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Effects of non-inverting deep tillage vs. conventional ploughing on collembolan populations in an organic wheat field

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Abstract

A study of the effect of different tillage methods on the soil system and crop yield in an organic agroecosystem has been carried out in Denmark as a joint effort of a team of soil scientists, microbiologists, zoologists and modellers. In this paper, the reaction of the collembolan community to two kinds of primary soil tillage in the autumn, i.e. deep tillage with a non-inverting tine subsoiler (modified Dutzi method) vs. conventional ploughing, is compared. A surprisingly high mean number of Collembola, i.e. more than 100,000 m^{-2}, were present in the field before soil tillage. The abundance of total Collembola was strongly reduced 1 week after tillage with both methods and the sum of populations in four strata between the soil surface and 32 cm in depth showed no significant difference between the two tillage treatments. Conventional ploughing reduced the collembolan population more than the non-inverting tillage in the uppermost 4 cm stratum, while in the deepest stratum the immediate effect was opposite. When the whole soil horizon is considered, the two tillage treatments resulted in similar population changes for most collembolan species whereas significant differences were observed in individual strata. Especially strong effects were observed in epedaphic and hemiedaphic species.

Keywords: Organic agriculture; Tillage; Collembola; Depth distribution

1. Introduction

Organic agriculture emphasizes sustainability of the agroecosystem and the best possible utilization of naturally occurring soil processes. Therefore, the maintenance of rich and well functioning soil biota has high priority in this type of agriculture. The soil fauna is unfortunately vulnerable to the mechanical disturbance caused by soil tillage which is crucial for preparation of a seedbed, for mixing manure, litter and soil and for controlling weeds through the growing season. It is considered important to find tillage methods which promote the highest possible productivity while causing minimum damage to the microflora and fauna in the soil.

As part of the Danish research effort concerning organic farming organized in the Danish Research Centre for Organic Farming (DARCOF), a team of soil scientists, microbiologists, zoologists and modellers studied the effect on the whole soil system of two different tillage methods: conventional ploughing where the soil is inverted and a non-inverting deep tillage method using a tine subsoiler. The effect of a superficial soil decompaction using a hoe during spring (secondary soil tillage) was also studied. The joint study emphasized that sampling for the different components was carried out at the same dates and sampling positions within a common split plot design in order to be able to detect interactions between soil physics, chemistry, microflora, fauna and development of crop plants. The hypothesis was that the physical soil structure and consequently the soil biotic community would be affected differently by the two tillage methods and that in particular the non-inverting tillage would promote a less compact soil structure resulting in higher biotic activity distributed more evenly through the soil profile than conventional ploughing. The study presented here reports results for Collembola

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from the autumn and spring 1998–1999. Only the results on effects of the primary soil tillage are treated here.

2. Materials and methods

The study was carried out in an organic wheat field at the agricultural research farm Rugballegaard near Horsens, East Jutland, during autumn and spring 1998–1999 and was continued in spring 2000 in an adjoining field. The experimental design consisted of four blocks (reduced to three from the third sampling date) each containing two treatment plots: (1) conventionally mouldboard ploughed to 20 cm in depth and harrowed; and (2) tilled with non-inverting tine subsoiler to 25–35 cm in depth and rotavated in the surface.

The first sampling (25.09.98) was carried out immediately before primary tillage. The second and third samplings were performed 1 and 19 d after soil preparation and sowing, the fourth in the following spring. Sampling for microarthropods was repeated at three horizontal locations within each plot (only two at the first sampling). At each sampling location, 4 cm thick strata were sampled in four depths: 0–4, 8–12, 16–20 and 28–32 cm below the soil surface. The strata were sampled by pushing a specially constructed rectangular shovel with 4 cm high sides horizontally into the soil from a previously dug pit. A cylindrical ring (78.6 cm^2 area) was then pushed into the soil in the shovel to obtain the sample unit which was extracted in a high gradient funnel extractor [3] for 10 d. The taxonomy follows that used by Fjellberg [1,2].

3. Results

3.1. Effects on total populations from four strata

A very high mean density of Collembola (sum of all species in four strata: ca. 90,000 m^{-2}) was present in the field at the first sampling just before the primary soil tillage. Density in the whole profile by far exceeds 100,000 m^{-2} if the density in non-sampled strata is estimated by interpolation. The abundance of total Collembola was strongly reduced 1 week after tillage with both methods (32,000 and 31,000 m^{-2} in ploughed plots and plots treated with non-inverting tillage, respectively). No significant treatment effect was found in the period between tillage and the sampling in March 1999 (Fig. 1, Table 1), but a significant block- and treatment*block interaction was observed (Table 1). Among the most abundant collembolan species, *Protaphorura armata* (Tullberg, 1869) and *Isotoma anglicana* Lubbock, 1862 had significantly lower population density in ploughed plots than in plots treated with non-inverting tillage. The treatment effect on *P. armata* may be doubtful because a lower density (not significant) was already observed before tillage in the plots selected for ploughing.

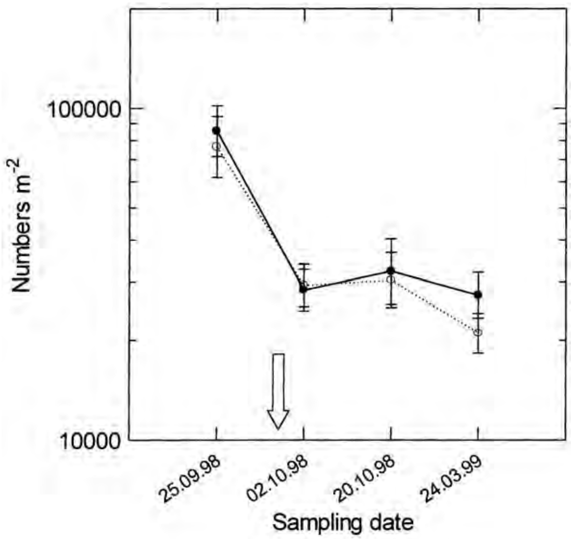

Fig. 1. Effect of two soil tillage methods on total collembolan density: sum of four soil horizons. Full-drawn line: non-inverting tillage. Dotted line: conventional ploughing. Arrow: time of tillage. The error bars represent standard error of mean based on log $(x + 1)$-transformed density data. Note the unequal intervals between sampling dates.

3.2. Effects on populations in individual strata

The population reduction in individual strata after the primary tillage (Figs. 2 and 3) tended to be strongest in the surface layer of the ploughed plots. This was statistically significant for total Collembola, *Folsomia fimetaria* (Linné, 1758), *Isotoma notabilis* Schäffer, 1896 and *I. anglicana* (Table 1). The effect seemed particularly distinct in the epedaphic species *I. anglicana* and the hemiedaphic *I. notabilis* (Fig. 3). In these species, the stronger reductions in the surface layer of ploughed plots as compared with the plots treated with non-inverting tillage were partly counteracted by population increments in the 16–20 cm stratum.

4. Discussion

Most studies of Collembola populations in agricultural soils have reported small density and biomass estimates compared with several natural and semi-natural ecosystems [7], but the present and other recent studies [8] have shown that a high number of Collembola can occur in organically managed fields. It is not known whether the basic cause is the application of organic manure or whether the avoidance of agricultural pesticides plays a role. An annual mean density of 246,000 m^{-2} for an alfalfa field on sandy soil in eastern Germany [6] shows that very dense collembolan populations are not restricted to organic fields.

Both tillage methods caused the collembolan density to decrease to about a third during the week where the primary

Table 1
Significance of ANOVA testing the effects of ploughing vs. non-inverting tillage, block and sampling time on collembolan density at three sampling dates after tillage (02.10.98, 20.10.98, 24.03.99). Based on $\log(x + 1)$-transformed data

	Sum of four strata				0–4 cm stratum				8–12 cm stratum				16–20 cm stratum				28–32 cm stratum			
	TM	BL	ST	TM–BL	TM	BL	ST	TM–BL	TM	BL	ST	TM–BL	TM	BL	ST	TM–BL	TM	BL	ST	TM–BL
P. armata s.l.	*** N > P	ns	ns	ns	ns	ns	ns	ns	** N > P	***	ns	ns	** N > P	ns	ns	ns	ns	ns	ns	ns
Mesaphorura spp.	ns	***	**	***	ns	*	**	ns	ns	*	ns	ns	ns	**	*	**	* P > N	*	**	ns
F. fimetaria	ns	ns	ns	*	* N > P	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
I. notabilis	ns	ns	ns	ns	* N > P	*	ns	ns	** N > P	***	ns	ns	** P > N	ns	ns	ns	ns	ns	ns	ns
I. anglicana	*** N > P	***	*	***	*** N > P	***	***	**	ns	ns	ns	ns	* P > N	ns	ns	ns	ns	ns	ns	ns
Total Collembola	ns	***	ns	*	* N > P	***	ns	ns	ns	ns	ns	ns	ns	*	ns	ns	ns	*	*	*

TM, tillage method; BL, block; ST, sampling time; TM*BL, interaction between tillage and block effect; P, ploughing; N, non-inverting tillage.
* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$, ns: not significant ($P > 0.05$).

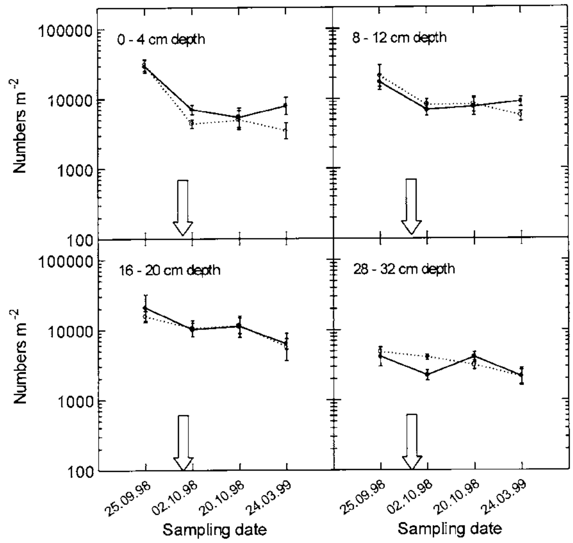

Fig. 2. Effect of two tillage methods on depth distribution of total Collembola. Explanation as in Fig. 1.

tillage was carried out. This agrees with previous reports [8] and constitutes the most serious negative effect of agricultural management on the collembolan community. The total decrease through the soil profile which persisted through the winter did not differ significantly between the two tillage methods in total Collembola or in most species. Only the surface-living *I. anglicana* had significantly lower populations after tillage in the conventionally ploughed plots than in the plots treated with the non-inverting tillage method.

Sabatini et al. [9] found few significant effects on the overall abundance of Collembola which could be related to differences due to long-term conventional ploughing and

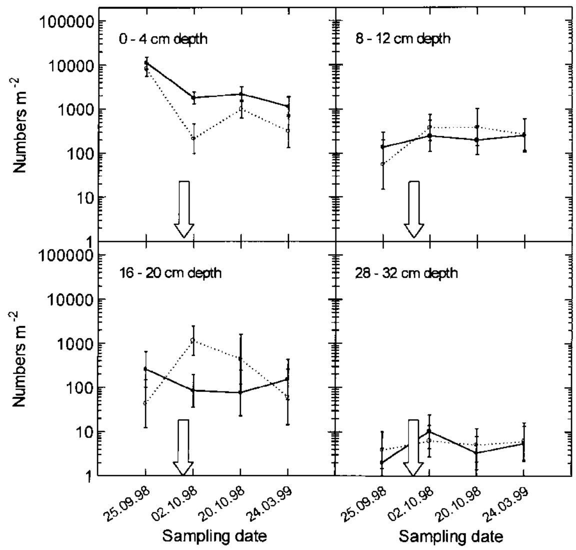

Fig. 3. Effect of two tillage methods on depth distribution of *I. notabilis*. Explanation as in Fig. 1.

minimum tillage but some species, e.g. *I. notabilis* and *P. armata*, were favoured by minimum tillage while others were favoured by conventional ploughing. Moore et al. [5] reported negative effect of no-tillage on Collembola as compared with conventional ploughing. The no-till treatment was combined with atrazin treatment and, although direct toxic effect was not observed, indirect negative effect on Collembola was assumed. House and Parmelee [4], however, found that all major microarthropod groups including Collembola had higher abundances under no-tillage than under conventional tillage practice.

Conventional ploughing resulted mostly in lower collembolan populations than non-inverting tillage in the surface layer. The opposite was the case in the deeper soil layers, especially in the 16–20 cm horizon. This was particularly distinct in epedaphic species such as *I. anglicana* and hemiedaphic species such as *I. notabilis*. The different reactions of Collembola to the two tillage methods in the surface and deeper soil layers can be explained by the physical impact in different depths of the soil combined with the relocation of the surface soil with its contained fauna caused by the inverting plough. Thus, the fauna in the deeper horizon is enriched by a surviving fraction of the surface fauna which to some extent compensates for the mortality due to abrasion, etc. On the other hand, the less abundant fauna of deeper soil layers are translocated to the surface layers where it is more exposed to drought and other microclimatic extremes. The ploughing depth was adjusted to be about 20 cm, so it is not surprising that the most distinct effects were observed in the surface and the 16–20 cm stratum. The non-inverting tine subsoiler, on the other hand, brings about the strongest physical effect in the deeper soil layers, especially between 25 and 35 cm in depth where the tine breaks up the soil, and in the surface layer exposed to the action of the rotary cultivator.

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