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Influence of cropping on the species composition of epigeic Collembola in arable fields

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Summary

Effects of cropping on summer abundance and species composition of epigeic Collembola were investigated during a six-year study in which nine different arable crops were sampled. Crops were sited on three farms, each with a different rotation and soil type. Species composition was usually similar between fields on the same farm but differed markedly between farms. Arthropleona were generally favoured by a grass and wheat rotation on calcareous clay whereas Symphypleona were favoured by a mixed cereals and break crops rotation on calcareous loam. A mixed cereals and root crops rotation on stony sand consistently had the lowest collembolan abundance and taxonomic richness in all years. Analysis of combined data from all three farms indicated that, except for barley, winter-sown crops had higher abundance and taxonomic richness than spring-sown crops. This pattern was also evident when all crops within individual farms were compared, but the differences were statistically significant only at one farm. However, when comparisons were restricted to cereals, differences in collembolan abundance between spring and winter-sown cereals were inconsistent between farms. Several collembolan species had restricted spatial distributions among fields, independent of cropping and soil type. These findings, which are compared with previous work on effects of cropping on Collembola, have implications for the interpretation of field ecotoxicological studies.

Key words: Crop rotation, soil type, spatial distribution, abundance, taxonomic richness

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Introduction

Numerous factors interact to determine the abundance and species composition of Collembola in arable fields. These include crop type (Jagers op Akkerhuis et al. 1988; Röske 1989; Mitra et al. 1983; Alvarez et al. 1997; Sabatini et al. 1997), farming system (Artemjeva & Gatilova 1975; Heijbroek & Bund 1982; Andrén & Lagerlöf 1983; Lagerlöf & Andrén 1991; Dekkers et al. 1994), tillage (Rickerl et al. 1989), crop rotation and weather conditions (Jagers op Akkerhuis et al. 1988), soil type (Röske 1989; Kováč & Miklisová 1995, 1997), crop age (Dekkers et al. 1994) and sampling date (Rickerl et al. 1989). As a result, effects of cropping practices on Collembola have been found to vary considerably between studies. However, in comparison with other insects, information on responses of Collembola to cropping practices is relatively limited. Previous studies have, with few exceptions (e.g. Alvarez et al. 1997), used soil cores to sample the fauna. Soil samples may capture epigeic species but are biased towards euedaphic and hemiedaphic insects. Previous work might therefore not have adequately represented epigeic species, particularly those present on crop foliage. Accordingly, the aim of the present study was to investigate the abundance and community composition of epigeic species in a range of arable crops, using suction sampling to estimate density and taxonomic richness.

Materials and Methods

Collembola were sampled in eight fields during 1991-1996. The fields were sited at three farms, each with a different crop rotation and soil type (Table 1). A total of nine different crop types was sampled as part of an investigation of long-term effects of pesticide use on arthropods (the 'SCARAB' Project; Frampton 1997). Although the experimental set-up was not designed primarily to address effects of cropping, several crops were duplicated sufficiently in space and time to allow their effects on Collembola to be investigated. All data presented here refer to crops managed under low-input regimes of herbicide and fungicide use, and without any insecticides (Ogilvy 2001). Suction sampling followed a standard protocol in all fields and years, using a 'D-vac' sampler (Dietrick et al. 1960) with a net sufficiently long that it completely enclosed crop plants up to 0.9 m in height when the nozzle (area 0.092 m²) was placed on the ground. Each sample was obtained by placing the sampler nozzle entirely over representative plants and holding the nozzle on the ground for 10 s at each of five randomly-selected locations, and pooling the catch from the five sub-samples to give a sample representing a ground-surface area of 0.46 m². Trials in a barley crop showed that D-vac sampling using this method was efficient at removing Collembola both from the crop and soil surface (Frampton 1989); a 10 s sampling duration was sufficient to remove the majority of arthropods that could be captured using this approach (Coombes 1987). To minimise effects of vegetation on sampling efficiency, and to avoid vegetation impeding the capture of ground-dwelling arthropods, suction sampling of plants that exceeded 0.9 m height was conducted in two stages: First, the upper foliage was sampled for 10 s by placing the sampler nozzle over the upper 0.9 m of the vegetation then, after excision of the foliage 0.3 m above the soil surface, the soil surface directly underneath was immediately sampled for 10 s. Five sub-samples taken in this manner were pooled to give a sample equivalent to 0.46 m² of the ground surface. In practice, separate sampling of the vegetation and soil (termed 'sample, cut, resample' by Hossain et al. 1999) was only required for crops of spring beans and winter oilseed rape at later growth stages; interpretation of the results takes into consideration possible differences in sampling efficiency be-

Table 1. Farms, soils and crops: ww: winter wheat, wb: winter barley, sw: spring wheat, sb: spring barley, bn: spring beans, po: potatoes, su: sugar beet, wr: winter rape, grass: short-term leys (mixed silage and livestock). Numbers in brackets are the number of suction samples taken from each crop

Farm	Drayton (D) 52.2° N 1.8° W		Gleadthorpe (G) 53.2° N 1.1° W			High Mowthorpe (H) 54.1° N 0.6° W		
Soil	*calcareous clay*		*stony sand*			*calcareous loam*		
Field	F1 *11 ha*	F5 *8 ha*	BA *12 ha*	NK *8 ha*	SO *12 ha*	BU *19 ha*	ON *17 ha*	OS *17 ha*
Crops[a]								
1991	ww (12)	grass (16)	su (25)	sb (12)	po (12)	wr (11)	bn (11)	bn (12)
1992	ww (12)	ww (12)	sw (20)	wb (12)	sw (12)	ww (12)	ww (12)	ww (12)
1993	grass (12)	ww (12)	wb (12)	bn (12)	wb (12)	sb (4)	wb (8)	wb (8)
1994	grass (12)	grass (16)	po (12)	ww (12)	su (12)	bn (15)	wr (12)	wr (12)
1995	grass (12)	grass (12)	sw (14)	wb (12)	sw (17)	ww (8)	ww (8)	ww (8)
1996	grass (14)	grass (12)	wb (10)	su (12)	wb (12)	wb (11)	sb (12)	sb (8)

[a]winter crops were sown in the previous autumn

tween crop types (see Discussion). Four samples per field were collected along a transect between 25 m and 150 m from the field margin (Frampton 1997) on up to two sampling dates in each of May, June and July in each year. Samples were preserved in 70 % methyl alcohol and Collembola were subsequently identified as described by Frampton et al. (2000). Means of $\ln(\chi+1)$-normalised Collembola counts, χ, from the 12 summer samples were used in Principal Components Analysis (PCA) (Jongman et al. 1995) to display differences in species composition among farms and crops, using data from all sampling years (total 580 samples; Table 1). In this analysis the species by sample matrix was introduced as species data and the farm, field and crop by sample matrix as passive explanatory variables. The analysis was performed using CANOCO software (ter Braak & Šmilauer 1998). Differences in abundance between crop types were analysed using t-tests on means of $\ln(\chi+1)$-normalised counts per sample; differences in taxonomic richness were analysed using t-tests on mean numbers of taxa per crop, with fields and years as replicates (Table 1).

Results

Taking all crops together, the dominant collembolan taxa were *Sminthurinus elegans* (Fitch, 1863) (22 %), *Sminthurus viridis* (L., 1785) (20 %), *Isotoma viridis* Bourlet, 1839 (20 %), *Lepidocyrtus* spp. (principally *L. cyaneus* Tullberg, 1871) (15 %), *Entomobrya multifasciata* (Tullberg, 1871) (6 %), *Deuterosminthurus* spp. (5 %),

Pseudosinella alba (Packard, 1873) (4 %), Sminthuridinae (3 %) and *Isotomurus* spp. (2 %). Other taxa captured were *Bourletiella hortensis* (Fitch, 1863), *Isotoma notabilis* Schäffer, 1896, *Entomobrya nicoleti* (Lubbock, 1867), *Heteromurus nitidus* (Templeton, 1835), *Orchesella villosa* (Geoffroy, 1764) and *Pseudosinella octopunctata* Börner, 1901 (together 2 %). Six taxa were spatially ubiquitous, being found in all study fields: *S. elegans, Deuterosminthurus* spp., *I. notabilis, I. viridis, Lepidocyrtus* spp. and Poduroidea. Several species had restricted spatial distributions in all years: *O. villosa* occurred only at Farm D, and *H. nitidus* only at Farm H, while *E. nicoleti* and *P. octopunctata* were each restricted in occurrence to individual fields (respectively F5 and BU; data not shown).
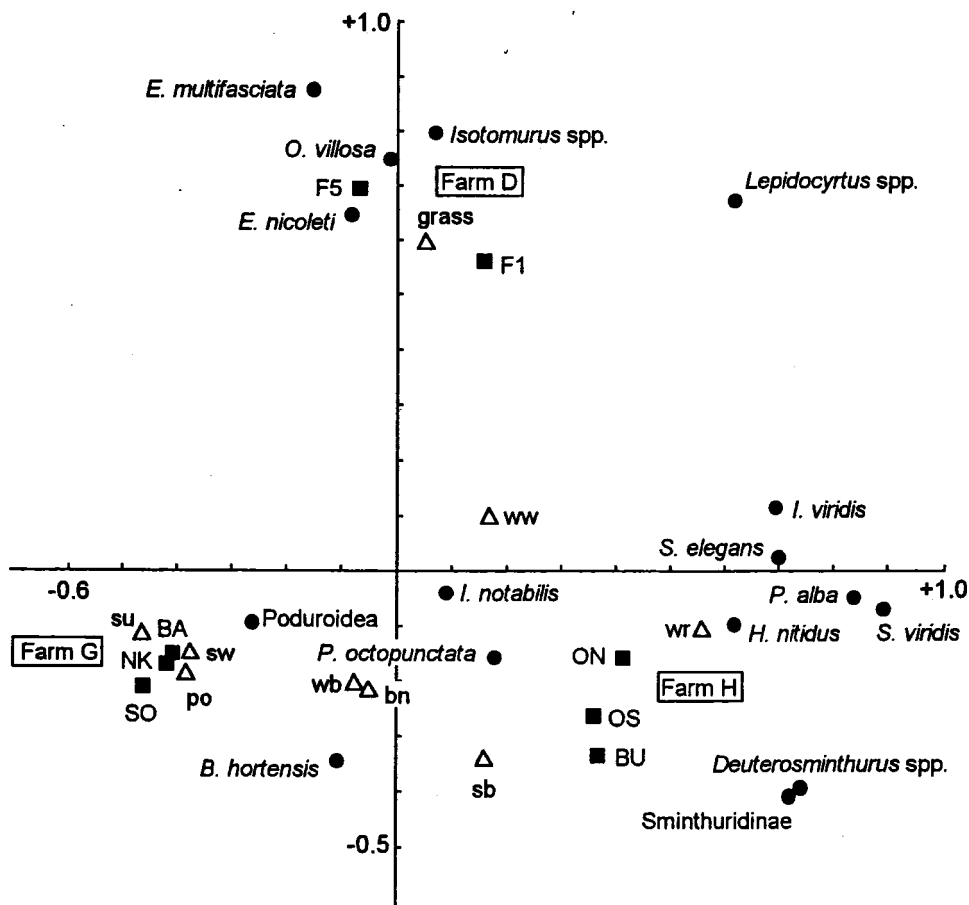

Fig. 1. PCA ordination diagram showing collembolan species composition in relation to crops and farms. Black circles are species points; black squares are field scores; white triangles are crop scores

The PCA ordination (Fig. 1) displays 73 % of the total variance, of which 50 % is explained by the first (horizontal) axis and 23 % by the second axis. The ordination shows that species composition differed considerably between farms but was similar for fields within the same farm. Arthropleona were favoured by the wheat and grass rotation on calcareous clay (Farm D) while Symphypleona were favoured by the mixed cereals and break crops rotation on calcareous loam (Farm H). The highest collembolan abundance was generally at Farm H whereas the highest taxonomic richness was at Farm D (Fig. 2), indicating that the dominance structure of the collembolan communities differed between farms. The mixed cereals and root crops rotation on stony sand (Farm G) consistently had the lowest overall abundance and taxonomic richness in all years (Fig. 2). With the exception of spring barley, spring-sown crops had lower collembolan abundance than winter crops, but not all differences were statistically significant (Fig. 3). Interpretation at the level of individual crops requires care, as several crops were correlated with farm and soil type; spring-sown crops were most frequent at Farm G, so their lower overall abundance could reflect an effect of farm rather than of crop per se. Within farms, collembolan abundance and taxonomic richness tended to be higher in winter-sown crops, but only at Farm H were these differences significant (Fig. 4). When cereals alone were compared within Farms G and H, the pattern of collembolan abundance and taxonomic richness was the same as that obtained when all crops were compared (Fig. 4), except that, at Farm G, abundance in spring cereals (mean per m²±S.E.) (217.7±73.9) was higher than in winter cereals (175.4±38.6).

(a) Total Collembola abundance

(b) Collembola taxonomic richness
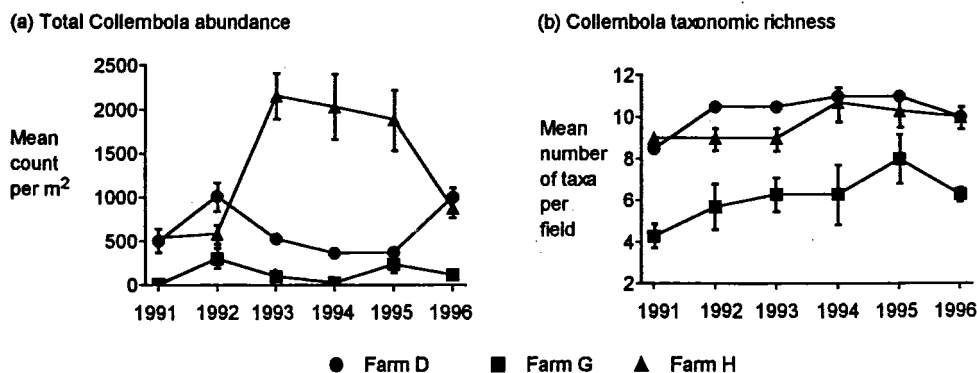
● Farm D   ■ Farm G   ▲ Farm H

Fig. 2. Mean (±S.E.) (a) abundance per m² and (b) number of taxa per field of epigeic Collembola during 1991–1996 at three farms. Sample sizes for abundance estimates are the total number of samples for each farm in each year as given in Table 1. Sample sizes for taxonomic richness estimates are the number of fields at each farm (Table 1) (S.E. bars are not given for Farm D, which had two fields only)
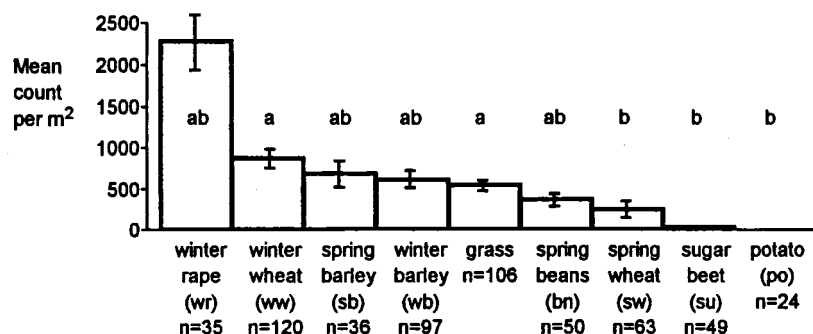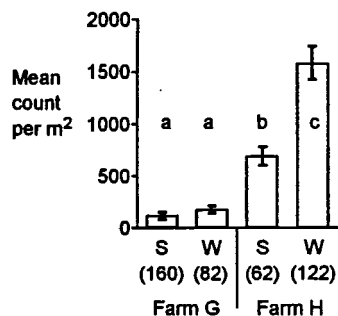
Total Collembola catch ranked by crop

Fig. 3. Crops ordered by mean collembolan abundance per m² (bars show ± S.E.). Crops not sharing letter codes (a,b) differ significantly in abundance (*t*-tests on $\ln(\chi+1)$-transformed counts χ, $P<0.05$)
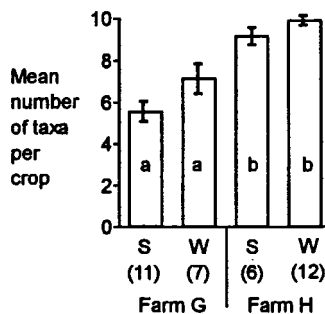
Fig. 4. Within-farm comparisons of (a) mean (± S.E.) collembolan abundance per m² and (b) mean (± S.E.) taxonomic richness in spring-sown (S) and winter-sown (W) crops. Crops not sharing letter codes (a,b,c) differ significantly in abundance (*t*-tests on $\ln(\chi+1)$-transformed counts χ, $P<0.05$). Sample sizes for (a) (number of suction samples) and (b) (number of crops) are given in brackets

Discussion

Sampling considerations

The efficiency of capturing arthropods by suction sampling is largely unknown in break crops such as oilseed rape and field beans, whereas for cereals and grasses there is evidence that capture efficiency of ground-dwelling arthropods can be high (Frampton 1989; Macleod et al. 1994). However, the extent to which vegetation height affects suction capture efficiency has varied between studies (examples in Hossain et al. 1999). Based on the recapture of certain predatory arthropods in lucerne, Hossain et al. (1999) recommended a 'sample, cut and resample' approach for suction sampling

of tall vegetation, similar to the method employed here for crops of spring beans and winter oilseed rape that exceeded 0.9 m height. Despite possible limitations of the sampling method, sampling efficiency is unlikely to have biased our conclusions. First, because the different approaches used to sample tall and short crops did not lead to consistent differences in arthropod captures (high Collembola counts from oilseed rape were not duplicated in spring beans, although 'sample, cut, resample' was employed in both these crop types). Second, because the majority of crops compared were cereals, which were sampled identically using a method with high capture efficiency for Collembola in cereals (Frampton, 1989).

Effects of cropping

The finding that winter-sown crops tended to have higher collembolan abundance than spring crops is consistent with other studies. Röske (1989) and Sabatini et al. (1997) found sugar beet generally unfavourable to Collembola, the highest catches being in winter cereals. Jagers op Akkerhuis et al. (1988) found that *I. viridis* was present only in winter wheat and absent from sugar beet, potato and spring barley, while abundance of *I. notabilis* and *P.alba* was higher in winter wheat and spring barley than in sugar beet. Several explanations have been proposed for negative effects of spring cropping on Collembola. These include: (i) the creation of an unfavourable microclimate (low humidity and high temperature) by the late development of canopy vegetation, (ii) negative effects of the timing of cultivations, (iii) high pesticide demands of spring crops such as sugar beet and potatoes, and (iv) lower return of organic matter in root crops. Although minimum pesticide inputs were used in all crops during the present work, pesticide inputs nevertheless differed between crops, with potatoes and sugar beet receiving higher inputs of, respectively, fungicides and herbicides than all other crops (Ogilvy 2001). The possibility that pesticide use contributed to the lower abundance of Collembola in these spring-sown crops cannot be ruled out. However, among cereals, the pattern of pesticide inputs was different, with spring-sown crops generally receiving lower pesticide inputs than winter crops (Ogilvy 2001). The finding that collembolan abundance was higher in spring- than winter-sown barley (Fig. 3) and spring-sown than winter-sown cereals within farm G (see above) might be a consequence of these differences in pesticide inputs between cereals and broadleaved crops. The highest collembolan abundance occurred in winter oilseed rape but this has to be interpreted cautiously because the crop was grown only at one farm. Despite the apparently favourable influence of this crop on collembolan abundance, the dominant species differed between the fields and the years that this crop was grown (see Table 1): *Sminthurinus elegans* was dominant in BU in 1991 (61 % of the total Collembola catch) whereas *Isotoma viridis* dominated in ON and OS in 1994 (79 % and 80 % respectively). Oilseed rape is important in terms of area planted (it accounts for 7 % of the area of all arable crops in Britain; Thomas et al. 1997) but the dynamics of Collembola in oilseed rape have not previously been investigated and the reasons for its favourable influence on collembolan abundance in this study are unclear.

Effects of farms

The principal differences between the farms were in their soil type and crop rotation. Weather such as spring precipitation can affect collembolan abundance and species composition (Frampton et al. 2000) and might explain some of the differences in

abundance and species composition between farms (mean annual precipitation, for instance, at Farms G, D and H was 593 mm, 604 mm and 641 mm respectively). However, weather cannot explain the observed differences among the fields within a farm (e.g. Fig. 4), as fields were sampled simultaneously. The low overall collembolan abundance and taxonomic richness at Farm G might be related to the sandy soil which had the lowest organic matter content of the three farms (Frampton 1997), although other work has shown that some sandy soils can support higher collembolan abundance than clay soils (Röske 1989). An alternative explanation could be that the collembolan fauna at Farm G was already impoverished by previous pesticide use because potatoes and sugar beet in the rotation before 1991 had received high pesticide inputs (Ogilvy 2001). An increase in abundance and taxonomic richness at Farm G under the reduced pesticide inputs employed during 1991–1996 is evident (Fig. 2) that would be consistent with long-term recovery.

Ecotoxicological implications

Most Collembola found during the current work are typical inhabitants of arable crops and grassland throughout Europe (e.g. Curry 1976; Jagers op Akkerhuis et al. 1988; Röske 1989; Ponge 1993; Kováč & Miklisová 1995; Alvarez et al. 1997). Although species composition was generally similar in fields on the same farm, certain species such as *E. nicoleti* and *P. octopunctata* had restricted distributions within farms that were not obviously related to cropping. Studies in agricultural grasslands (Dhillon & Gibson 1962) and winter wheat (Frampton 1999) have also found that occurrence and abundance of Collembola can differ considerably between fields with similar cropping, soils and management. Such small-scale variation in collembolan occurrence is important for ecotoxicological studies because the presence or absence of species vulnerable to agrochemicals, and hence the overall vulnerability of the community, varies among fields (Frampton 1999). Reasons for the restricted spatial distributions of Collembola at a field scale could include small-scale differences in habitat properties that would require more detailed sampling to detect.

Conclusions

Although there are exceptions among cereals, spring-sown crops appear generally to be less favourable than winter-sown crops to epigeic Collembola. However, because many variables differ between crops it is difficult to establish causal factors. Potatoes and sugar beet, which had the highest pesticide inputs, were the crops least favourable to Collembola. A mixed cereals and root crops rotation on a sandy soil was generally unfavourable to Collembola in all years, possibly reflecting a combination of a high proportion of spring-sown crops, previously high pesticide inputs in the rotation, and low soil organic matter content. Winter oilseed rape on a calcareous loam had the highest collembolan abundance but the reason is not clear, as the dominant species differed between fields and years. To establish whether this crop is generally favourable to Collembola on other soil types would require further study. There is a need to understand in more detail the factors governing the distribution patterns of Collembola at the scale of individual fields, to aid interpretation of ecotoxicological studies and to provide information on the factors that govern collembolan biodiversity

in agroecosystems, for instance to determine the most appropriate scales at which to estimate biodiversity.

Acknowledgements

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