (Spearman) between enchytraeids and plant residue for the 42 sample plots under conventional (CT) and reduced (RT) tillage (bold: significant).

Sampling date	CT	RT
Aug. 97	-0.099	0.158
Apr. 98	0.546	0.112
Aug. 98	0.453	-0.399
May 99	0.625	0.071
Apr. 00	0.199	-0.107
Oct. 00	0.578	-0.001
May 01	0.092	0.283
Oct. 03	0.104	-0.164
Apr. 04	0.007	0.077
Nov. 05	0.326	0.208
May 06	0.055	-0.073

3.3. Earthworm species composition and abundance and its correlation with enchytraeid abundance

Main earthworm species at the Lietzen site was the shallow-working *Aporrectodea caliginosa* (Savigny), especially *A.c. forma trapezoides* (Severon et al. 2007, Joschko et al. 2009). Besides this dominating species, *A. rosea* (Savigny) and the deep-burrowing *Lumbricus terrestris* L. was found. The proportion of *L. terrestris* was higher under reduced tillage compared to conventional tillage. The average earthworm abundance, assessed between 1997 and 2006 at 21 plots under both CT and RT was low, characterized by a mean abundance of 12 ind. m⁻². The average abundance of earthworms, shown in Fig. 4, indicates a strong negative effect of tillage on earthworm abundance. Under RT the average earthworm abundance was considerably higher than under CT. The data showed a remarkable spatial variability of abundances which were related to soil properties (Joschko et al. 2009).

As stated above, the two cultivation systems had the opposite effect on enchytraeids, with increased enchytraeid abundances under conventional tillage, suggesting an antagonistic relationship between the two families. However, no significant negative correlation between average enchytraeid and earthworm abundance could be established when the abundance data

of both groups from 42 plots at 12 sampling dates between 1997 and 2006 were compared. The only significant correlation was positive and was found under reduced tillage (Tab. 4).

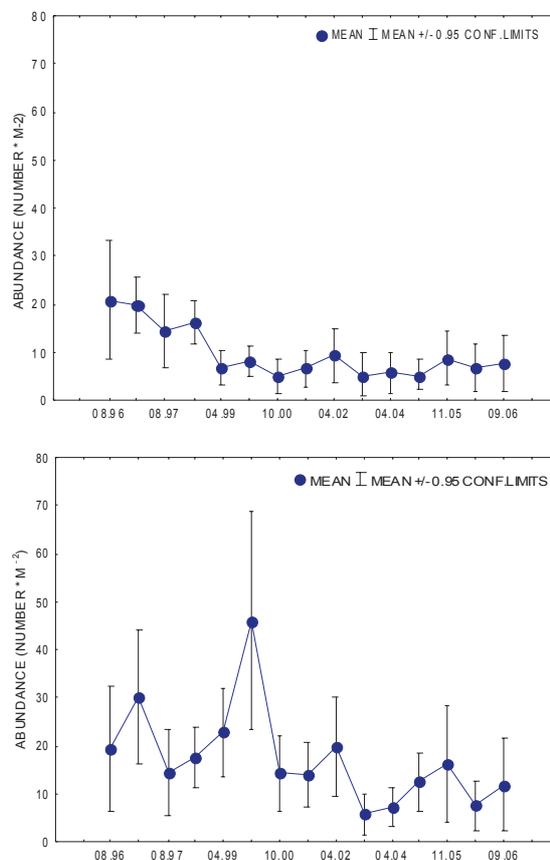


Fig. 4. Earthworm abundances under conventional (above) and reduced (below) tillage over a ten year period.

Tab. 4. Rank correlation coefficient (Spearman) between enchytraeids and earthworms at 42 plots and 12 dates under conventional (CT) and reduced (RT) tillage (bold: significant).

Sampling date	CT	RT
Aug. 97	0.43	-0.27
Apr. 98	0.10	-0.08
Aug. 98	-0.12	0.24
May 99	0.09	0.43
Apr. 00	0.11	0.55
Oct. 00	-0.27	-0.18
May 01	-0.21	0.02
Aug. 01	-0.02	0.00
May 02	-0.24	0.01
Nov. 05	-0.35	-0.04
May 06	0.11	-0.38
Sep. 06	0.08	-0.09

4. Discussion

The long-term field experiment Lietzen, installed in 1996 on a 74 ha field, enabled to monitor enchytraeid abundances on tilled soils as

influenced by conventional and reduced tillage. The research site is characterized by sandy soils typical of the dry Northeast of Brandenburg; corresponding to the suboptimal conditions, faunal activity such as earthworm activity, is usually low and spatially highly variable (Joschko et al. 2009).

Average enchytraeid abundance in Lietzen was 22567 ind. m⁻² under CT and 12318 ind. m⁻² under RT. These values are high but not unusually high compared to other studies carried out on arable sites; the majority of the enchytraeid species found here are typical of arable land (Didden et al. 1997).

Our main research question related to the effect of reduced, i.e. non-inverting tillage on the enchytraeid population compared to conventional tillage. Our data clearly showed that enchytraeid abundance was higher under conventional tillage. While under reduced tillage the “original” enchytraeid abundances found in autumn 1996 stayed more or less at the same level, enchytraeid numbers apparently increased under conventional tillage with, however, considerable fluctuations (Fig. 4).

The changes in cultivation management from CT to RT in Lietzen thus had a distinctly negative effect on enchytraeid abundance. This supports the findings of House and Parmelee (1985), Didden et al. (1994), and Zwart et al. (1994), who also noted that enchytraeids were negatively affected by RT.

Next, we found that under conventional tillage there was a close relationship between enchytraeid abundances and plant residues, with increasing enchytraeid numbers with increasing food supply. Plant residue and the microorganisms, which primarily decompose the plant residue, are the main food source for enchytraeids (Whitfield 1977, Diddern et al. 1994, Van Vliet et al. 1995).

Interestingly, the amount of plant residues in the soil was slightly higher in plots under reduced tillage compared to conventional tillage (Severon 2008). Since annual yields were more or less the same under both tillage systems (Barkusky et al. 2007), there must be other reasons for this result. First, the amount of plant residues under conventional tillage may be slightly underestimated due to a sampling depth of 0-20

cm only, while plowing depth was 20-25 cm. Second, higher amounts of plant residues could be due to reduced decomposition processes under reduced tillage, including sparser grazing by enchytraeids due to reduced abundances. This latter explanation refers mainly to the data from spring sampling, since harvest and incorporation of plant residues happened in autumn.

Obviously, under conventional tillage with high numbers of enchytraeids, the food resource was limiting for enchytraeids in the studied soil, reflected in the close relationship between plant residues and enchytraeid numbers. Under RT no correlation was detected.

But what could be the reason for enhanced enchytraeid numbers under conventional tillage? Next we addressed potential antagonistic relations between enchytraeids and earthworms, considering the striking contrast between our enchytraeid results and the earthworm abundances which were increased under reduced tillage between 1996 and 2006 (Fig. 4., Joschko et al. 2009). A possible reason for the negative effect that RT had on enchytraeid abundance could be the higher abundance of earthworms under RT. Some studies suggest an antagonistic relation between the two families (Schaefer & Schauer mann 1990, Zwart et al. 1994) whilst others state that this antagonistic relationship occurs only at the species level (Haimi & Boucelham 1991, Didden 1993, Hyvönen et al. 1994, Huhta & Viberg 1999, Yli-Olli & Huhta 1999). The results of this study indicate however, that the negative effect of RT on the enchytraeid abundance is not due to an antagonistic relationship between enchytraeids and earthworms. No negative correlation between earthworms and enchytraeids were found (Tab. 4). Also, earthworm abundances were generally low at the site, with only some plots with earthworm abundances above 150 ind. m⁻². Therefore, antagonistic effects of earthworms can be excluded as a possible cause for our findings. At sites with larger earthworm populations, however, they may well have a stronger effect on the enchytraeid population.

Our study does not allow to identify a clear cause, nevertheless speculations are possible. The conventional tillage may itself be beneficial

to enchytraeids. Our results are compatible with the theory that under CT there exists a bacteria based food web as suggested by Golebiowska & Ryszkowski (1977), House & Parmelee (1985) and Hendrix et al. (1986). It is possible that higher microbial activity under CT benefits the enchytraeids, because rapid decomposition and mineralization of the plant residue leads to a faster availability of nutrients for the enchytraeids. Thus a change in the amount of plant residue affects the availability of food resources for the enchytraeids via a bacteria-based food web. Under RT a fungi-based food web, as suggested by Hendrix et al. (1986), causes a much slower decomposition and mineralization of the plant residue. The nutrients are stored in the residue for a longer amount of time and so a change in the amount of plant residue does not directly affect the availability of food resources for the enchytraeids. This would explain why no positive correlation was found between enchytraeids and plant residue under RT. Also, differences in soil moisture between RT and CT may be important. The mixing in of plant residues under CT might prevent the deeper soil layers from drying out, and thus enhances microbial activity and food availability and fosters the survival of drought sensitive enchytraeids. Unfortunately, no data are available for soil moisture under reduced compared to conventional tillage at the studied site. The relationship between soil water and enchytraeid abundance in differently tilled sandy soils should definitely be studied in more detail.

As stated in the introduction, the aim of the German Federal Soil Protection Act is to improve the biological activity in arable soil by using site-specific management methods (BBodSchG 1998). This study suggests a higher level of enchytraeid activity and indicates higher microbial activity under CT at the sandy soil studied. Further research is necessary to substantiate our findings in other soils and climates. The development of fungi-based food webs under RT, when substantiated for other soils and climates, can however have many advantages, such as a slower and steadier release of nutrients as well as the promotion of earthworms. Thus the effect of cultivation management on the biological activity of soil has to be viewed differently, depending on the groups of soil organisms favored by the

cultivation system and the impact they have on processes in soil.

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