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Effects of Bio-dynamic, Organic and Conventional Farming on Ground Beetles (Col. Carabidae) and Other Epigaeic Arthropods in Winter Wheat

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ABSTRACT

In a long-term comparison of agricultural systems, bio-dynamic, organic and conventional farming have been compared since 1978. The treatments differ mainly in plant protection management and fertilization (organic vs. mineral, and intensity). The experimental field is situated on a Luvisol from loess in Therwil (Switzerland). Here, the fauna of beneficial epigaeic arthropods (carabids, staphylinids and spiders) in differently cultivated winter wheat plots was investigated with pitfall traps (live catches) in 1988, 1990 and 1991. Compared with the conventional plots (= 100%), the bio-dynamic plots contained 193% of epigaeic arthropods, the organic plots 188%. The activity-density of carabids, staphylinids and spiders was higher in the bio-dynamic and the organic than in the conventional plots in all three years. In two out of three years, the difference between the conventional and the biodynamic, organic plots was significant. For carabids, the differences between treatments were most pronounced in spring. In the biological plots, the species number of carabids was higher in each year than in the conventional ones: On average bio-dynamic plots contained 18–24 species, organic plots 19–22 species and the conventional ones 13–16 species. The frequency distribution of the carabid species was also more even in the bio-dynamic and the organic plots. The influences of plant protection and fertilization on epigaeic arthropod populations are discussed.

INTRODUCTION

Agricultural production has been greatly intensified over the recent decades. Agrochemicals are increasingly applied, heavier machinery is used, crop rotations are simplified and surrounding seminatural habitats are eliminated. These profound changes have led to adverse effects on soil and to water pollution. Furthermore, they are also responsible for the drastic decline in species diversity and the abundance of the typical flora and fauna of agricultural land (Potts & Vickerman, 1974; Meisel, 1977; Heydemann & Meyer, 1983; Basedow, 1990). The number of pesticide resistant species has risen sharply in the past 50 years as a consequence of intensive pesticide use (Georghiou, 1990).

To protect natural resources, sustainable agricultural systems will be of increasing importance in the future. Ecological habitat management and promotion of beneficials should be the strategies of modern plant protection (Altieri, 1991; Lys & Nentwig, 1992). In arable crops, beneficial epigaeic arthropods play an important role in the regulation of various pests (Scherney, 1961; Basedow, 1973; Sunderland & Vickermann, 1980; Cocquempot & Chambon, 1990; Symondson, 1993). In addition, certain arthropods, especially ground beetles, are considered sensitive indicators of habitat quality (Blumenthal, 1981; Matthey *et al.*, 1990; Steinborn & Heydemann, 1990; Völkl, 1991). Arthropods are increasingly used for integral evaluation of soil fertility (Ducommun, 1991).

The effects of different agricultural production systems on epigaeic arthropods have been investigated on *differently cultivated farms*: In biologically cultivated fields, more species and higher densities of epigaeic arthropods were found than in conventionally cultivated fields (Dritschilo & Wanner, 1980; Dritschilo & Erwin, 1982; Hokkanen & Holopainen, 1986; Letschert, 1986; Basedow, 1987; Ingrisch *et al.*, 1989; Kromp, 1989). In the study presented here, epigaeic arthropods have been investigated *in a long term experiment consisting of plots* which are cultivated bio-dynamically, organically or conventionally since 1978 (called DOC trial).

MATERIALS AND METHODS

In the DOC trial located in Therwil (309 m above sea level), bio-dynamically (D), organically (O) and conventionally (C) cultivated plots have been compared since 1978. The treatments D and O will be referred to as "biological"; both are farmed according to the guidelines of biological agriculture. The climate is mild and dry with a mean precipitation of 785 mm per year and a mean temperature of 9.5°C. The soil is a Luvisol from loess. A detailed description of the DOC trial is given by Besson & Niggli (1991), while physical parameters, chemistry and microbiology of the soil are described in Alföldi *et al.* (1993a, b) and Mäder *et al.* (1993).

The trial is designed as a randomized block with four replicates of each treatment. The plot size is 10 × 20 m. The crop rotation is the same in all treatments: potatoes, winter wheat, cabbage or beetroot, winter wheat, barley and two years grass-clover meadow. The cabbage was replaced by beetroot in the 2nd rotation. Also cultivars, machinery and cultivation techniques are identical for all treatments; the main differences lie in plant protection and fertilization. Plant protection in the conventional plots is largely oriented towards integrated production. In the biological plots, weeds were controlled mechanically. No measures against diseases or insect pests were taken in the winter wheat plots. Both the dynamic and organic systems are fertilized with farmyard manure corresponding to 1.2 cow/ha. In the conventional system, the mean input of organic manure is similar to the input into the biological ones, but mineral fertilizers are added to a level of 1.2 times the amount officially recommended, but the conventional wheat is only minerally fertilized.

The investigations were made in 1988, 1990 and 1991 in winter-wheat plots of DOC long-term trial (2nd crop rotation). Beetroot had been the preceding crop in 1988 and 1990, and potatoes in 1991.

The epigaeic arthropods were caught with pitfall traps, which had a diameter of 10 cm and were 17 cm deep (Greenslade, 1964). The pitfalls were sheltered by non-transparent plastic roofs of 16.5 cm × 16.5 cm. Four traps were used per treatment. Only in 1988, an additional 2–4 traps were placed at the margins of the plots to investigate migration between them (Pfiffner, 1990). To minimize disturbance of the populations in the plots, carabids were caught alive, identified in the field and released to the same plot. If necessary, the beetles were anaesthetized with CO_2 for identification. The capturing periods lasted 5 days in 1988 and 4 days in 1990 and 1991. The arthropods were identified and released daily, and their numbers summed over the capturing period. Seven capturing periods in 1988, eight in 1990 and five in 1991 were realized (May 2–July 29, 1988; March 19–September 21, 1990; March 18–July 26, 1991).

Soil coverage and species diversity of the flora were recorded in stage 29/30 of wheat (according to Zadoks *et al.*, 1974), and plant density of the wheat shortly before harvest.

Data were analysed with one way analysis of variance and Duncan's multiple range test (BMDP program).

RESULTS

Abundance of carabids, staphylinids and spiders

On average, almost twice as many carabids, staphylinids and spiders were found in the biological than in the conventional plots. The bio-dynamic and the organic treatment never differed significantly from each other, but in most cases differed significantly from the conventional treatment. The differences between the biological plots (D and O) and the conventional plots (C) were significant in 1988 and 1990 for carabids and staphylinids, and in 1990 and 1991 for spiders (Table 1).

TABLE 1

Activity density of beneficial arthropods for different farming systems and years (preharvest). Mean numbers of arthropods caught per treatment and standard error of mean (S.E.M.).

Treatment	1988 mean	S.E.M.		1990 mean	S.E.M.		1991 mean	S.E.M	
	Carabids								
D	207.5	48.2	a	71.5	19.1	a	60.2	14.4	
O	156.0	13.0	ab	74.7	8.9	a	56.5	20.7	
C	88.5	20.5	b	45.5	5.1	b	30.5	11.7	
F-test*			*			*			ns
	Staphylinids								
D	41.7	5.0	a	58.2	5.1	a	20.2	5.1	
O	43.7	7.4	a	50.0	4.9	a	17.0	3.6	
C	20.2	6.0	b	33.2	3.5	b	15.0	2.9	
F-test*			*			**			ns
	Spiders								
D	41.5	10.4		81.5	4.6	a	63.5	6.6	a
O	54.5	11.2		88.7	13.9	a	73.2	12.4	a
C	26.2	4.3		45.0	2.9	b	28.0	3.2	b
F-test*			ns			**			**
	Total beneficial arthropods								
	1988			1990			1991		
	rel.			*rel.*			*rel.*		
D	215			181			183		
O	188			178			197		
C	100			100			100		

*F–test; p = 0.05 (*), p = 0.01 (**). Data log transformed.
Means with the same letters do not differ significantly at p = 0.05 (Duncan test).

Carabid populations

Table 2 shows the total occurrence of carabids in the different cultivated wheat plots. More carabid species were found in the biological than in the conventional plots in all three years. 28–34 carabid species were found in treatment D, 26–29 species in treatment O and 22–26 species in treatment C (Table 3). Compared with the conventional plots, the bio-dynamic plots contained on average 7.5 species more and the organic plots 4 species more.

Seven ground beetle species occurred only in the biological plots: *Acupalpus meridianus*, *Agonum sexpunctatum*, *Brachinus explodens*, *Dyschirius aeneus*, *Carabus violaceus*, *Harpalus distinguendus* and *Stenolophus teutonus*. The species *Diachromus germanus* was regularly found in the biological plots, but

TABLE 2

Total number of carabids found in the different farming systems.
Data are pooled for the years 1988, 1990 and 1991.

Carabid species	Farming systems: Bio-dynamic D	Organic O	Conventional C
Acupalpus meridianus L.	12	1	0
Agonum muelleri Herbst	124	128	106
Agonum sexpunctatum L.	4	3	0
Amara sp.	152	105	13
Anisodactylus binotatus Fabr.	9	12	3
Asaphidion flavipes L.	54	47	61
Badister bullatus Schrank	1	0	1
Bembidion lampros Herbst	125	72	26
Bembidion obtusum Serv.	41	30	13
Bembidion properans Steph.	55	63	34
Bembidion quadrimaculatum L.	21	31	11
Brachinus explodens L.	6	9	0
Calistus lunatus Fabr.	3	1	1
Carabus cancellatus Illig.	37	43	13
Carabus monilis Fabr.	39	50	12
Carabus nemoralis Müll.	6	0	2
Carabus violaceus L.	6	3	0
Clivina fossor L.	49	62	30
Demetrias atricapillus L.	3	8	2
Diachromus germanus L.	35	26	1
Dyschirius aeneus Dej.	2	1	0
Harpalus affinis Schr.	32	14	10
Harpalus distinguendus Duft.	5	3	0
Harpalus rufipes De Geer	67	32	25
Loricera pilicornis Fabr.	40	48	69
Nebria brevicollis Fabr.	7	8	3
Notiophilus palustris Duft.	1	1	2
Platynus assimilis Payk.	0	0	4
Platynus dorsalis Pont.	177	137	78
Poecilus cupreus L.	119	90	30
Pterostichus anthracinus Illig.	9	24	21
Pterostichus melanarius Illig.	18	26	45
Pterostichus niger Schaller	1	0	1
Pterostichus vernalis Panz.	10	3	6
Stenolophus teutonus Schr.	41	24	0
Stomis pumicatus Panz.	16	17	4
Tachys bistriatus Duft.	11	9	4
Trechoblemus micros Herbst	9	13	16
Trechus quadristriatus Schr.	9	5	12
Total individuals	1356	1149	659
Total species	38	35	32

only one specimen was captured in a conventional plot. Species of the large, endangered genus *Carabus* were more than three times as abundant in the biological than in the conventional plots (Table 2). The burrowing species *Clivina fossor* was up to twice as abundant in the biological as in the conventional plots in 1988 and 1990. *Brachinus explodens*, *Dyschirius aeneus* and *Diachromus germanus* are among the valuable species in Switzerland (Marggi, in prep.), judged by the method of Mossakowski and Paje (1985). Parameters such as occurrence, abundance and habitat requirements of species are used for this valuation. *Agonum sexpunctatum*, *Clivina fossor* and *Carabus violaceus* are among the moderately valuable species. One carabid species (*Platynus assimilis*) was found only in the conventional plots, but only in 1988.

The activity dominance spectra were more even in the biological compared to the conventional plots: the eudominant species (> 10%) accounted for 12–19% of all individuals in the bio-dynamic, for 12–13% in the organic, and for 20–23% in the conventional plots. The redecent (1–2%) and subredecent (< 1%) species were more frequent in the biological than in the conventional plots. Fifty percent of the dominance spectrum contained 3.5–4.75 species in the bio-dynamic plots, 4–5.25 in the organic plots and 2.5–3.75 in the conventional plots.

The phenology of the carabid population is shown for 1990 in Figure 1. Until the end of June, considerably more carabids were found in the biological than in the conventional plots. The greatest differences were found in March and April. Towards the end of the vegetation period of winter wheat, and especially after harvest, carabid activity density was similar in all treatments.

DISCUSSION

Causes of differences in arthropod abundance

In the DOC trial, factors such as macroclimate, soil, relief, crop, preceding crop, shape of field and surrounding habitat were similar for all treatments.

TABLE 3

Carabid species occurrence in differently cultivated winter wheat plots for different years. Mean number of species, minimum and maximum per treatment and total number of species found in all plots within each treatment.

Treatment	1988			1990			1991		
	mean	min.—max.	total	mean	min.—max.	total	mean	min.—max.	total
D	24	19–27	34	18	17–21	28	18	14–23	33
O	22	17–24	29	19	18–21	26	19	12–26	29
C	15	13–17	22	16	13–18	24	13	9–19	26

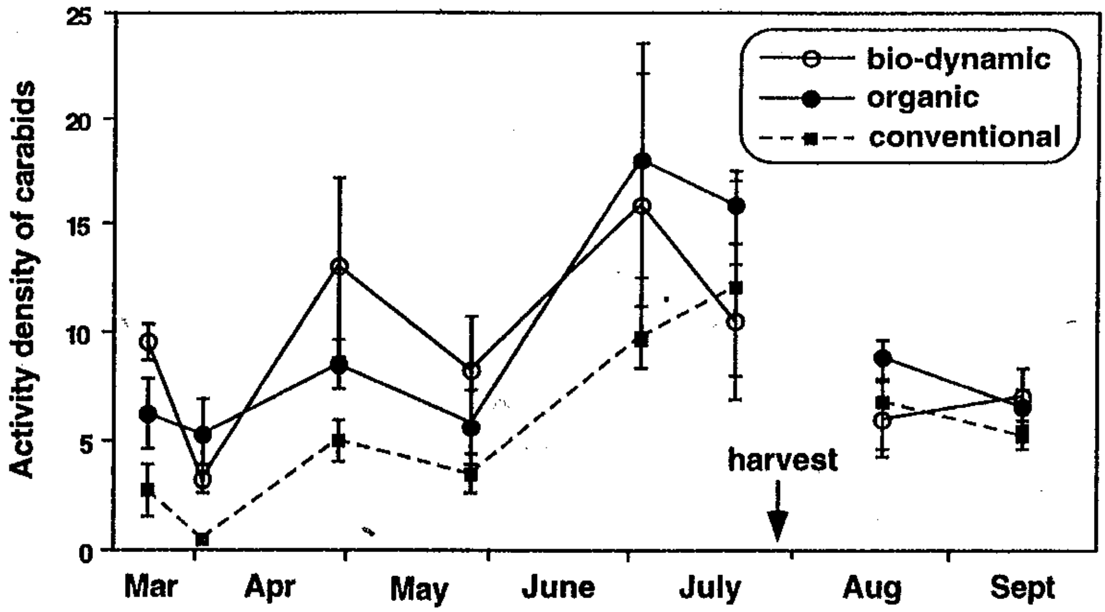

FIGURE 1. Phenological pattern of activity-density of carabids in differently cultivated winter wheat plots (1990). Bars indicate the standard error of mean.

Soil cultivation was also very similar in all treatments. The factors responsible for the differences in arthropod populations must therefore lie in the spheres of fertilization, plant protection or their consequences such as weed flora, wheat plant density or microclimate. In the following, the treatments will be discussed with special regard to their potential effect on carabid populations.

In the conventional plots, pesticides were used in all cultures except for the two years of grass-clover meadow, following integrated pest management strategies. Over the whole crop rotation (which lasts 7 years), 9.3 applications of fungicides, 1.7 applications of insecticides and 6.3 applications of herbicides were carried out on average. In wheat, insecticides were used only in 1990, while fungicides (1–2 applications) and herbicides (1 application) were normally used. In the biological plots, the following pesticides were used: copper oxychloride (potatoes: in organic plots only), Rotenon Pyrethrin extracts (potatoes) and *Bacillus thuringiensis* (cabbage, 1st crop rotation only (1978–84)). These pesticides are considered harmless for beneficials by the IOBC working group on side-effects of pesticides (Hassan *et al.*, 1991). In wheat no pesticides were used in the biological plots.

In the conventional winter wheat plots, insecticides and fungicides used in the winter wheat culture or one of the preceding crops may have affected epigaeic arthropods either directly, via contamination or reduction of their prey, or through alterations of the microhabitat (Vickermann, 1977; Basedow, 1990). The various carabid species show different sensitivity towards pesticides, depending on their life stage, ability of dispersal, hibernation behaviour, etc. Reproduction rate may be reduced by sublethal long-term effects (Burn, 1989). A reduction of prey caused by pesticide application can also affect carabid fecundity (van Dijk, 1986). For example, routine use of foliar fungicides can lead to mortality of colembola and thus negatively influence polyphagous predators (Burn, 1989). Thus, colembola are an important prey item for small carabids and liniphiid spiders. Basedow (1987) considers pesticide application to be the main factor responsible for the reduced carabid populations in conventionally farmed wheat fields.

Herbicides may also influence carabids indirectly by reducing the weed flora. The conventional wheat plots were almost free of weeds after application of herbicide in springtime until harvest. In contrast, there was always a certain weed flora in the biological plots, with slightly more coverage and species in the bio-dynamic than in the organic plots. The reduction of the weed flora in the conventional plots may have caused a reduction in the herbivorous and flower-depending entomofauna. This can lead to a reduced food spectrum for the predators. Even a minor weed occurrence can positively influence polyphagous predators (Speight & Lawton, 1976; Powell *et al.*, 1985). By contrast, mechanical weed control may even create hiding places for large carabids. The richer weed flora or the lower wheat density of the bio-dynamic plots, compared with the organic plots, may have caused the tendentially higher abundance and species diversity of carabids in the former.

Fertilization is another factor in which the treatments deviate strongly. The conventional wheat plots were fertilized with mineral fertilizer only, while the biological wheat plots were only organically fertilized. Furthermore, the conventional plots were fertilized to a higher level than the biological plots. Organic fertilization (as opposed to mineral fertilization) can benefit epigaeic arthropods through a richer supply of saprophagous mesofauna (Purvis & Curry, 1984). It is not clear whether the composted manure in the bio-dynamic system or the slurry fertilization in the organic have distinct effects on carabids or other epigaeic arthropods. The higher fertilization level in the C treatment led to a higher density of wheat plants, which changed the microclimate and possibly also reduced the surface activity of carabids and spiders (Honek, 1988).

In summary, chemical plant protection may have influenced epigaeic arthropods directly. However, both plant protection and fertilization may also affect these arthropods indirectly through alterations of their micro-environment, such as changes in plant density, weed flora and also soil surface structure.

Occurrence and distribution of carabid species

The biological plots contained more carabid species than the conventional plots, and a more even species distribution. Generally speaking, more species and a more even species distribution indicate a higher habitat diversity and a less disturbed agroecosystem (Remmert, 1992). Besides carabids (this study), diverse coleopteran families, heteroptera, chilopods, isopods and spiders can be more abundant in biological than in conventional plots as e.g. Ingrisch *et al.* (1989) have found in their investigations at farm level. This was also shown for mites (Hoffmann, 1991). The floral diversity is also often higher in organically farmed arable fields than in conventional fields (e.g. Wolff-Straub, 1989). Taken together, all these groups of organisms indicate that biologically cultivated fields seem to be more ecologically balanced and have a higher habitat diversity.

Carabids are highly mobile insects showing distinct habitat preferences. Abiotic factors such as humidity, light and temperature are of paramount importance for them and influence habitat selection more strongly than biotic factors (Thiele, 1977). The exclusive occurrence of seven carabid species in the biological plots (which are very small and close to other plots) shows their specific habitat requirements. Helio- or thermophilous species found their preferred microclimates in these plots (*Agonum sexpunctatum*, *Brachinus explodens*, *Stenolophus teutonus* and *Dyschirius aeneus*). The hygro- and/or thermophilous *Carabus* species were also most abundant in the biological plots.

Again, indirect effects may be very important. The biological plots contain more earthworms than the conventional plots (Pfiffner, 1993). This may influence the distribution of earthworm eating *Carabus* species. These large carabids of the genus *Carabus* are becoming endangered because of the increasing intensity of farm practices. In particular, *C. monilis* is considered as a sensitive bioindicator of production intensity (Matthey *et al.*, 1990). *C. monilis* was found 2–3 times more often in the biological than in the conventional plots. Burrowing carabids, such as *Clivina fossor*, may benefit from the improved soil structure due to the higher earthworm abundance and the higher microbial activities of the biological plots (Mäder *et al.*, 1993). Phyto-zoophagous carabids may benefit from a lusher weed flora. For example, the larvae of *Harpalus rufipes* depend on weed and grass seeds for their nutrition (Luff, 1980). This may be the reason why *Amara* and *Harpalus* species were even more abundant in the bio-dynamic than in the organic plots, and much less abundant in the conventional plots. Kromp (1990) has also found a relation between the weed density and the occurrence of *Amara consularis* and *Harpalus rufipes* in biologically farmed potato fields.

Most carabid species hibernate outside arable fields, in the uncultivated edges or in more natural habitats nearby (Sotherton, 1984; Wiedemeier & Duelli, 1993). The possible hibernation habitats in the DOC trial were extensively used grassland or the adjacent biologically farmed arable fields. This emphasizes the highly specific, small-scale selectiveness of the carabids, when they migrate into the DOC plots in spring. Investigations with traps at the edges of the DOC plots have shown that more carabids migrate into the biological than into the conventional plots, but that even more carabids emigrate from the biological plots (as opposed to the conventional plots) (Pfiffner, 1990).

In conclusion, epigaeic beneficial arthropods have been strongly promoted by biological farming and some endangered carabid species were preserved. The main factors responsible for the higher abundance and the greater species richness of carabids were probably the renunciation of chemical plant protection, the higher weediness and the lower plant density of wheat.

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