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ScienceDirect
Environmental Pollution 147 (2007) 14–25
ENVIRONMENTAL POLLUTION
www.elsevier.com/locate/envpol

Collembola and macroarthropod community responses to carbamate, organophosphate and synthetic pyrethroid insecticides: Direct and indirect effects

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Received 23 May 2006; received in revised form 25 August 2006; accepted 29 August 2006

Direct and indirect insecticide effects differ among closely-related arthropod taxa; resurgence of Collembola may occur widely after synthetic pyrethroid insecticide applications.

Abstract

Non-target effects on terrestrial arthropod communities of the broad-spectrum insecticides chlorpyrifos and cypermethrin and the selective insecticide pirimicarb were investigated in winter wheat fields in summer. Effects of chlorpyrifos on arthropod abundance and taxonomic richness were consistently negative whereas effects of cypermethrin were negative for predatory arthropods but positive for soil surface Collembola. Pirimicarb effects were marginal, primarily on aphids and their antagonists, with no effect on the Collembola community. Collembola-predator ratios were significantly higher following cypermethrin treatment, suggesting that cypermethrin-induced increases in collembolan abundance represent a classical resurgence. Observations in other studies suggest Collembola resurgences may be typical after synthetic pyrethroid applications. Collembola responses to insecticides differed among species, both in terms of effect magnitude and persistence, suggesting that coarse taxonomic monitoring would not adequately detect pesticide risks. These findings have implications for pesticide risk assessments and for the selection of indicator species.

Keywords: Indicators; Non-target effects; Principal response curves; Resurgence; Risk assessment

1. Introduction

Synthetic pyrethroids are the most widely used class of insecticide in European agriculture (in 2004, they accounted for 75% (4.9 million ha) of the insecticide-treated arable crop area in Britain, with cypermethrin being the most widely-used individual insecticide (2.0 million ha); UK Government, Pesticide Usage Survey Statistics). A selective carbamate aphicide, pirimicarb, is also used extensively in Europe (in 2004 it accounted for ca 7% (0.4 million ha) of the area of insecticide-treated arable crops in Britain). Non-target effects of cypermethrin and pirimicarb on terrestrial arthropod populations have been studied in detail for predatory macroarthropods (e.g. Coleoptera and Araneae) but relatively little is known about their effects on Collembola (springtails). Epigeic (soil surface) Collembola are abundant in arable fields (where densities may exceed 10,000 m^{-2}) and are likely to be exposed to sprayed and soil-applied pesticides. They are also important in food webs, as fungivores and as prey for a wide range of specialist and generalist predators, including Arachnida and Coleoptera (Hopkin, 1997).

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doi:10.1016/j.envpol.2006.08.038

The majority of literature suggests that Collembola abundance is generally not affected adversely by synthetic pyrethroid insecticides in arable agriculture or forestry field studies (Heungens and van Daele, 1979; Hill, 1985; Shires, 1985; Inglesfield, 1989; Smart et al., 1989; Dewar et al., 1990; Huusela-Veistola et al., 1994; Bishop et al., 1998; Frampton, 1999; Baker et al., 2002). Synthetic pyrethroid applications decreased Collembola catches in barley (Huusela-Veistola et al., 1994) and beans (Tripathi and Sharma, 2005) whereas in hops, spatially inconsistent effects occurred (Filser and Nagel, 1993). However, not all studies were clearly reported and in some cases it is unclear whether the pesticide treatments were appropriately replicated. In four studies, Collembola catches increased after applications of synthetic pyrethroids in forest plots (Funke et al., 1994; Holopainen and Rikala, 1995) and arable crops (Gimeno and Perdiguer, 1995; Frampton, 1999). With the exception of three studies (Funke et al., 1994; Filser and Nagel, 1993; Frampton, 1999), responses of individual Collembola species were not investigated in detail; usually only the total Collembola catch was reported.

Hardly any studies of the effects of pirimicarb on natural populations of Collembola have been published, with only one detailed field investigation (Frampton, 1999) and a study in which individual species were introduced into microcosms (Løkke, 1995). In the field study, pirimicarb had no significant effect on the abundance of 12 taxa but increased catches of two taxa. However, the effects of pirimicarb were based on the change in abundance from one pre-treatment sampling to one post-treatment sampling and appear sensitive to the statistical method of analysis (see Section 4). In the microcosm study, pirimicarb had a negative effect on the abundance of one introduced species (*Folsomia fimetaria*) but only on one sampling date (70 days after treatment), with statistical significance of the effect dependent on the presence of data outliers (Løkke, 1995).

This paper provides a more detailed analysis of the field study carried out in 1994 by Frampton (1999), which extends the data available on effects of cypermethrin and pirimicarb from two to seven sampling dates. Analysis of archived arthropod samples from the original study has been made possible by the provision of additional resources (see Acknowledgements). Since the original field study was carried out there has been relatively little new information in the literature about effects of cypermethrin and pirimicarb on Collembola, although some contract testing laboratories have observed increased collembolan abundance after synthetic pyrethroid applications (Ecotox Ltd., Tavistock, UK; ECT Ökotoxikologie GmbH, Flörsheim, Germany; Mambo-Tox, Southampton, UK; personal communications). Such increased abundance reflects indirect effects that might be more widespread than the published literature suggests. Understanding the extent of such indirect effects is important in risk assessment because they cannot be predicted using single-species toxicity tests (Wiles and Frampton, 1996).

Collembola and macroarthropod community responses to cypermethrin and pirimicarb are presented in detail, to clarify the persistence and taxonomic spectrum of effects observed previously (Frampton, 1999). Effects of the broad-spectrum organophosphorus insecticide chlorpyrifos are also included for comparison. To our knowledge, this work represents the most detailed examination of how natural Collembola and terrestrial macroarthropod communities respond to cypermethrin and pirimicarb. The implications of the findings are discussed in terms of whether individual Collembola species or groups might be useful as indicators of adverse pesticide effects on their predators.

2. Methods and materials

Full details of the study site, experiment design, insecticide applications and arthropod sampling are given by Frampton (1999). The study was carried out in south-east England (51° 16′ N, 0° 23′ E) during summer 1994 and employed four insecticide treatments (unsprayed, chlorpyrifos, cypermethrin and pirimicarb). Chlorpyrifos was included as a toxic reference treatment. Each pesticide was applied to plots (0.58 to 0.85 ha) in four contiguous fields of winter wheat such that each field contained one randomized replicate of each treatment. These four fields had previously been treated together as a single management unit and were selected in view of their apparent homogeneity of soils, previous cropping and husbandry.

2.1. Insecticide applications

Insecticides were applied on 23 June using a tractor-mounted boom sprayer, according to label recommendations for winter wheat (chlorpyrifos (‘Spannit’®; PBI): 480 g a.i. ha^{-1}; cypermethrin (‘Ambush C’®; Zeneca): 25 g a.i. ha^{-1}; pirimicarb (‘Aphox’ ®; Zeneca): 40 g a.i. ha^{-1}). These resulted in homogeneous spray deposition rates on the soil surface (0.11 to 0.13 μl cm^{-2}) that did not differ between treatments (Wiles and Frampton, 1996). The wind speed during applications was mostly 3 to 5 km h^{-1} and screen temperature 20–22 °C. A notable feature of the weather is that approximately 30 h after the insecticide applications a ca 3-h period of heavy rainfall (total ca 40 mm) occurred.

2.2. Arthropod sampling

Arthropods were sampled during dry weather using a Ryobi suction sampler (Macleod et al., 1994) on seven sampling occasions (35 d and 2 d pre-treatment and 6 d, 10 d, 17 d, 27 d and 44 d after treatment; the last sampling was one week before crop harvest). On each occasion, five samples (0.052 m^2) were taken randomly from the centre of each plot (each sample was obtained by pooling five randomly-placed 104-cm^2 sub-samples; Frampton, 1999). Samples were preserved in methylated spirit and stored in darkness below 15 °C prior to sorting. Due to the large number of specimens collected, identification of all individual species was not feasible. Thus, *Isotoma viridis* and *I. anglicana* (Isotomidae) are reported together as ‘*Isotoma viridis* group’, whilst *Sminthurinus aureus* and *Sminthurinus niger* (Sminthuridae) are reported together as ‘*Sminthurinus aureus* group’. The name *Isotoma notabilis* used previously (Frampton, 1999) is now considered a junior synonym of *Parisotoma notabilis* (Hopkin, in press). Macroarthropods in the samples were also identified to enable effects of the insecticides on the collembolan and macroarthropod communities to be compared. A notable exception is that it was not feasible to record predatory Acari due to their low abundance in the majority of samples.

2.3. Data analysis

All statistical analyses were carried out on normalised data, using the log $(x + 1)$ of arthropod counts x. Community responses to the insecticide treatments were analysed using the software program CANOCO 4 (Ter Braak and Šmilauer, 1998) to generate Principal Response Curves (PRC) for Collembola and macroarthropods. For each species (k), date (d) and treatment (t), the response (T_{dtk}) was modelled as a multiple (the species weight, b_k) of one basic community response pattern (c_{dt}), with the unsprayed treatment nominated as