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Epigeic Collembola in winter wheat under organic, integrated and conventional farm management regimes

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Abstract

Community characteristics of Collembola assemblages in conventional, integrated and organic fields of winter wheat were compared among three randomly chosen areas in England using analysis of similarities, cluster analysis, multi-dimensional scaling and several measures of diversity and evenness. Indicator values were used to identify indicator species. Significant differences were found in the abundance of most species and in community structure among the three geographical regions but few differences between the farming regimes were significant. Despite a lack of significant differences among regimes, *Entomobrya multifasciata* and *Isotomurus* spp. were consistently, although not significantly more common in conventional than organic fields whereas the opposite was true for *Isotoma viridis* and *Isotoma notabilis*. Farming regime significantly affected the abundance of *Sminthurinus elegans* and *Sminthurus viridis* but the effect differed between geographical regions. Community composition and species dominance were influenced by farming regime, but no species were indicative of the different farming systems, as most occurred ubiquitously in all fields. Organically and conventionally farmed fields were found not to differ significantly from each other in community composition, but both differed from integrated fields. These findings are compared with the results from other recent European studies of the effects of farming systems on arthropods and their wider ecological implications are discussed. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Pesticide effects; Farming system; Arable; Arthropods; United Kingdom

1. Introduction

Previous studies investigating the invertebrate fauna of arable fields managed under organic, conventional and integrated farming regimes have reported significant differences between regimes in faunal diversity. Compared with crops under conventional management, organically farmed arable crops had higher diversity and abundance of Carabidae, Staphylinidae and Araneae (e.g. Kromp, 1989, 1990; Booij and Noorlander, 1992; Steinborn and Meyer, 1994), Collembola (Paoletti et al., 1992) and a range of other beneficial arthropods (El Titi and Ipach, 1989; Moreby et al., 1994; Drinkwater et al., 1995; Reddersen, 1997). Other low-input farming systems also had a positive effect on Carabidae and Araneae (Steiner et al., 1986; Ulber et al., 1990), Staphylinidae (Krooss and Schaefer, 1998), soil microarthropods (Siepel, 1996) and other soil invertebrates (Steiner et al., 1986; Bardgett and Cook, 1998). Increased biotic diversity

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has been associated with greater ecosystem stability and sustainability (Seasted, 1984; Bardgett and Cook, 1998). Such potential ecological benefits have been highlighted in support of organic farming for conservation purposes (e.g. Drinkwater et al., 1995).

Results of farming systems studies have, however, not always been consistent. A greater abundance and diversity of carabid beetles was found in conventional than organic fields by Armstrong (1995), perhaps because mechanical weed control disturbed faunal populations in the organic fields. Brussaard et al. (1990) observed that some species of edaphic Collembola in experimental wheat plots were more abundant under conventional management whereas other species were more abundant under integrated crop management. Foissner (1992) found that climate and farm type were more important than management regime as determinants of species presence and abundance of earthworms, nematodes and Protozoa.

Collembola are among the most abundant of farmland arthropods, and are important both in arthropod food webs (e.g. Hopkin, 1997) and in decomposition and soil nutrient dynamics (e.g. Petersen and Luxton, 1982; Kiss and Jager, 1987; Mebes and Filser, 1998). Some species of Collembola are vulnerable to the pesticides used under conventional farming practices (e.g. Frampton, 1999; Frampton and Wratten, 2000) so a potential exists for pesticide-mediated differences in collembolan abundance between farming systems. No pesticides are permitted in organic farming except for restricted use of copper- or sulphur-based fungicides (Lampkin, 1992). Conventional farming regimes use insecticides, herbicides and fungicides according to need as determined by individual farmers whereas under integrated management pesticide use is reduced where possible: generally insecticides are avoided and the main inputs comprise herbicides and fungicides.

Relatively few studies have investigated variation in collembolan abundance between farming systems and none have so far investigated the effects of management practices upon diversity and community composition of epigeic species. Steiner et al. (1986) reported a greater abundance of Collembola in integrated than in conventional fields of cereals and sugar beet, whereas in a study by Brussaard et al. (1990), conventional and integrated management in plots of winter wheat appeared to favour different species of edaphic Collembola, although differences in abundance were not tested statistically. Paoletti et al. (1992) and Moreby et al. (1994) found a greater abundance of Collembola in organic than conventional cereals, but in the latter case only in one of 2 years. Large-scale regional studies in cereals (Reddersen, 1997) and other arable crops (Dekkers et al., 1994; Czarnecki and Paprocki, 1997) have not detected differences between organic and conventional fields in collembolan abundance.

Given the inconsistencies of results obtained from previous work, the present study focused on winter wheat. On one of the study farms where no organic wheat crops were available, a winter triticale crop (wheat×rye hybrid) was sampled instead (Table 1). Management of winter triticale and winter wheat on the farm in question would have been identical in terms of preparatory cultivations, drilling and harvesting dates, and pesticide inputs (M.J. Collins, Farm Manager, personal communication). For present purposes therefore, the triticale crop is considered in analyses as a ‘surrogate’ wheat crop. Using collembolan presence, abundance and community measurements, the aim of the current work was to determine any effects of conventional, organic and integrated farming regimes on epigeic Collembola and whether or not species or community parameters can be identified which are indicative of particular farming systems.

2. Materials and methods

2.1. Study area and experimental design

Organic farms were randomly selected from the list of certified organic growers in southern England. Certification requires a minimum of 2 years without pesticide use before organic approval (Lampkin, 1992) so all the organic crops sampled had experienced at least 3 years without pesticide use. Conventional and integrated farms were chosen to be within 25 km of the organic ones. Two research farms, managed by the Cooperative Wholesale Society Agriculture (‘CWS Agriculture’, Leicestershire) and the Rhône–Poulenc Farm Management Study (‘FM’, Essex) were included in this study to permit sampling of neighbouring fields managed under conventional, organic and integrated regimes. In total, 24 fields were sampled, located in

Table 1

Characteristics of the organic (Org), conventional (Con) and integrated (Int) fields investigated in this study[a]

Regime	Location	Number of fields	Average field size (ha)	Regime history (years)	Soil type	Cultivar, growth stage	Date sampled	Field edges	Pesticide inputs	Tillage
Org	Stoughton (CWS Agriculture) (midland) 52°40′N, 1°0′W	3	12.0	8	Medium to heavy clay loam	Axona, Hereward; g.s.64–65	17/6/97	HHFF, HHWW, HHFW	None	Ploughed
Org	White Waltham (Waltham Place) (south east) 51° 20′N, 0° 30′W	2	2.0	10	Medium loam on flinty clay	Maris Widgeon; g.s.64–65	24/6/97	HHWF	None	Ploughed
Org	Ongar (Rhône–Poulenc, FM) (south east) 51°30′N, 0°20′W	1	2.6	4	Medium loam over chalky boulder clay	Hereward; g.s. 64–65	10/6/97	HHHG	Sulphur as a fungicide	Ploughed
Org	Heckfield (Park Farm) (central south) 51°0′N, 1°10′W	1	14.9	>7	Medium loam on chalky clay	Purdy*; g.s.60–61	9/6/97	HHFW	None	Ploughed
Org	Ham (Doves Farm) (central south) 51°40′N, 1°30′W	2	9.6	>6	Chalky flinty clay	Pastiche; g.s.64–69	16/6/97	HHFT	None	Ploughed
Int	Stoughton (CWS Agriculture) (midland) 52°40′N, 1°0′W	3	4.5	4	Medium to heavy clay loam	Hunter, Reaper, Hussar; g.s.64–65	17/6/97	HFWW, HHFT	Herbicides: glyphosate, isoproturon, fenoxaprop-P-ethyl, metsulfuron-methyl, fluroglycofen-ethyl Fungicides: cyproconazole, prochloraz, epoxiconazole, fenpropidin	Minimum
Int	Ongar (Rhône-Poulenc, FM) (south east) 51° 30′N, 0° 20′W	3	3.9	3	Medium loam over chalky boulder clay	Spark, Rialto, Hunter g.s.64–65	10/6/97	HHHT, HHFF	Herbicides: isoproturon, diflufenican, mecoprop-P Fungicides: tebuconazole triadimenol, propiconazole, chlorothalonil, Insecticides: cypermethrin, fenpropathrin	Minimum

Table 1 (*Continued*).

Regime	Location	Number of fields	Average field size (ha)	Regime history (years)	Soil type	Cultivar, growth stage	Date sampled	Field edges	Pesticide inputs	Tillage
Con	Stoughton (CWS Agriculture) (midland) 52° 40′N, 1°0′W	3	4.4	>10	Medium to heavy clay loam	Hunter, Reaper, Brigadier; g.s.64–65	19/6/97	HHHF, HHFT	Herbicides: isoproturon, diflufenican, glyphosate, fluroglycofen-ethyl Fungicides: cyproconazole, prochloraz, fenpropidin, propiconazole, tebuconazole, kresoxim-methyl, fenpropimorph, epoxiconazole, difenoconazole, quinoxyfen, Insecticide: cypermethrin	Ploughed
Con	Ongar (Rhône–Poulenc, FM) (south east) 51°30′N, 0°20′W	2	3.8	>10	Medium loam over chalky boulder clay	Rialto; g.s.64–65	10/6/97	HHHF, HHFF	Herbicides: glyphosate, isoproturon, diflufenican, mecoprop-P Fungicides: chlorothalonil, tebuconazole, triadimenol Insecticides: cypermethrin, pirimicarb	Ploughed
Con	Ham (The Wansdyke Farms) (central south) 51°40′N, 1°30′W	4	12	>10	Chalky flinty clay	Hereward; g.s. 64–68	16/6/97	HHHT, HHHF, HHHH	Herbicides: diflufenican, fluoroxypyr, isoproturon Fungicides: chlorothalonil, cyproconazole, epoxiconazole	Ploughed
Con	Ham (The Wansdyke Farms) (central south) 51°40′N, 1°30′W	4	12	>10	Chalky flinty clay	Hereward; g.s. 64–68	16/6/97	HHHT, HHHF, HHHH	Insecticide: deltamethrin	

[a] All fields contained winter wheat (except *: triticale) sown in autumn 1996. For field edges, H: hedgerow, F: arable field, W: woods, T: track or road, G: grass bank. Regime history is the number of years fields had been managed under the farming regime. Tillage is the husbandry before crop drilling: 'Ploughed' indicates ploughing followed by harrowing and rolling; 'Minimum' indicates previous stubble disced followed by soil press or rolling. Growth stages (g.s.) follow Tottman (1987).

three areas of England which are here referred to as midland, central south and southeast (Table 1).

2.2. Sampling and species identification

Suction sampling was carried out using a leaf-blower (Ryobi RSV3100) adapted as described in Stewart and Wright (1995). Samples were taken 30 m from the nearest hedgerow and more than 50 m away from any other field edge. Four suction samples were taken at random from each field. For each sample a total area of 0.5 m^2 was sampled, comprising five pooled sub-samples each of 10 s duration. All sampling took place between the 9 and 24 June 1997.

Samples were frozen within 3 h of collection. Collembola were later separated by flotation in water and sieving (3 μm mesh) then transferred into 80% methylated spirit. Species were examined using binocular and compound light microscopes and identified with Fjellberg (1980) and Christiansen and Bellinger (1980, 1998).

2.3. Univariate statistical analysis

Collembolan abundance, number of species, and several different indices of diversity were examined. Shannon–Wiener diversity, Pielou's evenness, Margaleff species richness and Simpson's measure of dominance were obtained using PRIMER computer software (Carr, 1997). Multi-way analysis of variance (ANOVA) was performed on $\log(x+1)$-transformed species counts x, and on untransformed diversity measures to test statistically differences in Collembola parameters among farming regimes and geographical locations. Before analysis each data set was tested for heterogeneity of variances using Cochran's test (Underwood, 1997) and for departures from normality using the Kolmogorov–Smirnov test (Sokal and Rohlf, 1995). Main effects in the ANOVA model were farming regime (fixed factor), regional area (random factor) and field (random factor) nested within regime and area. A lack of integrated farms in the central south region (Table 1) precluded a fully balanced design so two separate ANOVAs were carried out: (1) organic fields were compared with conventionally managed fields in three areas; (2) all three farming regimes were compared but using farms only in the midland and southeast regions. A missing conventional field replicate from the southeast group was substituted in analyses with the mean count data from the other eight conventional fields; the loss in variance was compensated for by adjusting the degrees of freedom used to test the F-value (Underwood, 1997). Differences among regimes in measures of overall diversity and abundance were compared using a one-way ANOVA. Species compositions among regimes were compared using a linear regression of relative abundance against rank number of species. The regression slopes for each farming regime were compared using t-tests for each pairwise comparison. Because multiple tests were carried out, Bonferroni methods were used to adjust the significance level in the t-tests (Sokal and Rohlf, 1995).

2.4. Multivariate analysis

Multivariate analysis was carried out to investigate the complex community data and was complementary to univariate analysis. These techniques are useful for representing communities in two-dimensional space and testing for differences in community composition. Hierarchical agglomerative cluster analysis, multi-dimensional scaling (MDS) and two-way crossed analysis of similarities (ANOSIM) were carried out on $\log(x+1)$ transformed field mean counts x in order to group fields containing similar communities. Bray–Curtis coefficients of similarity (Bray and Curtis, 1957) were used to produce similarity matrices. Analysis of the species similarity matrix was used to identify species assemblages. Rare species, where they contributed less than 1% to the total abundance, were omitted from species similarity analysis. Presence/absence data for all species was also used for community comparisons. Species indicative of the different groupings were identified using species indicator values (INDVAL; Dufrêne and Legendre, 1997).

3. Results

3.1. Species abundance

The most commonly encountered species were: *Lepidocyrtus* spp., *Pseudosinella alba* (Packard),

Table 2
Differences in individual species counts between organic and conventional fields sampled in three areas (midland, south east and central south)

Species	Regime	Area	Regime×area	Field
Lepidocyrtus spp.	$F_{1,2}=1.48$ NS	$F_{2,11}=2.22$ NS	$F_{2,11}=0.32$ NS	$F_{11,51}=16.46^{***}$
S. elegans	$F_{1,2}=0.06$ NS	$F_{2,11}=7.94^{**}$	$F_{2,11}=4.31^{*}$	$F_{11,51}=9.98^{***}$
I. viridis	$F_{1,2}=10.48$ NS	$F_{2,11}=5.65^{*}$	$F_{2,11}=0.10$ NS	$F_{11,51}=24.42^{***}$
E. multifasciata	$F_{1,2}=4.06$ NS	$F_{2,11}=0.28$ NS	$F_{2,11}=1.18$ NS	$F_{11,51}=10.60^{***}$
I. palustris	$F_{1,2}=0.77$ NS	$F_{2,11}=25.13^{***}$	$F_{2,11}=2.61$ NS	$F_{11,51}=11.15^{***}$
I. notabilis	$F_{1,2}=0.29$ NS	$F_{2,11}=5.34^{*}$	$F_{2,11}=1.21$ NS	$F_{11,51}=13.45^{***}$
S. viridis	$F_{1,2}=0.10$ NS	$F_{2,11}=1.03$ NS	$F_{2,11}=4.92^{*}$	$F_{11,51}=14.41^{***}$
P. alba	$F_{1,2}=0.02$ NS	$F_{2,11}=3.25$ NS	$F_{2,11}=0.43$ NS	$F_{11,51}=18.63^{***}$

* $P<0.05$.
** $P<0.01$.
*** $P<0.001$ (three-way nested ANOVA).

Sminthurinus elegans (Fitch), *Sminthurus viridis* (L.), *Isotomurus* spp., *Isotoma viridis* Bourlet, *I. notabilis* Schäffer, and *Entomobrya multifasciata* (Tullberg). A substantial amount of variation was found to occur among the three geographical areas investigated, but the most important source of variation was between fields at a local scale. Consistently significant differences were found between fields for all the common species investigated (Tables 2 and 3).

Four different trends in the abundance of lower taxa were evident: (1) *E. multifasciata* and *Isotomurus* spp. were consistently although not significantly more common in conventionally than organically managed fields in all three areas (Fig. 1a, b), and *E. multifasciata* was most numerous in integrated fields. (2) *I. viridis* and *I. notabilis* were consistently although not significantly more numerous in organic than conventional fields (Fig. 2a, b). (3) *S. elegans* and *S. viridis* showed a significant interaction between regime and area indicating that differences among regimes were not consistent at all geographical locations (Fig. 3a, b). For both of these species few differences were found in counts between organic and conventional fields in the central south region; however, populations were much higher in conventionally managed fields than organically managed midland fields. (4) *Lepidocyrtus* spp., *I. viridis*, *Isotomurus* spp. and *I. notabilis* all differed significantly in abundance between the midland and southeast regions (Table 3).

3.2. Community parameters

As with the lower taxa, major differences in overall collembolan abundance and diversity counts were

Table 3
Differences in individual species abundance between southeast and northeast areas in fields managed under organic, integrated or conventional regimes

Species	Regime	Area	Regime×area	Field
Lepidocyrtus spp.	$F_{2,2}=0.37$ NS	$F_{1,11}=8.49^{**}$	$F_{2,11}=3.61$ NS	$F_{11,51}=16.79^{***}$
S. elegans	$F_{2,2}=0.14$ NS	$F_{1,11}=11.55^{**}$	$F_{2,11}=5.31^{*}$	$F_{11,51}=19.09^{***}$
I. viridis	$F_{2,2}=9.31$ NS	$F_{1,11}=9.14^{*}$	$F_{2,11}=0.39$ NS	$F_{11,51}=11.76^{***}$
E. multifasciata	$F_{2,2}=4.52$ NS	$F_{1,11}=0.45$ NS	$F_{2,11}=0.78$ NS	$F_{11,51}=18.73^{***}$
I. palustris	$F_{2,2}=10.48$ NS	$F_{1,11}=57.94^{***}$	$F_{2,11}=0.74$ NS	$F_{11,51}=15.40^{***}$
I. notabilis	$F_{2,2}=3.59$ NS	$F_{1,11}=9.56^{**}$	$F_{2,11}=1.23$ NS	$F_{11,51}=14.47^{***}$
S. viridis	$F_{2,2}$ =0.38 NS	$F_{1,11}=1.75$ NS	$F_{2,11=}5.15^{*}$	$F_{11,51}=9.39^{***}$
P. alba	$F_{2,2}=0.01$ NS	$F_{1,11}=0.08$ NS	$F_{2,11}=0.88$ NS	$F_{11,51}=6.82^{***}$

* $P<0.05$.
** $P<0.01$.
*** $P<0.001$ (three-way ANOVA).

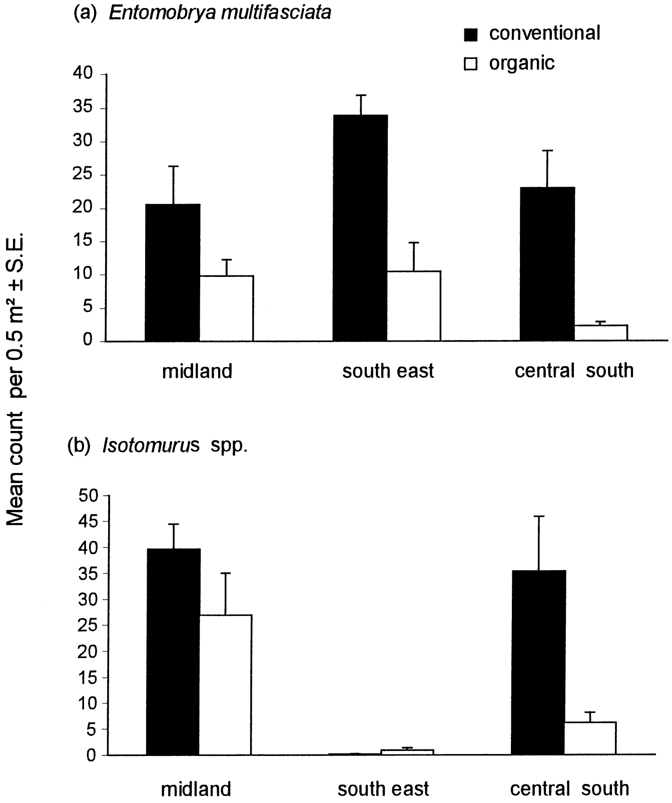

Fig. 1. Differences in the abundance of (a) *E. multifasciata* and (b) *Isotomurus* spp. between fields farmed organically and conventionally in three areas. Mean abundance did not differ significantly between regimes (Tables 2 and 3).

found at a field scale (Tables 4 and 5). Only dominance differed significantly among regimes (Table 4), the highest values being found in fields farmed organically (mean=0.28, S.E.=0.01) compared with those farmed conventionally (mean=0.26, S.E.=0.01) or under an integrated regime (mean=0.25, S.E.=0.01). Abundance of the order Symphypleona differed between regimes but inconsistently in different areas. Counts of the order Arthropleona and the total Collembola differed significantly among geographical regions but not between management regimes. No significant differences were found in species richness, diversity and evenness measures because of regime or area (Tables 4 and 5).

When only comparing overall regime effects (i.e. irrespective of regional differences; one-way ANOVA), total collembolan abundance differed significantly, with the highest abundance occurring under integrated management. No other measures of diversity differed significantly between farming regimes (Fig. 4).

Differences in community composition were found between geographical areas and between regimes using ANOSIM (Table 6), although this technique does not show where the differences are. The regression slopes for rank-abundance plots differed significantly among regimes (Fig. 5). Slopes of the linear regressions for catches in conventional and organic fields did not differ significantly from each other (Bonferonni significance level for a 5% experiment-wise error rate is 0.017; $t_{73}=2.37$, $P>0.017$). However, both conventional ($t_{65}=7.23$, $P<0.01$) and organic ($t_{62}=6.85$, $P<0.01$) fields differed from integrated fields. *E. multifasciata*, *I. viridis*, *I. notabilis* and *Isotomurus* spp. made up 70% of the total collembolan abundance in integrated fields (20, 20, 15 and 15%, respectively). In organic and conventional fields the

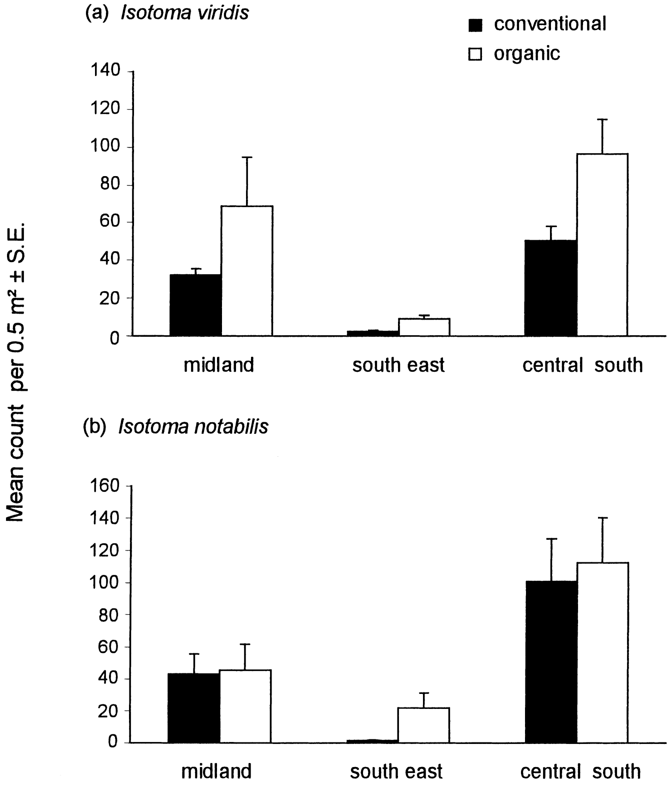

Fig. 2. Differences in the abundance of (a) *I. viridis* and (b) *I. notabilis* between fields farmed organically and conventionally in three areas. Mean abundance did not differ significantly between regimes (Tables 2 and 3).

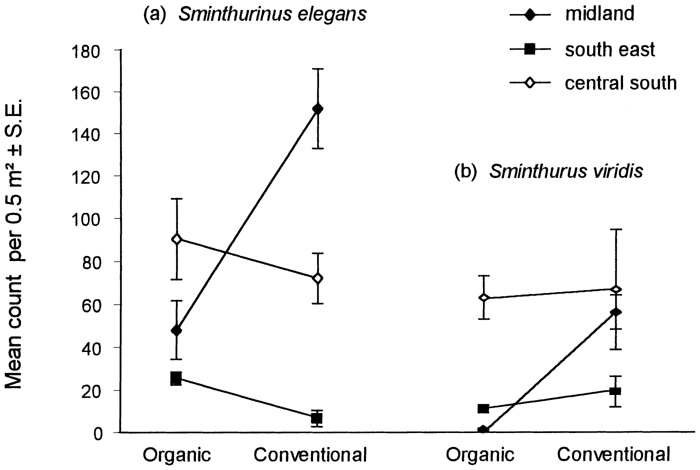

Fig. 3. Interaction plots for regime (organic and conventional) and region for (a) *S. elegans* and (b) *S. viridis*.

Table 4

Differences in overall abundance and diversity measures for Collembola counts between organic and conventional regimes sampled in three areas (midland, southeast and central south)

Measure	Regime	Area	Regime × area	Field
Total Symphypleona	$F_{1,2}=0.002$ NS	$F_{2,11}=3.85^{*}$	$F_{2,11}=4.06^{*}$	$F_{11,51}=14.38^{***}$
Total Arthropleona	$F_{1,2}=0.24$ NS	$F_{2,11}=5.72^{*}$	$F_{2,11}=0.19$ NS	$F_{11,51}=17.64^{***}$
Total Collembola	$F_{1,2}=0.07$ NS	$F_{2,11}=6.93^{*}$	$F_{2,11}=0.74$ NS	$F_{11,51}=15.76^{***}$
Total species number	$F_{1,2}=0.58$ NS	$F_{2,11}=2.85$ NS	$F_{2,11}=0.38$ NS	$F_{11,51}=8.47^{***}$
Richness	$F_{1,2}=2.29$	$F_{2,11}=0.37$ NS	$F_{2,11}=0.29$ NS	$F_{11,51}=16.93^{***}$
Diversity	$F_{1,2}=2.69$ NS	$F_{2,11}=0.58$ NS	$F_{2,11}=0.10$ NS	$F_{11,51}=16.93^{***}$
Evenness	$F_{1,2}=11.81$ NS	$F_{2,11}=0.16$ NS	$F_{2,11}=0.09$ NS	$F_{11,51}=7.78^{***}$
Dominance	$F_{1,2}=19.7^{*}$	$F_{2,11}=0.43$ NS	$F_{2,11}=0.06$ NS	$F_{11,51}=13.43^{***}$

* $P<0.05$.

*** $P<0.001$ (three-way ANOVA).

Table 5

Differences in overall abundance and diversity measures for Collembola counts between midland and southeast areas in fields managed under organic, conventional or integrated regimes

Species	Regime	Area	Regime × area	Field
Total Symphypleona	$F_{2,2}=0.13$ NS	$F_{1,11}=5.24^{*}$	$F_{2,11}=5.40^{*}$	$F_{11,51}=12.36^{***}$
Total Arthropleona	$F_{2,2}=6.82$ NS	$F_{1,11}=8.31^{*}$	$F_{2,11}=0.70$ NS	$F_{11,51}=19.55^{***}$
Total Collembola	$F_{2,2}=2.97$ NS	$F_{1,11}=16.18^{**}$	$F_{2,11}=1.17$ NS	$F_{11,51}=13.91^{***}$
Total species number	$F_{2,2}=2.69$ NS	$F_{1,11}=11.75^{**}$	$F_{2,11}=0.42$ NS	$F_{11,51}=4.84^{***}$
Richness	$F_{2,2}=12.80$	$F_{1,11}=0.73$ NS	$F_{2,11}=0.07$ NS	$F_{11,51}=7.67^{***}$
Diversity	$F_{2,2}=3.84$ NS	$F_{1,11}=1.17$ NS	$F_{2,11}=0.01$ NS	$F_{11,51}=12.61^{***}$
Evenness	$F_{2,2}=0.77$ NS	$F_{1,11}=0.01$ NS	$F_{2,11}=0.54$ NS	$F_{11,51}=1.58$ NS
Dominance	$F_{2,2}=26.16^{*}$	$F_{1,11}=0.89$ NS	$F_{2,11}=0.03$ NS	$F_{11,51}=11.51^{***}$

* $P<0.05$.

** $P<0.01$.

*** $P<0.001$ (three-way ANOVA).

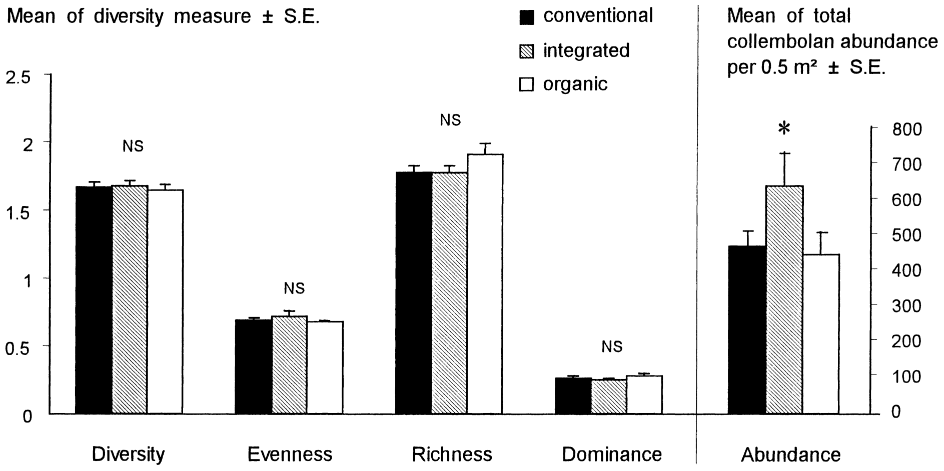

Fig. 4. Comparison of community measures for Collembola in fields managed under organic, conventional and integrated regimes. $*=P<0.05$; NS: no significant difference (one-way ANOVA).

Table 6
Differences in collembolan communities among three agricultural management regimes and three areas in southern England: results of two-way ANOSIM

Details of comparison	Test statistic, *R*	Significance level
Total collembolan abundance (log-transformed)		
Regimes: organic vs. conventional	0.469	$P=0.008$
Areas: all three areas	0.588	$P=0.001$
Regimes: all three regimes	0.593	$P=0.0001$
Areas: midland vs. southeast	0.753	$P=0.001$
Presence/absence data for all species		
Regimes: organic vs. conventional	0.296	$P=0.022$
Areas: all three areas	0.374	$P=0.011$
Regimes: all three regimes	0.451	$P=0.0001$
Areas: midland vs. southeast	0.630	$P=0.001$

community was dominated by *Lepidocyrtus* spp. (28 and 34%, respectively).

Cluster analysis grouped species together which were widespread and abundant. The main group comprised *Lepidocyrtus* spp., *S. elegans, I. viridis, E. multifasciata, Isotomurus* spp., *I. notabilis, S. viridis* and *Deuterosminthurus* spp. Rarer species showed no relationship to other species' patterns of abundance (Fig. 6a and b). MDS analysis of the species composition in the samples from each field grouped fields together which were farmed under the same regime in the same area (Fig. 7a and b). However, species indicator values (Dufrêne and Legendre, 1997) showed that no species or groups of species were indicative of the groupings produced by MDS and cluster analysis. All numerous species had their highest INDVAL value when the whole data set was treated as one group, suggesting that these species are ubiquitous in all the arable systems investigated; rare species did not differ in abundance from a random distribution among samples.

4. Discussion

4.1. Farming system effects on species abundance

Overall, *E. multifasciata, Isotomurus* spp., *I. notabilis*, total Arthropleona and total Collembola were most abundant under integrated management. Pesticide use alone probably does not account for the apparently favourable effect on these species of integrated farming because pesticide inputs were lowest under organic management and broadly similar in the integrated and conventional regimes. The most obvious difference between the management of the integrated and conventional regimes was in the cultivations employed before the crop was drilled. Minimum tillage (e.g. Locke and Bryson, 1997) was used under the integrated regimes whereas all conventional fields were ploughed. Minimum tillage generally involved disc harrowing of an existing crop stubble, followed by rolling. These pre-drilling differences in crop management might have contributed to the

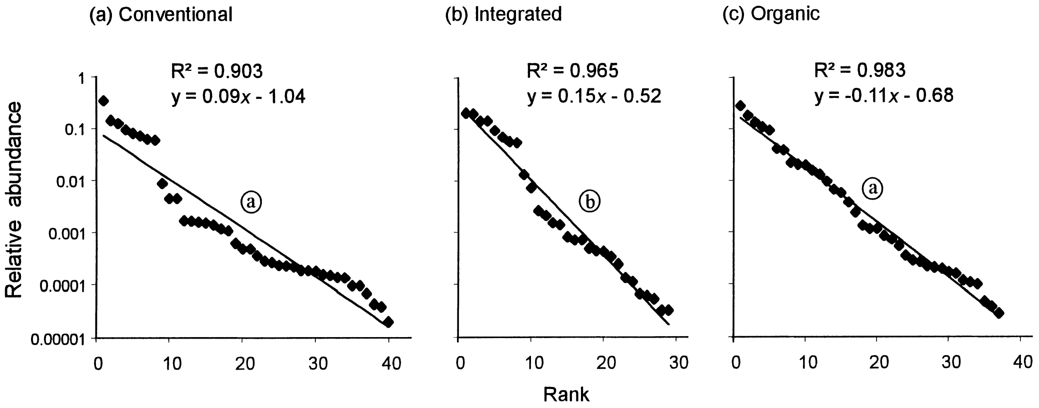

Fig. 5. Rank-abundance plots for species trapped in (a) conventional, (b) integrated and (c) organic fields. Slopes for regimes with different letter codes (encircled) differ significantly (t-test; $P<0.05$).

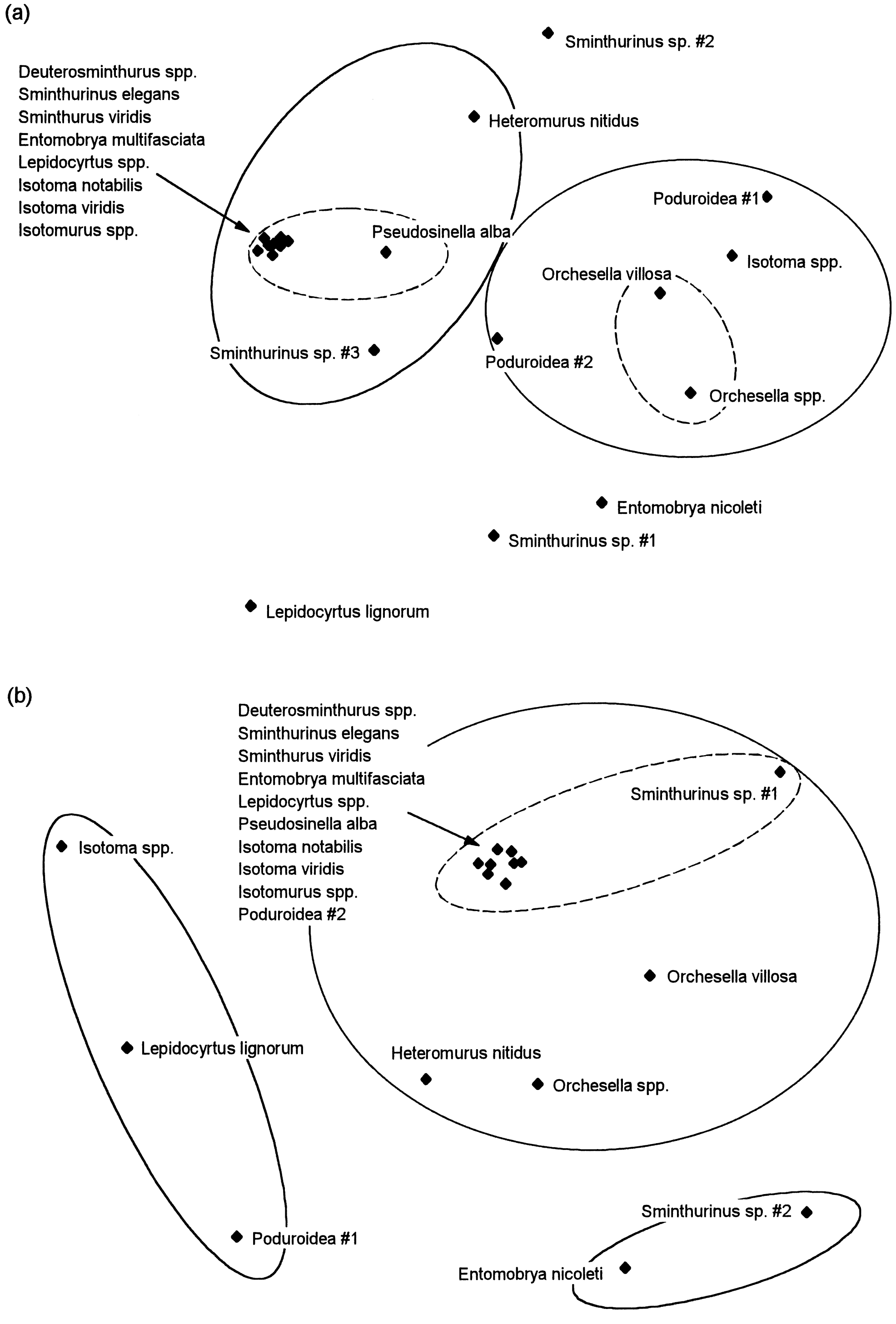

Fig. 6. Species groupings found by Multi-Dimensional Scaling upon the species similarity matrix. (a) Mean abundance data (MDS stress= 0.17); (b) presence and absence data (MDS stress=0.17). Groups are delineated according to the results of cluster analysis. The dashed line groups samples on a basis of >45% (a) or >70% (b) similarity; the black line groups samples on a basis of >30% (a) or >40% (b) similarity.

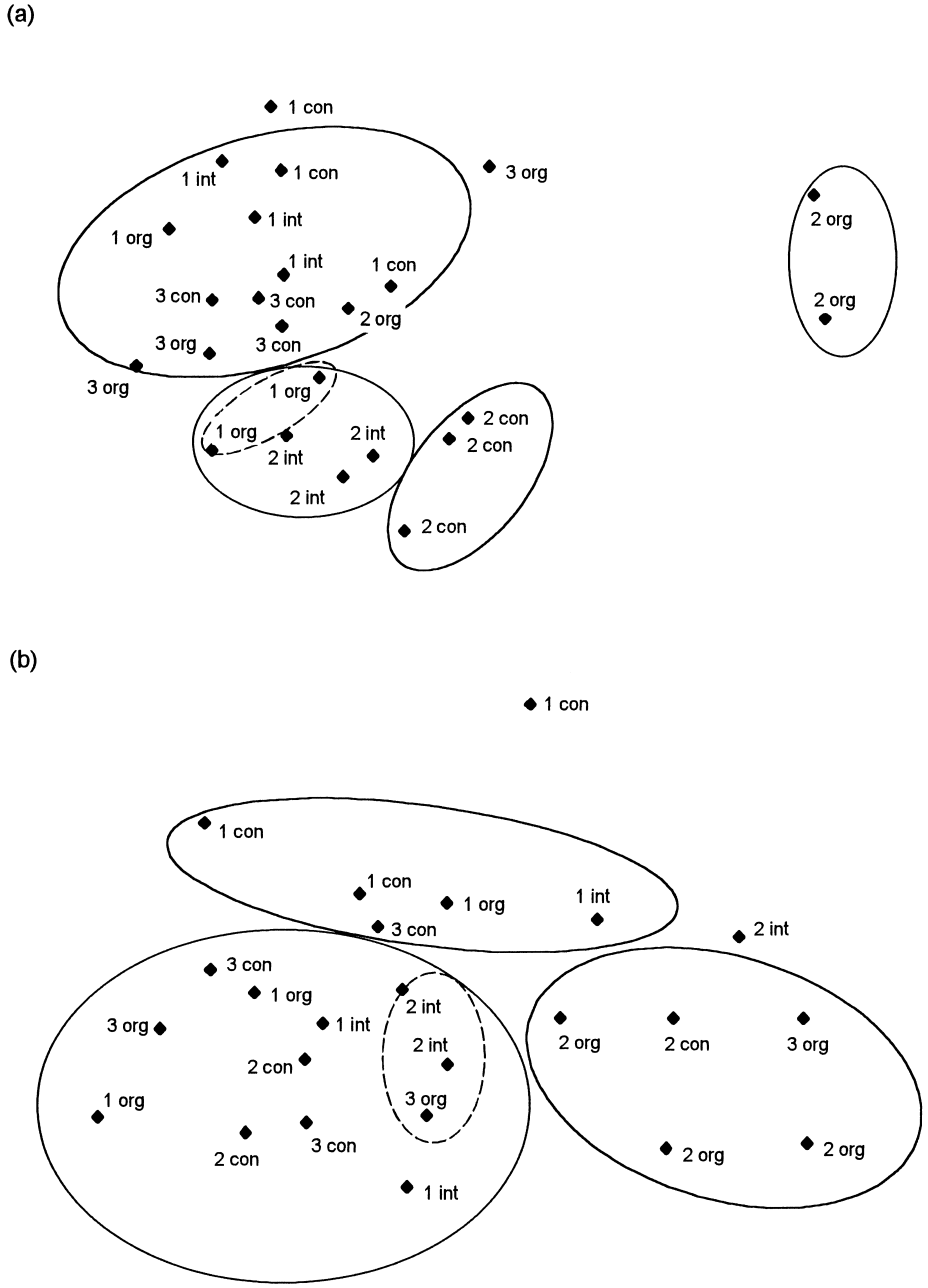

Fig. 7. Field groupings found by Multi-Dimensional Scaling analysis upon the sample similarity matrix. (a) Mean abundance data (MDS stress=0.12); (b) presence and absence data (MDS stress=0.18). Groups are delineated according to the results of cluster analysis. The dashed line groups samples on a basis of >70% similarity, the black line groups samples on a basis of >65% similarity. Numbers 1–3 refer to areas (1: midland, 2: south east, 3: central south). Letters refer to farming regime (org: organic, con: conventional, int: integrated).

observed differences in collembolan abundance under the integrated and conventional regimes, as Collembola populations are known to be reduced by soil disturbance, in particular deep ploughing and heavy machinery use (Heisler, 1991; Kracht and Schrader, 1997).

For species whose abundance was highest in organic fields, e.g. *I. viridis* and *I. notabilis*, pesticide use is a possible explanation because the conventional and integrated fields had substantially higher numbers of pesticide applications than organic fields. These species are known to be detrimentally affected by herbicide use (Prasse, 1985). The lack of herbicide use in organic crops can lead to increased weed cover which would affect microclimate, e.g. by maintaining a higher humidity at the soil surface (Moreby et al., 1994). Both *I. notabilis* and *I. viridis* are susceptible to low humidity (Davies, 1929) and it is notable that these species were most abundant under organic management whereas the more xeric species *E. multifasciata* was more abundant in conventionally farmed than organic fields. Several species of epigeic Collembola, including *I. viridis*, have been found to be vulnerable to the fungicides propiconazole and triadimenol (Frampton and Wratten, 2000), which were used in the integrated and conventional but not organic fields. Few of the fungicides routinely applied to wheat crops have been tested for side-effects on Collembola and other fungicides used in the study fields might have negatively affected Collembola by reducing their fungal food supply. Although several insecticides were used in conventional and integrated fields, these were primarily pirimicarb and cypermethrin, which appear not to be harmful to epigeic Collembola in winter wheat (Frampton, 1999).

A consistently although not significantly higher abundance of *E. multifasciata* and *Isotomurus s*pp. was recorded in conventional fields than in organic fields. The former species is relatively xeric and might be at a competitive advantage where humidity at the soil surface is lower, as could occur in conventionally farmed fields where herbicide use reduces weed cover (Moreby et al., 1994). However, such an explanation is unlikely to account for the higher abundance of *I. palustris* in conventional fields as this species is hygrophilic (e.g. Fjellberg, 1980). Recent work has shown that synthetic pyrethroid insecticides (e.g. cypermethrin), which were used in conventional but not organic fields, can lead to increased abundance of Collembola, including *E. multifasciata.* (Frampton, 1999). Higher abundance of some collembolan species in conventional fields could reflect a negative effect of insecticide use or other conventional crop management practices on predators of Collembola. This would be consistent with observations that numbers of predatory arthropods are often higher in organically than conventionally farmed fields (e.g. Kromp, 1989, 1990; Booij and Noorlander, 1992; Steinborn and Meyer, 1994). Long-term monitoring has shown that negative effects on predatory arthropods of synthetic pyrethroid insecticides can persist for more than one season (Ewald and Aebischer, 1999), meaning that previous insecticide use in the study fields might have contributed to the observed differences between farming systems in collembolan abundance.

Despite the ubiquitous nature of the common Collembola which were identified, considerable variations were found in species abundance among regions. The differences in abundance among the three regions investigated are likely to reflect variations caused by differences in local climate and soil type. For ecological monitoring of farming system effects, the high regional variation in abundance is problematic. Collembolan species composition has been found to vary at a very small geographical scale, between contiguous fields which had identical cropping histories, soil types and management histories (Frampton, 1999). There is a need to integrate the findings from farming systems studies conducted at different geographical scales, first because it is difficult to determine the wider significance of results obtained from small-scale studies (e.g. Moreby et al., 1994). Second, because in studies conducted at a large spatial scale (e.g. Reddersen, 1997 and the current work), effects of farming regimes may be difficult to detect against background ‘noise’ in arthropod abundance caused by factors which vary considerably among geographical regions, such as soil type, climate, sowing date and regional differences in pesticide use.

4.2. Farming system effects on community composition

In common with Prasse (1985), differences were found in community composition between agricultural regimes. The communities in integrated fields were less equitable and less speciose than those found under either of the other two regimes. This pattern of high abundance for a few species is associated with highly stressed environments (Begon et al., 1990). However, it is not clear why fields farmed under an integrated regime with minimum tillage should be more disturbed than either organic or conventional fields which were ploughed. No support was found for organic fields having a greater diversity than other farming regimes, but the most equitable community structure was found under organic farming, in agreement with Steinborn and Meyer (1994). Community equitability has been linked to ecosystem resilience and hence sustainability (Naeem et al., 1995).

It is possible that the diversity measures used were not ideal for detecting community level effects. Many criticisms have been made of the use of diversity measures (e.g. Cousins, 1991) and multivariate analytical techniques are generally accepted as a better approach for detecting pollutant effects (Cairns et al. (1993) and Cao et al. (1996) give general reviews). In comparisons made among multivariate techniques, MDS in particular was found to provide the clearest spatial separation of community structure, although unlike detrended correspondence analysis it does not indicate species importance (Cao et al., 1996). In this study, the ordination techniques did not show any clear differences in species groups among the regimes, although ANOSIM demonstrated significant differences according to regime. In conjunction with the rank-abundance plots, different patterns were discernible but should be treated with caution as these were produced on the whole data set without taking into account regional differences.

5. Conclusions

Several species of epigeic Collembola occurred ubiquitously in winter wheat crops in different geographical regions but their populations did not vary significantly with organic, integrated or conventional farming regimes. This study agrees with most of the existing literature that these farming regimes are not a major determinant of arable Collembola populations, although it should be noted that none of the conventional wheat crops received organophosphorus insecticides, which are particularly harmful to Collembola. Differences between farming regimes in community structure and consistent patterns of abundance among individual species were detected which, though not statistically significant, might indicate subtle effects of farming regime masked by background variation in abundance. The possibility that consistently higher abundance of certain species under conventional than organic management is indicative of negative effects of synthetic pyrethroid insecticides on predatory arthropods warrants further investigation, as these are among the most frequently-used insecticides in conventional wheat production.

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