How do arable rotations influence pesticide side-effects on arthropods?

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Summary

Results of long-term arthropod monitoring under three arable rotations of the MAFF SCARAB project show that the most severe effects of conventional pesticide use occurred in a grass-wheat rotation. Reasons for the relative lack of substantial pesticide effects in other rotations and the mechanisms whereby crop rotations affect arthropod responses to pesticide use are discussed.

Key words: SCARAB project, pesticides, side-effects, arable rotations, arthropods

Introduction

Rotations, cultivations, pest control measures and fertilization are the main inputs into arable land. These inputs not only have direct chemical, physical and biological effects on arthropods, but also interact to produce a wide range of indirect effects (Edwards, 1989). The potential outcome of interactions between different inputs may be difficult to predict, given that pesticides and fertilisers usually affect a wider range of organisms than their intended targets. For instance, fertilisers may increase the incidence of pests and diseases by increasing the nutrient supply; insecticides may decrease incidence of plant viruses and increase weed populations by depleting populations of virus vectors and herbivores; fungicides may decrease populations of soil microorganisms and insect pathogens; and herbicides may deplete arthropod populations by removing host plants or refuges (Edwards, 1989). Studies of the impact of arable farming practices on arthropods have been ill-equipped to explore such complex scenarios, as they have tended either to investigate effects of individual inputs in isolation, as in traditional pesticide and fertiliser trials comparing single-chemical treatments, or, more recently, to investigate effects of overall farming systems, especially with regard to conventional, integrated and organic strategies (Holland et al., 1994). Neither approach is ideal, as the former cannot identify effects of interactions between different inputs which may operate over long temporal scales, whilst the latter often cannot isolate effects of individual inputs within a system. The aim of the work described in this paper was to investigate effects on arthropods of the pesticide component of conventional (average) and reduced-input farming systems. This approach was neither a conventional single-input field trial nor a whole farming systems study. Instead, it investigated the side-effects of long-term, cumulative use of pesticides in several arable rotations but excluded other variable components of a farming system such as cultivations and fertilisation. Results of the work are presented to demonstrate mechanisms whereby crop rotation may influence the severity and persistence of side-effects of pesticide use experienced by non-pest arthropods.

Materials and Methods

The Ministry of Agriculture, Fisheries and Food (MAFF) SCARAB project ("Seeking Confirmation About Results At Boxworth") was initiated in 1990 to determine whether severe side-effects of pesticide use on arthropod populations in commercial wheat production during the 1980s (Burn, 1992; Vickerman, 1992) could occur in other crop rotations under 1990s pesticide inputs (Cooper, 1990). The project involves a split-field comparison of two pesticide regimes in seven fields (Table 1). From autumn 1990 to harvest 1996 each field has received current farm practice (CFP) and reduced input approach (RIA) pesticide inputs. The CFP regime mirrors conventional farming practice as indicated by MAFF Pesticide Usage Surveys (Garthwaite *et al.*, 1995) whereas RIA represents a managed, lower input of pesticides based on monitoring pests, weeds and diseases in the crop (Table 1). Three rotation types are included in the study, reflecting the typical farming practice at three locations in England (Table 1). Although cropping changed temporally as the rotations progressed, for each crop, cultivations and fertilisation did not differ between the two pesticide regimes.

Populations of arthropods were monitored routinely during the course of the study by continuous pitfall trapping and frequent suction (D-vac) sampling at matched locations in the CFP and RIA areas of each field so that the number and size of samples, their spacing and distance from the field boundary were identical in the two regimes (Cooper, 1990). This paper presents results of arthropod monitoring between 1990 and 1995 to illustrate how the crop rotations may have affected pesticide side-effects on arthropod populations. Further details of the project's background, design and layout were given by Cooper (1990) and Frampton & Çilgi (1993).

Results

During 1990-1995 the RIA inputs of herbicides, fungicides and insecticides were, on average, 48%, 51% and 100% lower than CFP inputs. There were considerable differences between fields, with the highest overall inputs being in the Gleadthorpe rotation, where South Field had received the most applications of all pesticide types (Table 1).

Long-term arthropod population differences between the CFP and RIA pesticide regimes were most pronounced in Field 5 under the grass-wheat rotation (Drayton Research Centre; Table 1). In this field, which received an organophosphorus insecticide application in every year from 1990 to 1995, several species of Collembola disappeared from the CFP half of the field in January 1991, a few days after chlorpyrifos was applied only under the CFP regime, and there was no evidence of population recovery by summer 1995 (Frampton, 1997). The persistent difference between CFP and RIA catches of *Entomobrya multifasciata* and *Lepidocyrtus* spp. is evident in the 1994 and 1995 summer suction sample catches shown in Fig 1. The absence of these species from the CFP regime area of the field persisted despite the presence of relatively large populations in the adjacent RIA area (Fig. 1). Differences in populations of predatory arthropods between the pesticide regimes were also most pronounced in Field 5. This field was the only one of the seven study fields in which consistently more species of Carabidae were trapped in the RIA regime, a pattern that was particularly clear after the use of chlorpyrifos in January 1991 and in March 1995 (Fig. 2).

Although such long-term population differences have not yet been detected in the other SCARAB project rotations, a number of recently-emerging patterns in other fields could represent indirect effects of pesticide use. Among the Collembola trapped in Bugdale field (High Mowthorpe Research Centre; Table 1) since the start of 1994, for instance, *Lepidocyrtus* spp. have only been trapped in the RIA regime area whereas *Pseudosinella octopunctata* has only been trapped in the CFP regime (Frampton, 1997).

Table 1: Details of sites, fields and rotations in the MAFF SCARAB project. s: spring sown; w: winter sown.

Farm name:	Drayton		Gleadthorpe			High Mowthorpe	
Location	52.2°N 1.8°W		53.2°N 1.1°W			54.1°N 0.6°W	
Soil	calcareous clay		stony sand			calcareous loam	
Field name:	Field 1	Field 5	Balk	Near Kingston	South	Bugdale	Old Type
Area (ha)	11	8	12	8	12	19	34
Cropping:							
1990-1991	w. wheat	grass	sugarbeet	s. barley	potatoes	w. rape	s. beans
1991-1992	w. wheat	w. wheat	s. wheat	w. barley	s. wheat	w. wheat	w. wheat
1992-1993	grass	w.wheat	w. barley	s. beans	w. barley	s. barley	w. barley
1993-1994	grass	grass	potatoes	w. wheat	sugarbeet	s. beans	w. rape
1994-1995	grass	grass	s. wheat	w. barley	s. wheat	w. wheat	w. wheat
Pesticide input ratios, 1990-1995 (Current Farm Practice : Reduced Input Approach) (number of full label-rate applications, excluding seed treatments)							
insecticides	3 : 0	5 : 0	6 : 0	5 : 0	7 : 0	6 : 0	6 : 0
herbicides	7 : 2.5	8 : 4	13 : 11	6 : 3	15 : 9.5	6 : 3.5	7 : 5
fungicides	9 : 3	7 : 3	10 : 6.5	10 : 5	12 : 8	8 : 2.5	8 : 3.5
total pesticides	19 : 5.5	20 : 7	29 : 17.5	21 : 8	34 : 17.5	20 : 6	21 : 8.5

Figure 1. Current farm practice (■) and reduced input approach (□) summer suction sample catches of Collembola in the fourth (1994) and fifth (1995) years of three arable rotations. Details of rotations are given in Table 1. Data are geometric means from four D-vac samples (w: winter-sown crop; s: spring-sown crop; M J J: May, June, July; asterisks denote no data).

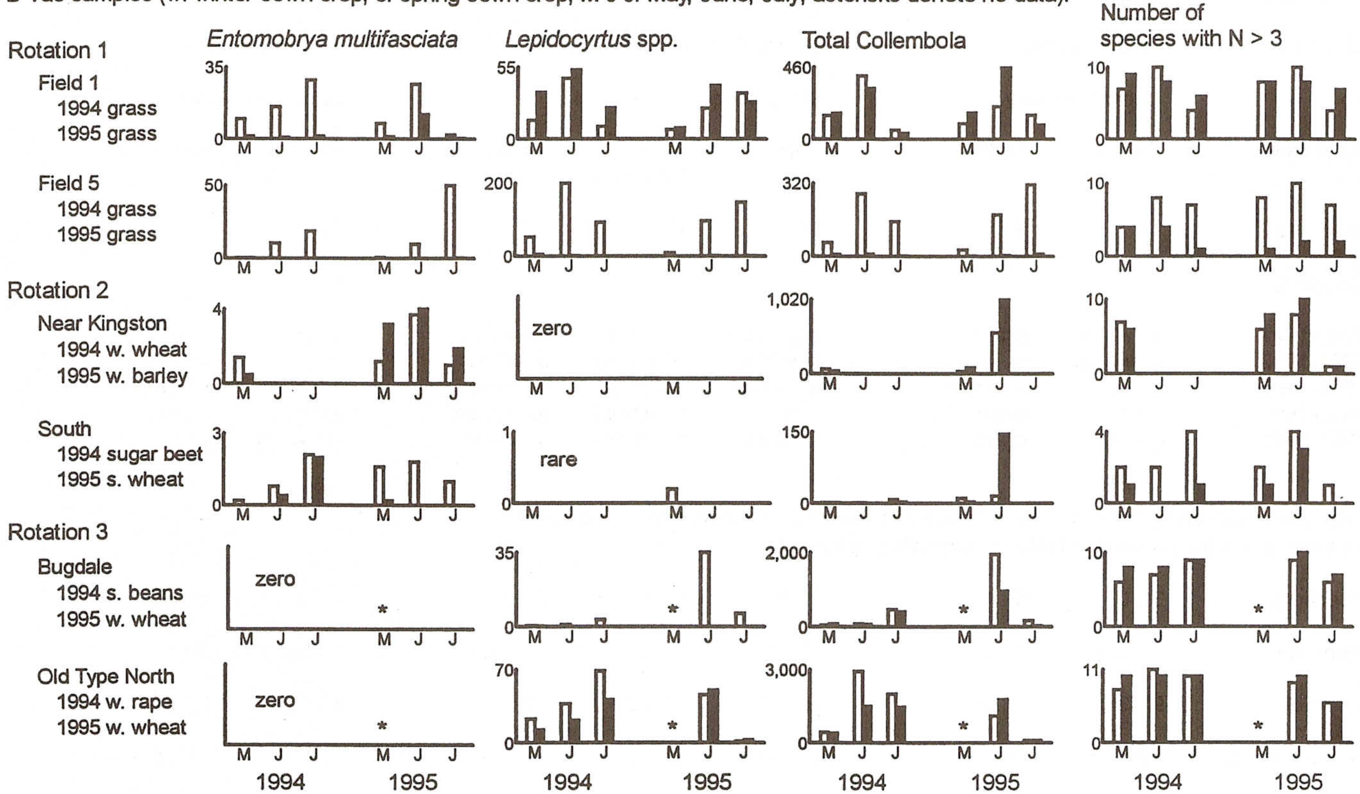


Figure 2. Relative differences in the number of ground beetle species between two treatments over 6 years in Field 5

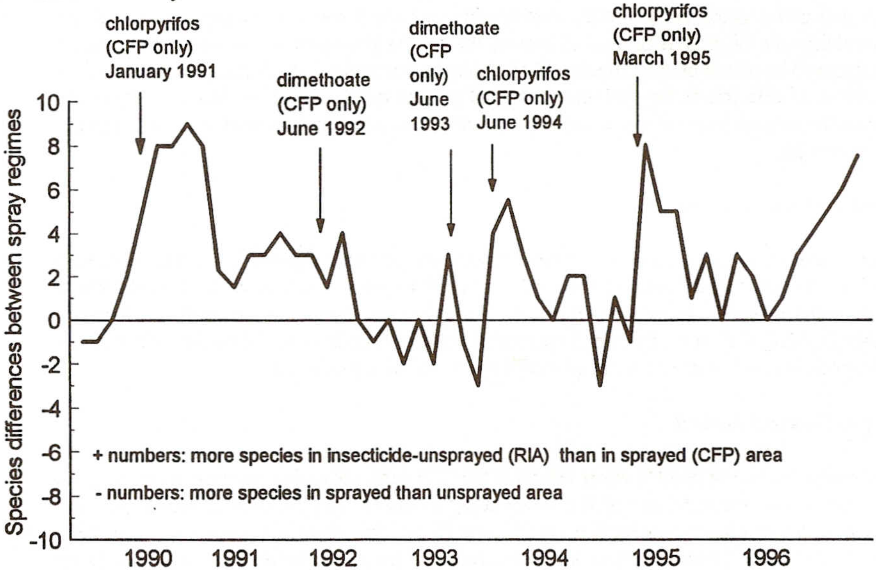
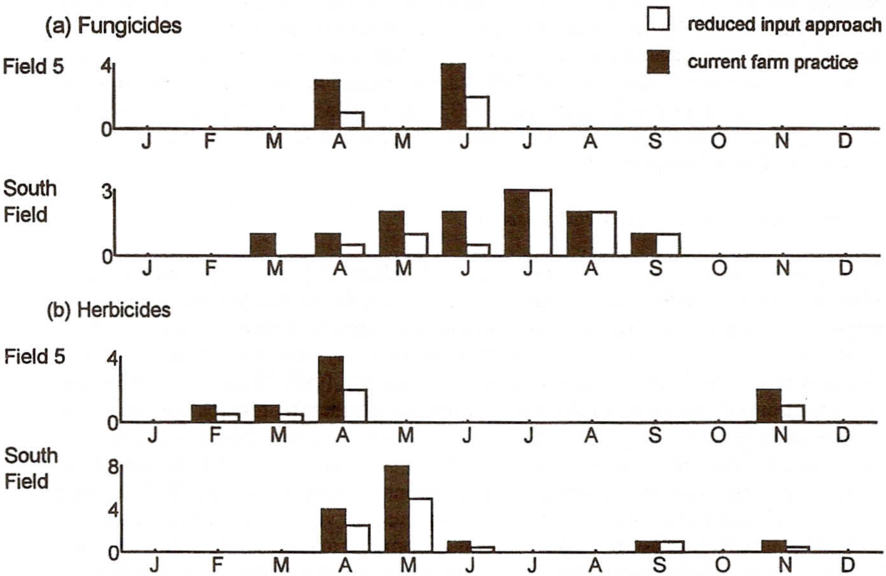


Figure 3. Comparison of overall number and timing of full-rate fungicide and herbicide applications to Field 5 and South Field, 1990 -1995.



Discussion

A full multivariate analysis of arthropod monitoring data will include results from the 1995-96 crop year and it is too early to draw firm conclusions about some of the population patterns observed in the SCARAB project. However, the results presented in this paper allow some inferences to be drawn on the influence of rotations on pesticide side-effects. Here we consider a number of differences between the SCARAB project rotations in a preliminary attempt to explain the marked long-term vulnerability of arthropod populations to pesticide use in the grass-wheat rotation.

Number of pesticide applications

The substantial population differences between the pesticide regimes in SCARAB project Field 5 were not related directly to the number of pesticide applications made to the field. Other fields without such marked population differences had received more pesticide applications (Table 1). Booij & Noorlander (1992) concluded that the abundance and diversity of beneficial arthropods in arable systems is not governed by chemical inputs alone.

Type of chemical applied

A unique feature of Field 5, where effects of the CFP pesticide regime were most pronounced, was that it was the only one of the seven study fields to have received a broad-spectrum organophosphorus insecticide application (chlorpyrifos or dimethoate) in every year up to 1995 (Fig. 2). Although South Field had on average received more insecticide applications (1.4) per year (Table 1), organophosphorus chemicals were not used in this field in 1990-91 and 1992-94. Monitoring Carabidae (Fig. 2) and Collembola populations (Frampton, 1997) indicated that within Field 5 there was some evidence for a more pronounced effect of chlorpyrifos than of dimethoate. Toxic effects of chlorpyrifos on Carabidae (Asteraki *et al.*, 1992) and Collembola (Wiles & Frampton, 1996) are well known but it is important to consider whether different timings of the dimethoate and chlorpyrifos applications could have resulted in different exposure of arthropods to each chemical (see below). Pirimicarb, cypermethrin and deltamethrin were the other most widely used insecticides in the SCARAB project fields but these have been found to be relatively less harmful than organophosphorus chemicals to carabids (Çilgi, 1997) and Collembola (Wiles & Frampton, 1996).

Timing of chemical applications within a season

Timing of a pesticide application in relation to arthropod phenology is important in determining effects of the pesticide on populations. In Field 5, for example, populations of some arthropods, e.g. the collembolan species *Sminthurinus elegans,* declined before late June applications of dimethoate had occurred so these species may only have been exposed to applications of chlorpyrifos, which were made earlier (Frampton, 1997). The ability of *S. elegans* to to recover from effects of chlorpyrifos also depended on whether chlorpyrifos was applied in two consecutive seasons or not (Frampton, 1997). Because organophosphorus residues may dissipate rapidly after application, the precise timing of an application may be crucial in determining the extent of subsequent effects on populations (Wiles & Frampton, 1996). Timing of applications is also important in relation to the growth stage of vegetation as denser vegetation can considerably reduce exposure of ground-dwelling arthropods to foliar sprays (Çilgi & Jepson, 1992). Fig. 3 shows another aspect of the timing of pesticide applications that could be influential on population effects, viz the frequency and temporal spread of applications within a season; the overall distribution of fungicide and herbicide applications clearly differed between Field 5 and

South Field, reflecting the inherently higher fungicide and herbicide demand of the root crops in the latter field.

Crop pesticide demand

Rotations involving root crops generally have a higher pesticide demand than cereals and grass, as is evident in Table 1; maximisation of sugar beet leaf area necessitates high herbicide inputs whereas control of blight in potatoes creates an inherently high demand for fungicides. The high requirement for fungicides in the rotation of South Field meant that it was not always possible to achieve reductions in RIA inputs compared to CFP, particularly for late summer applications (Fig. 3). Although the data in Fig. 3 present a summary for the period 1990-1995, it is clear that any effects on arthropod populations of early season differences between CFP and RIA fungicide inputs would probably have been difficult to detect in the long-term, being hidden by similar fungicide inputs to both CFP and RIA regimes later in the season. Consideration of fungicide use also raises another point, namely that although fungicides are known to be toxic to some Collembola (Frampton, 1988, 1994), they are applied only during the summer months (Fig. 3) when crop foliage would considerably reduce exposure of arthropods. However, exposure in silage and pasture leys may represent a unique situation in this respect (see below).

Crop effects on arthropod populations and their exposure

One of the principal attributes of a crop affecting both the densities of arthropods and their exposure to foliar applied pesticides is the amount of vegetation cover and its duration in a season. Late-sown crops are generally less favourable than early-sown crops to ground-dwelling arthropods; this was demonstrated for Carabidae in a range of crop types (Booij & Noorlander, 1992) and for Staphylinidae in early and late-sown spring cereals (Good & Giller, 1991). Other groups of arthropods such as fungivorous and predatory Diptera (Vickerman, 1992; Reddersen, 1994) and Aphididae (Vickerman, 1992) may also be favoured by early sowing dates in winter cereals but some Heteroptera and Thysanoptera were favoured by later sowing dates (Vickerman, 1992). Everts *et al.* (1989) concluded that ground-dwelling arthropods are unlikely to be exposed to deltamethrin in oilseed rape because of the shielding effect of the dense foliage, and in winter wheat up to 94 per cent of foliar applied pesticide deposition may be intercepted by the crop at growth stages 47-90 (Çilgi & Jepson, 1992). The grass leys in the Drayton Research Centre grass-wheat rotation were managed both by grazing and silage cutting. The maintenance of a short sward would not only have increased exposure of arthropods to pesticide sprays but could also have exacerbated pesticide side-effects in those populations affected by pesticide use by impeding their recovery, since silage cutting is well-known to be detrimental to arthropod populations including Collembola (Curry & Tuohy, 1978), Linyphiidae (Halley *et al.*, 1996) and Staphylinidae (Good & Giller, 1991).

Temporal continuity of a crop (frequency of tillage)

A notable difference between the grass-wheat rotation and the other SCARAB project rotations is that the former was less frequently disturbed by ploughing. This could in part explain why long-term pesticide effects were only clearly detectable in the grass-wheat rotation; tillage has an important effect on arthropod populations and its effects may often be greater than those of pesticide use (Edwards, 1989).

Geographical heterogeneity of faunas

The species composition of the Collembola fauna differed between the three SCARAB project rotations; *Entomobrya multifasciata*, which was adversely affected by pesticide use in Field 5 (Rotation 1), was never found at the High Mowthorpe site (Rotation 3), whereas *Lepidocyrtus* spp. were rarely trapped at the Gleadthorpe site (Rotation 2) (Fig. 1). Differences in faunal composition between different geographical locations are clearly important in determining the species spectrum of side-effects. It is perhaps noteworthy that South Field, which received the highest number of pesticide applications, had the lowest species richness (Fig. 1); previous pesticide history could be one of the variables determining faunal richness of a particular location.

Although it may be difficult to isolate important variables from the complex interactions discussed above, it is clear from the preliminary results of the SCARAB project that rotations do affect the side-effects of pesticides experienced by arthropod populations. One of the important determinants of pesticide effects in the SCARAB project rotations was the frequency of use of organophosphorus insecticides; repeated use of these chemicals in consecutive years in SCARAB and in the Boxworth project (Vickerman, 1992) both led to adverse long-term declines in populations of beneficial arthropods. However, use of such chemicals cannot be considered as a single variable, being intricately linked with other factors such as the crop type and pest pressure, the latter in turn depending upon sowing date and geographical location, etc. Results from SCARAB indicate that the perceived species spectrum of pesticide effects observed in any one arable rotation may be misleading if highly vulnerable species are restricted in their geographical distribution.

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