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Effects of pesticide use and cultivation techniques on ground beetles (Col., Carabidae) in cereal fields

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The effects of two pesticide regimes (conventional, reduced) and two types of cultivation systems (customary, integrated farming practice) on ground beetles were studied in a large-scale field experiment. Plots on conventional pesticide regime were sprayed with herbicide, insecticide, fungicide and growth regulator annually. The plots on reduced pesticide regime were treated only when the control threshold was exceeded, i.e. in 1992 with a selective insecticide (pirimicarb) and in 1994 with a herbicide. The numbers of ground beetles in pitfalls differed between years and pesticide use regimes. In 1992, the broad-spectrum insecticide, dimethoate, reduced the number of Carabidae more than pirimicarb, but the effect was short, and the trend was opposite in late summer and in total catches. The number of Carabidae in pitfalls was significantly lower in the dimethoate-treated plots than in the non-treated plots in 1993 and 1994. The difference was obvious for four weeks after spraying. Prophylactic pesticide use decreased the abundance of ground beetles remarkably. However, pesticides affected only the numbers of spring (early season) species, because their active period occurred during application, the numbers returned to normal after three or four weeks, probably due to immigration from untreated areas. Effects on species dominant in autumn were not observed because these species were not exposed directly to pesticide treatments. During a period of three years, no differences were found in the numbers of ground beetles between the two cultivation systems tested.

1. Introduction

Ground beetles are considered beneficial arthropods in agriculture, because they are natural enemies of cereal pests (Luff 1987, Kröber & Carl 1991) and because they represent a food source for species at other trophic levels. Being normally abundant, and not dependent on only one prey species, they may provide a good buffer against pests as their populations may be more stable than those of aphid-specific predators (Helenius 1990).

Pesticides used in cereal fields are targeted against specific pest species. However, they may have adverse effects on beneficial and other non-target species inhabiting the treated areas because of their basic physiological similarities (Croft 1990). Thus, pesticide treatment may decrease dramatically the diversity and abundance of beetles. In addition,

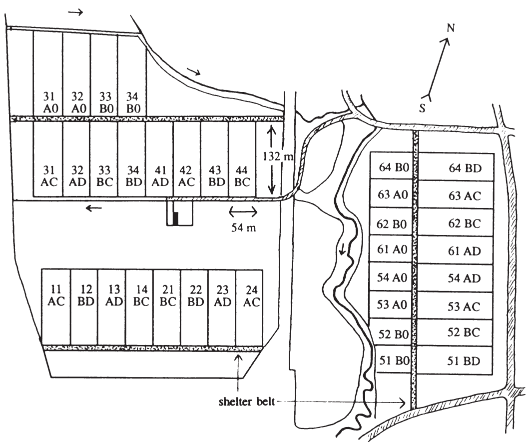

Fig. 1. The schema of the field experiment. Letters show the cultivation system (A = customary, B = integrated) and the pesticide regime (C = conventional, D = reducued, 0 = no use of pesticides), first number shows the replicate.

pesticide treatments are not always economically profitable because of the more rapid invasion of pests than their natural enemies after pesticide use.

Adverse effects of pesticides on ground beetles have been widely documented (eg. Jepson 1989, Croft 1990, Heimbach *et al.* 1992, 1994), but studies conducted in northern latitudes are not available. The bioavailability of pesticides depends on the species, the chemical properties of the pesticide and environmental factors (Wiles & Jepson 1994). For example, insecticides have been found to exert different effects in different temperatures and humidities (Everts *et al.* 1991, Heimbach *et al.* 1995). This study focuses on cooler regions where the effects of pesticides may be longer-lasting and more dramatic. The adverse effects of pesticides on ground beetles have normally been studied in laboratory and small-scale field trials, and less frequently in extensive and more realistic field trials.

In general, cultivated fields are habitats subject to frequent disturbances. Cultivation methods (tillage, fertilizing, undergrowth etc.) may have a positive or a negative effect on ground beetle populations and modify the effects of pesticides. Tillage changes the habitats of carabids by mechanical disturbances, by changing the amount of litter and organic matter and the number and dominance structure of weeds (Stinner & House 1990). Reduced tillage tends to increase the number of carabids, although opposite trends have been found (Stinner & House 1990). Undergrowth vegetation is usually justified by decreasing of erosion and for its fertilizing effect, not for plant protection reasons. However, the use of undergrown crops in cereal fields increased the numbers and the diversity of arthropods as compared with monoculture (Vickerman 1978).

Ecological effects of intensity of farming on field ecosystem are studied in a large-scale field experiment. The study attempts to assess in practice the effects of two pesticide use regimes (conventional and reduced) and two cultivation systems (customary farming and integrated farming practices) on beneficial and other non-target organisms in cereal field. Results of carabids are presented in this paper. The carabid species which can be used as indicators of adverse effects of pesticides in Finnish fields are also determined.

2. Material and methods

2.1. Experimental design

The use of plant protection chemicals and intensity of farming have been studied within the Nummela project, which started in 1992 at the Institute of Plant Protection, Agricultural Research Centre of Finland (ARC). The ecological effects of two pesticide regimes (C = conventional, D = reduced) on the field ecosystem have been evaluated in the present study as part of the Nummela Project. The plant protection programmes were contrasted with two types of cultivation systems (A = customary, B = integrated farming pratice). The permanent shelter belts (perennial green fallow strips) at the margins of the treated plots and the untreated plots provided additional elements.

The experimental field is situated on the Nummela Experimental Farm of the ARC in Jokioinen (60°52′N, 23°25′E) about 120 km northwest of Helsinki. Before the replicated field experiment, the fields were under conventional grain and grass production and cattle pasture. The plot size used was 54 × 132 m (0.7 ha). There were six replicates (blocks) and the treatments were fully randomised in blocks (Fig. 1).

The experiment consisted of two cultivation system treatments as follows: A = customary farming practice (deep ploughing, no undergrowth), B = integrated (lighter) farming practice (soil treatment with cultivator only, reduced use of fertilizers, green undergrowth), and two pesticide regimes: C = conventional (routine, prophylactic) treatment with pesticides (high pesticide pressure), D = reduced plant protection programme (low pesticide pressure).

The plots on conventional pesticide regime were sprayed with herbicides, insecticides, fungicides and growth regulators annually. The plots on reduced pesticide regime were treated only when the control thresholds were exceeded. The use of pesticides in 1992–1994 is given in Table 1. Fertilizers were applied simultaneously with sowing N-P-K 90–15.6–23.5 kg/ha was applied in A plots and N-P-K 60 10.4–15.6 kg/ha in B plots. In autumn 1992, all plots were ploughed, but different tillage systems according to the experimental scheme were later applied in A and B plots.

In 1992 and 1993, the crop was barley (c.v. Arra) and in 1994 spring wheat (c.v. Satu). Undergrowth vegetation in B plots was established with a mixture of timothy and red clover. Shelter belts (12 m wide perennial strips) were located at the shorter ends of each plot, and were sown in 1991 with a mixture of timothy, meadow fescue and red and white clover. The perennial strips were not cut or renewed after the establishment. A 4 m wide strip of *Phacelia tanacetifolia* was added beside the shelter belts in 1992. Sowing of the *Phacelia* strip was repeated annually.

2.2. Monitoring of epigeal arthropods

Arthropods on the soil surface were sampled with pitfall traps, despite the fact that trap catches are affected by many factors, e.g. species, sex, activity level of the species, vegetation, climatic conditions and trap design (Greenslade 1964, Luff 1975, Adis 1979, Honek 1988, Halsall & Wratten 1988). In spite of the disadvantages, pitfall trapping is a widely used method in ground beetle studies. Pitfall trap data do not estimate absolute density of different species but abundance of different species and activity and the term 'activity-density' is referred to in pitfall trap data (Thiele 1977). However, pitfall trapping may be a useful method for estimating the predation efficiency of beetles, because the probability of a foraging beetle contacting a prey item may correlate with 'activity-abundance' (Luff 1987). In addition, pitfall trapping is an easy way to collect both nocturnal and diurnal species as compared with other methods. According to Sunderland *et al*. (1995), pitfalls may provide a useful technique in cases where inaccuracy is low as compared with the extent of effects that are measured.

The pitfall traps consisted of plastic cups with a diameter of 9.5 cm and depth of 10 cm. The trapping liquid was concentrated NaCl solution (300 g/l) and the traps were covered with a plastic roof. Three pitfalls per cereal plot were placed in line in the middle of the plot at predetermined distances (12, 66 and 120 m) from the edge of the perennial grass strips. The trapping periods were usually 7 days. The sampling started

Table 1. Use of pesticides in 1993–1994 in the Nummela project. (H = herbicide, G = growth regulator, F = fungicide, I = insecticide).

		Conventional (C)	Reduced (D)
1992			
Seed coating	F	Carboxin + Imazalil (Täyssato S)	–
1st spraying (24 Jun.)	H	Chlorsulfuron (Glean 20 DF), A plots	–
	H	MCPA + Bentazone (Basagran MCPA), B plots	–
	I	Dimethoate (Roxion)	Pirimicarb (Pirimor)
2nd spraying (30 Jun.)	G	Etefon (Cerone)	–
	F	Propiconazole (Tilt)	–
1993			
Seed coating	F	Carboxin + Imazalil (Täyssato S)	–
1st spraying (10 Jun.)	H	Chlorsulfuron (Glean 20 DF), A plots	–
	H	MCPA + Bentazone (Basagran MCPA), B plots	–
	I	Dimethoate (Roxion)	–
2nd spraying (28 Jun.)	G	Etefon (Cerone)	–
	F	Propiconazole (Tilt)	–
1994			
Seed coating	F	Carboxin+Imazalil (Täyssato S)	–
1st spraying (16 Jun.)	H	MCPA + Mecoprop-P, A plots (Hormoprop Duplosan)	MCPA + Mecoprop-P (Hormoprop Duplosan)
	H	MCPA + Bentazone (Basagran MCPA), B plots	MCPA + Bentazone (Basagran MCPA)
	I	Dimethoate (Roxion)	–
2nd spraying (13 Jul.)	G	Etefon (Cerone)	–
	F	Propiconazole (Tilt)	–
	I	Deltamethrin (Decis)	–

after sowing and ended at harvest. The number of sampling times and duration of the whole sampling period differed between years because of variations in the growing seasons. In 1992 and 1993 one trapping period was after harvest (Table 2). The Carabidae catches were stored in 70% alcohol and thereafter identified into species.

2.3. Statistical analyses

The differences in numbers of carabids between treatments after pesticide use were assessed using an analysis of variance for repeated measures with sampling time as a repeated factor in balanced complete block design (SAS/PROC GLM; Littel *et al*. 1991). REPLICATE, PESTICIDE TREATMENT, CULTIVATION TREATMENT, TIME and their interactions were included in the models.

Catches of three pitfall traps (12, 66 and 120 m from shelter belts) per plot were pooled for analyses concerning effects of pesticide and cultivation treatments. Sampling time V/94 with many failed samples and catches too low for analysis was omitted. The effects on only four individual carabid species were tested because they had catches high enough for analysis. Log-transformed or root square-transformed values were used in the analysis, but original medians in the figures.

3. Results

3.1. Carabid catches

The most abundant species were *Trechus quadristriatus*, *T. secalis*, *Pterostichus melanarius*, *P. niger*, *Bembidion guttula*, *Patrobus atrorufus* and *Clivina fossor*. Each year carabids peaked in early August (Fig. 2). The dominant species in catches at peak abundance of beetles were *Pterostichus* and *Trechus*. These were also the dominant species over the whole season.

The species composition varied between seasons and years. Small species (*Trechus* and *Bembidion*) were common in early season and larger *Pterostichus* species in July (Table 3). The dominant species during and immediately after pesticide treatment were the *Pterostichus* and *Trechus* species in 1992 (application later than in other years), *T. secalis* in 1993 and *B. guttula* in 1994 (Table 3).

In 1994, pitfall catches were very low especially in July and August, and the total catch of carabids was only about 60% of that of the previous years (Table 3, Fig. 2). The reason was probably a severe drought in July which decreased the efficiency of pitfall traps.

3.2. Effects of pesticide use

The difference in overall abundance of carabids between the pesticide treatments was statistically significant in 1993 and 1994 (Table 4). Carabid catches were lower in conventional pesticide treatment plots than in reduced use plots (Fig. 2). In 1992, a marginally significant opposite trend was observed, although soon after insecticide spraying less carabids were caught from conventional plots like in other years (Table 4, Fig. 2).

The effects of pesticide treatment were tested with the four most abundant species, i.e. *Pterostichus melanarius*, *P. niger*, *Trechus secalis* and *Bembidion guttula*. The numbers of *B. guttula* were significantly different between pesticide treatments in 1993 and

Table 2. Pitfall trapping periods in 1992–94 (duration in days in parenthesis), (* trapping period after harvest). Period V in 1994 was omitted because of low trapping efficiency.

	1992	1993	1994
I	02 Jun.–15 Jun. (13)		
II	25 Jun.–01 Jul. (6)	28 May–04 Jun. (7)	06 Jun.–15 Jun. (9)
III	01 Jul.–08 Jul. (7)	04 Jun.–09 Jun. (5)	16 Jun.–23 Jun. (7)
IV	08 Jul.–15 Jul (7)	11 Jun.–18 Jun. (7)	23 Jun.–30 Jun. (7)
V	15 Jul.–29 Jul. (14)	18 Jun.–24 Jun. (6)	30 Jun.–07 Jul. (7), (omitted)
VI	29 Jul.–12 Aug. (14)	24 Jun.–01 Jul. (7)	07 Jul.–14 Jul. (7)
VII	12 Aug.–20 Aug. (8)	01 Jul.–08 Jul. (7)	14 Jul.–21 Jul. (7)
VIII	31 Aug.–07 Sep. (8)*	08 Jul.–15 Jul. (7)	21 Jul.–28 Jul. (7)
IX		15 Jul.–29 Jul. (14)	28 Jul.–04 Aug. (7)
X		29 Jul.–12 Aug. (14)	04 Aug.–11 Aug. (7)
XI		13 Sep.–22 Sep. (9)*	

1994 (Table 4, Fig. 3). In 1993, the difference was significant in the numbers of *T. secalis*, too (Fig. 3). The effect of pesticides on *Pterostichus* sp. was not so clear, but the conventional pesticide regime decreased marginally the number of *P. niger* in 1992 (Table 4, Fig. 3). Overall, spring (early season) species were more affected by pesticides than autumn species, because they have their active period during application.

3.3. Effects of cultivation systems

The overall catches of carabids did not differ between the two cultivation systems, but in 1992 and 1994 a marginally significant interaction of cultivation system and time was detected (Table 4). In both years there were more carabids in the integrated plots than in the customary plots in the early season, but later the trend was opposite. There was no statistically significant difference between cultivation methods in the abundance of dominant species (Table 4).

4. Discussion

The total numbers of ground beetles in catches from reduced pesticide use plots were higher than in conventional plots in 1993 and 1994. The number of ground beetles remained low for three or four weeks after spraying. Thus, the use of pesticides has only short-term adverse effects on ground beetles in Finnish cereal fields. The dominance pattern of species varied during the season, and the species dominant in the late summer catches were not exposed directly to pesticide treatments and the effects of pesticide treatments on total carabidae catches could not be detected later.

In 1992 on the contrary, when plots on reduced use were also treated with an insecticide (more selective chemical), the total carabid catches were higher in plots of conventional use than on reduced pesticide use. However, in the early season of 1992 the general patterns were similar to those in other years, but in the beginning of August the trend was opposite. The efficiency of the insecticides used varied: there were more aphids in pirimicarb-treated (reduced use) plots than in dimethoate-treated (conventional) plots (unpubl. data). The decrease of prey may increase the activity of ground beetles in some cases,

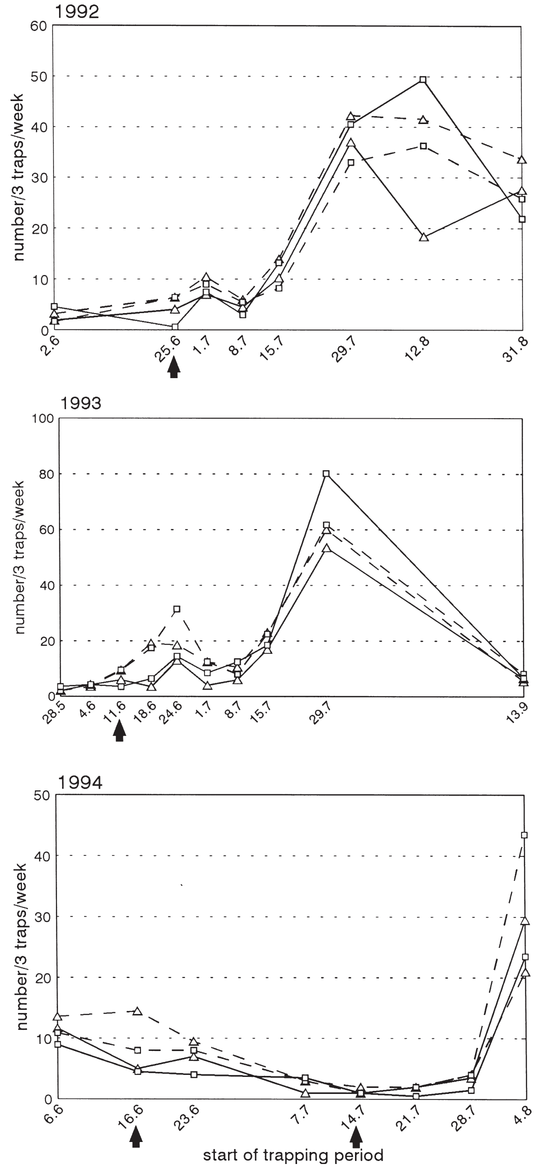

Fig. 2. Median number of ground beetles in samplings in 1992–1994. Solid line = conventional pesticide treatment, broken line = reduced pesticide treatment, square = customary farming practice, triangle = integrated farming practice, arrow = time of insecticide treatment.

thereby increasing the number of pitfall catches in conventional plots (Chiverton 1984). Because of very windy and unstable weather, in 1992 the first spraying was delayed to the end of June whereas in other years it was done in the beginning of June. Due to the late application time both the growth stage of the crop and the carabid fauna differed from those in other years. This may naturally have affected the results.

The difference between pesticide treatments in carabid catches persisted for four weeks after spraying. However, longer-lasting effects would probably have been detected if the treated areas had been larger. Because many ground beetles overwinter at the edges of fields or in other uncultivated habitats, they will invade the field every year in spring. In the present experiment carabids probably spread out to the whole

Table 3. Abundance of ground beetle species immediately after first pesticide treatment and 4–8 weeks after the treatment in 1992–1994.

	1992		1993		1994	
	25 Jun.–8 Jul.	15.–29 Jul.	11.–24 Jun.	15.–29 Jun.	16.–30 Jun.	14.–28 Jul.
Pterostichus melanarius	90	96	48	132	17	21
Pterostichus niger	70	104	3	70	2	5
Trechus quadristriatus	43	25	8	68	0	0
Trechus discus	3	8	0	13	0	13
Trechus secalis	65	41	267	74	11	10
Clivina fossor	2	1	64	18	95	1
Bembidion guttula	12	7	33	14	175	3
Patrobus atrorufus	26	11	7	49	3	1
Harpalus rufipes	17	5	4	11	6	22
other	56	41	54	21	71	16
Total	384	339	488	470	380	92

Table 4. Effects of PESTICIDE TREATMENT (PT), CULTIVATION TREATMENT (CT) and TIME on the numbers of ground beetles in 1992–1994. The dominant species were analysed separately. Only *F* values with statistically significant effects ($p < 0.1$) are presented. The repeated MANOVA (See Methods) was used. (times = trapping periods included in analysis) (– = not analysed; ° = $p < 0.1$, * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$).

	1992	1993	1994
Carabidae	(times 2–8)	(times 4–11)	(times 3–10)
PT	4.09°	28.67 *	4.91 *
PT × TIME	5.13 ***	3.55 **	
CT × TIME	1.95°		2.08°
PT × CT × TIME	2.40 *		1.86°
Pterostichus niger	(times 2–7)	(times 9–10)	(times 3–10)
PT	4.33°		–
Trechus secalis	(times 2–8)	(times 4–10)	(times 3–10)
PT		20.54 ***	–
PT × TIME		4.04 **	–
PT × CT × TIME		2.09°	–
Bembidion guttula	(times 6–8)	(times 4–10)	(times 3–10)
PT		8.42 *	22.76 ***
PT × CT			3.24°
PT × TIME			6.00 ***
CT × TIME		1.99°	
PT × CT × TIME	2.54°		

experimental field fairly regularly (irrespective of the treatment) the following spring, and it is therefore not probable that the effects on the following year can be detected. In small-scale within-field trials the impact of pesticides on populations of certain predatory groups (e.g. ground beetles) may be underestimated and the impact on certain prey groups such as aphids may be overestimated (Duffield & Aebischer 1994). However, in areas of intensive cereal production treated areas may be large and uncultivated habitats are limited. In these circumstances recovery is slower and long-term effects are more likely (Powell *et al.* 1985a, Duffield & Baker 1990). Long-term effects may result also from repeated applications of short-acting chemicals (Burn 1989).

Adverse effects of pesticides were found only on species which have adult activity phases during the spraying periods. *Pterostichus melanarius* and *P. niger* were most abundant in late summer, not at spraying time, and they did not show any clear response to pesticide treatments. *Bembidion guttula* and *Trechus secalis* were common during and immediately after pesticide application in early June, and they showed response to insecticide treatments. However, later the differences had vanished due to low numbers or due to immigration from untreated areas.

If we want to determine the adverse effects of pesticides in Finnish fields, I suggest that *Bembidion guttula* and *Trechus secalis* should be used as indicator species, because they are active at spraying time of spring cereals. The two species are representative and abundant and play an important role in the ecosystem. In addition, practical reasons have to be taken into account when choosing indicator species; they should be easy to collect and identify (Everts *et al.* 1989, Çilgi 1994). Carabids meet most of these requirements and are therefore often used as indicators of environmental quality (Stork 1990), but the choice of the most representative species is not easy. Response of species to environmental changes depends on the susceptibility, exposure patterns and life style of the species (Wiles & Jepson 1994). In cultivated areas, very sensitive species have disappeared and those left in field communities are used to repeated disturbances of cultivation. Everts (1983) recommends that more than one taxonomic group should be used in studies concerning adverse effects of pesticides in order to avoid false negative observations. Selection of indicator species from other epigeic arthropod groups, such as rovebeetles

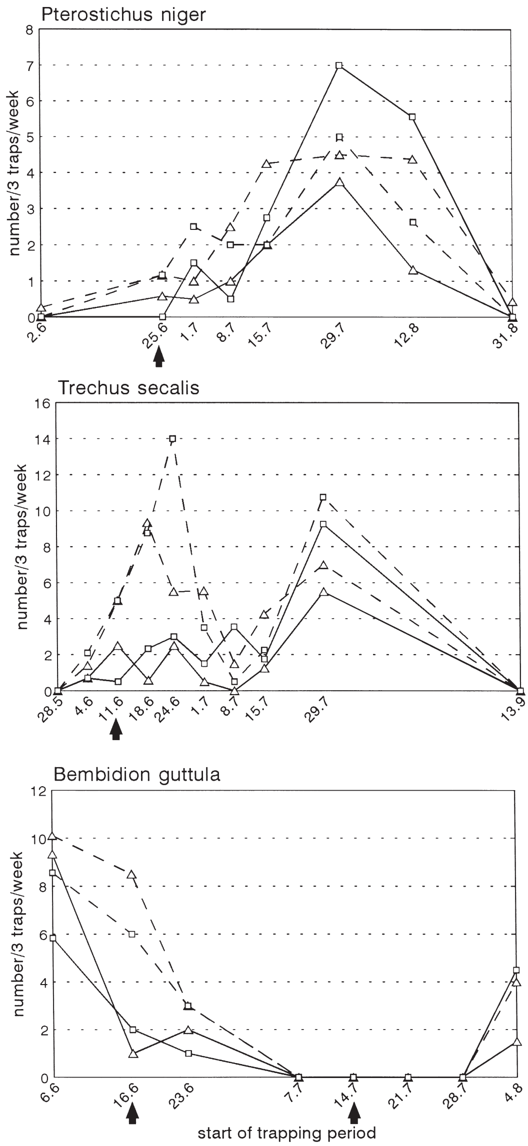

Fig. 3. Median number of *Pterostichus niger* (1992), *Trechus secalis* (1993) and *Bembidion guttula* (1994). Solid line = conventional pesticide treatment, broken line = reduced pesticide treatment, square = customary farming practice, triangle = integrated farming practice, arrow = time of insecticide treatment.

(Col., Staphylinidae) or spiders (Araneae), would improve and diversify the assessment of pesticides in an agroecosystem.

Insecticides may have both direct and indirect effects on non-target species, but the effects of other pesticide groups (herbicides and fungicides) are usually indirect and not so common. However, some fungicides, e.g. pyrazophos, may have an insecticide effect (Sotherton & Moreby 1988). Interpretation of results of complicated field experiments is never easy and simple. The outcome may be the same irrespective of the diversity of factors. An insecticide may act through its toxicity to a species or by changing the availability of food (Jepson 1989), and a herbicide changes the availability of food of carabids and the movement of beetles on the ground through alterations in weed cover (Powell *et al*. 1985b).

Because the two pesticide programmes included several pesticides, it is not possible to name a specific factor which was strictly responsible for the variation in carabid numbers. However, I assume that insecticides (especially dimethoate) have the greatest effect on carabid numbers. In 1992, two different insecticides were used: a broad-spectrum organophosphate, dimethoate, in conventional plots and a selective carbamate, pirimicarb, in reduced plots. Dimethoate has often been reported to be more harmful to carabids and to other beneficial arthropods than pirimicarb (Powel *et al*. 1985a, Vickerman *et al*. 1987, Riedel & Cole 1994). In this experiment the difference in carabid catches between dimethoate and pirimicarb were not so clear. In other years when dimethoate plots were compared with untreated plots the effect on carabids was more obvious. In many other field studies dimethoate has had severe effects on the carabid fauna (Vickerman & Sunderland 1977, Jepson & Thacker 1990, Duffield & Aebischer 1994). In 1994, the numbers of ground beetles in pitfall catches were too low to detect differences between pesticide treatments after spraying of deltamethrin.

There were no statistically significant differences between the two cultivation systems in terms of total catches of carabids or abundance of dominant species. The cultivation systems varied in tillage, fertilizing level and use of undergrowth. However, undergrowth vegetation was poor in all years due to spring drought and clay soil. Tillage may have affected the overwintering of carabids, but pitfall trapping was started too late to show this. Overall, different tillage treatments may require a longer time than this experiment to affect the size of populations.

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