



Effects of groundcover management on ground beetles (Coleoptera: Carabidae) in an apple orchard

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Abstract

A field experiment was conducted in a cider-apple orchard to evaluate the effect of six groundcover management systems (pine-bark, plastic and straw mulches, tillage, herbicide and natural soil) on the occurrence of ground beetles (Coleoptera: Carabidae).

Eight species of carabids were collected in pitfall traps. The three most common beetles, *Steropus gallega* Fairmaire (65.8%), *Pseudophonus rufipes* (DeGeer) (18.2%) and *Poecilus cupreus* L. (14.6%), represented more than 98% of the total catches. The specific dominance depended on the sampling date. The soil management treatment significantly affected the following parameters. (1) The overall carabid catch: the plastic mulch (5.6% of the total catches) negatively affected total carabid collection, which was higher in the tilled (24.3%) and herbicide-treated (21.4%) plots, although not significantly different from the natural soil (16.5%), straw mulch (16.3%) and pine-bark mulch (15.9%) treatments. (2) The specific preferences of the three most common carabids: the plastic cover adversely affected the catches of *S. gallega* whilst *P. rufipes* was collected in greater numbers in tilled areas and *P. cupreus* in the herbicide treatments. (3) The structure of the carabid community: based on species richness, diversity and evenness indices, herbicide and tillage provided the most diverse carabid community and the straw mulch the poorest. It was concluded that groundcover management in apple orchards may affect the activity density of epigeic predators which may contribute to the natural control of pests.

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1. Introduction

The control of weeds in the first few years after planting is of critical importance for the satisfactory development of an orchard. Correct groundcover management is necessary to reduce competition for water and nutrients. Each agronomic practice used to control weeds has its advantages and disadvantages, resulting in differences in tree growth and fruit production

(Merwin and Stiles, 1994; Utkhede and Hogue, 1998), nutrient supply and uptake (Merwin and Stiles, 1994) as well as in the management of diseases and pests, such as crown and root rot infection (Utkhede and Hogue, 1998) or vole damage (Sullivan et al., 1998; Merwin et al., 1999).

The disturbance of the soil structure produced by agricultural practices has a considerable influence on the abundance and diversity of the epigeic fauna (e.g. House and Alzugaray, 1989). Carabids, which are especially sensitive to habitat alteration, have been commonly used as a model to study the impact of groundcover management practices on the occur-

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rence of soil arthropods (Holliday and Hagley, 1984; Barney and Pass, 1986; Cárcamo, 1995; Cárcamo et al., 1995; Baguette and Hance, 1997; Andersen, 1999). In addition, carabid beetles are polyphagous, mainly carnivorous, feeders (Lövei and Sunderland, 1996) that prey on a wide range of agricultural pests from aphids (Losey and Denno, 1998) to slugs (Symondson et al., 1996). Therefore, agricultural practices used to suppress vegetation may affect pest populations indirectly through differential density of beneficial arthropods. In apple orchards, ground beetles may feed on pests with a ground-dwelling life-stage or even on other pests such as aphids that may fall from the canopy either accidentally or as a dropping response to a predator attack (Losey and Denno, 1998). Mature larvae of the codling moth, *Cydia pomonella* L. (Lepidoptera: Tortricidae), a major apple pest world-wide, are potential prey of epigeic predators when they seek a cocooning site in the soil. Indeed, some studies have confirmed predation of carabids on codling moth larvae in the field (Glen and Milsom, 1978; Hagley and Allen, 1988; Riddick and Mills, 1994).

Because of their significance as bioindicators and their role as agents of biological control of agricultural pests, carabids have been extensively used to assess the impact of soil management on ground-dwelling arthropods in many crops. In the present study, the influence of six groundcover management systems on the activity density and diversity of carabids in a cider-apple orchard was investigated.

2. Material and methods

2.1. Study orchard and experimental design

Field studies were conducted during 2000 in a 5-ha commercial orchard at Villaviciosa (43°30'N, 5°30'W), Asturias (NW Spain). The orchard consisted of 3-year-old apple trees of local cider-apple cultivars growing on MM 106 rootstocks. The trees were planted 2.75 m apart within rows and there were 5.50 m between rows. All necessary management practices were performed by the farm owner, who followed integrated production guidelines. The only insecticide applied in 2000 was pirimicarb (Aphox, Zeneca) against aphids.

In February 1998, a short time after planting, the following experiment was established in order to assess the effect of the orchard groundcover management on the growth and yield of the trees (Dapena and Iglesias, unpublished data). The layout was a completely randomized block design of six treatments replicated four times. Each block consisted of a tree row of the local cultivar *Xuanina* and each plot of 11 consecutive trees. The treatments and the actions performed in 2000 were: (1) pine-bark mulch consisting of a pine-bark layer 15–20 cm thick; (2) plastic mulch consisting of a black polyethylene sheet; (3) straw mulch consisting of a layer of withered herb 15–20 cm thick; (4) tillage: the plots were rotovated in early spring and on 31 August; (5) herbicide: glyphosate (Roundup, Rhône Poulenc) was applied in early spring and on 30 August; and (6) natural soil: the plots were mowed three times from April to July. Each treatment extended approximately 0.70 m on either side of the rows.

The alleys were cleaned when necessary using a shredder. Composition and density of weeds either in the natural soil plots or in the alleys were not recorded. Weed competition in the tree rows in the rest of the orchard was reduced by glyphosate application. Artificial soil fertilizers were applied to the entire orchard in early spring and the plantation was not irrigated.

2.2. Trapping of ground beetles

Carabids were collected in pitfall traps of 6.5 cm diameter. Two traps per plot, separated by 14 m, were put in place on 28 July. Traps contained a solution of detergent and ethanol to reduce the surface tension and preserve the beetles. They were protected against rainwater with a roof tile. Pitfall traps were emptied weekly from 3 August to 2 November. This period was selected because it covers approximately the dispersal period of the mature larvae of codling moth, a key pest in this region. Collected specimens were transferred to 70% alcohol and identified in the laboratory.

2.3. Data analysis

Community structure of the ground beetles was described by the number of species collected, the Shannon–Wiener's diversity index and evenness. The composition of the carabid community as well as their

Table 1
Effect of the orchard groundcover management on carabid captures

Species	Groundcover management ^a						Total	
	T	H	NS	SM	PBM	PM	Number	%
<i>Steropus gallega</i> Fairmaire, 1859	119	178	219	248	229	46	1039	65.8
<i>Pseudophonus rufipes</i> DeGeer, 1774	221	38	1	0	3	25	288	18.2
<i>Poecilus cupreus</i> Linné, 1758	36	111	41	6	19	17	230	14.6
<i>Nebria brevicollis</i> Fabricius, 1792	5	6	0	2	0	0	13	0.8
<i>Calathus circumseptus</i> Germar, 1824	2	2	0	0	0	0	4	0.3
<i>Calathus fuscipes latus</i> Serville, 1821	0	3	0	0	0	0	3	0.2
<i>Lagarus vernalis</i> Panzer, 1796	0	0	0	1	0	0	1	0.1
<i>Leistus (Leistophorus) fulvibarbis</i> Dejean, 1826	1	0	0	0	0	0	1	0.1
Total	384	338	261	257	251	88	1579	100.0
%	24.3	21.4	16.5	16.3	15.9	5.6		100.0

Number of catches in eight traps per treatment throughout the sampling period.

^a T: tillage; H: herbicide; NS: natural soil; SM: straw mulch; PBM: pine-bark mulch; PM: plastic mulch.

activity density in the six treatments were compared by ANOVAs and Duncan's multiple range tests.

3. Results

During the sampling period 1579 individuals belonging to eight species of carabids were collected (Table 1). The three most common species represented 98.6% of the total catches and were *Steropus gallega* Fairmaire (65.8%), *Pseudophonus rufipes* (DeGeer) (18.2%) and *Poecilus cupreus* L. (14.6%). The three main species showed seasonality in the

catches (Fig. 1). *P. cupreus* was numerically the most frequently-collected species in the first few weeks of the survey. The decline in its abundance coincided with an increase in numbers of *P. rufipes* while from mid-September *S. gallega* became prevalent.

The groundcover management system significantly affected the captures (Table 2). Plastic mulch produced the lowest catches and was significantly different from the five other treatments ($F_{5,42} = 3.28$; $P < 0.05$). Among these, higher numbers of carabids were collected in the tilled and the herbicide-treated plots; however, the differences between these five treatments were not significant. The three main species showed

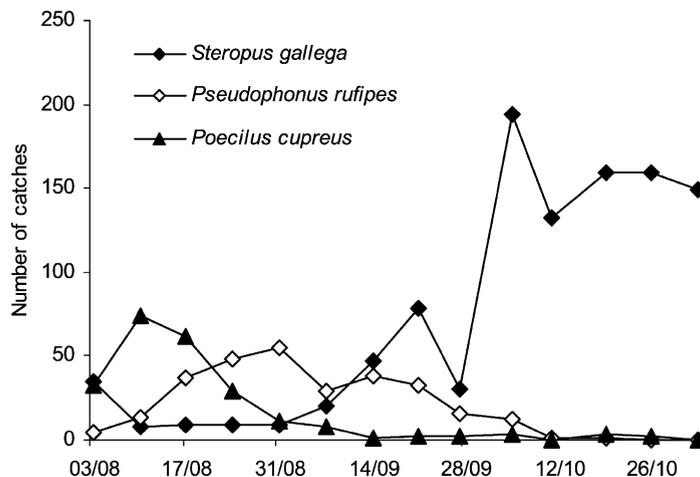


Fig. 1. Population dynamics of the three commonest carabids. Number of catches in 48 pitfall traps for each sampling date.

Table 2

Effect of groundcover management systems on the activity density of the overall carabids and of the three main species (mean captures/trap over the sampling period \pm standard deviation are given)

Groundcover management	Carabids	<i>S. gallega</i>	<i>P. rufipes</i>	<i>P. cupreus</i>
Tillage	48.00 \pm 23.64 a	14.88 \pm 6.36 ab	27.63 \pm 19.57 a	4.50 \pm 4.17 b
Herbicide	42.25 \pm 27.69 a	22.25 \pm 19.45 a	4.75 \pm 4.59 b	13.88 \pm 14.59 a
Natural soil	32.63 \pm 13.30 a	27.38 \pm 13.54 a	0.13 \pm 0.35 b	5.13 \pm 8.08 b
Straw mulch	32.13 \pm 20.99 a	31.00 \pm 21.00 a	0.00 \pm 0.00 b	0.75 \pm 1.16 b
Pine-bark mulch	31.38 \pm 18.90 a	28.63 \pm 19.18 a	0.38 \pm 0.52 b	2.38 \pm 1.85 b
Plastic mulch	11.00 \pm 5.73 b	5.75 \pm 3.45 b	3.13 \pm 4.73 b	2.13 \pm 1.73 b

Within each column, mean values followed by the same letter are not significantly different (Duncan's multiple range test).

treatment preferences. *S. gallega* catches were significantly lower under plastic than in other treatments ($F_{5,42} = 3.16$; $P < 0.05$); *P. rufipes* showed a strong preference for tillage ($F_{5,42} = 13.03$; $P < 0.001$), and *P. cupreus* was collected in significantly higher numbers in the herbicide treatment ($F_{5,42} = 3.54$; $P < 0.01$). *P. rufipes* and *P. cupreus* maintained a strong preference for their favorite treatments throughout the sampling period, in contrast to *S. gallega*, which showed seasonality in its treatment preference (Fig. 2). During August, when the numbers of *S. gallega* were relatively low, this species was collected almost exclusively under the pine-bark cover, but this trend changed as the catches increased in September and October, when *S. gallega* was collected in high numbers in the straw mulch, herbicide and natural soil plots. The other five species were collected in small numbers and no treatment preferences were established (Table 1).

Species richness was significantly higher in the herbicide and tillage management plots ($F_{5,42} = 9.71$; $P < 0.001$) (Table 3). In these plots, six of the eight species were trapped, while in the rest of the treat-

ments not more than four species were collected. There were also significant differences among treatments in the Shannon–Wiener's diversity index ($F_{5,42} = 7.03$; $P < 0.001$), which was highest in the herbicide plots although not significantly different from tillage. Evenness was significantly highest in the plastic mulch, herbicide and tillage plots ($F_{5,42} = 5.87$; $P < 0.001$), although the latter two were not significantly different from the natural soil value. The straw mulch displayed the lowest values for the three indices (Table 3) since *S. gallega* was strongly dominant in this treatment.

4. Discussion

Although pitfall traps have been the sampling technique most frequently used to study ground beetles because this method is cheap and rapid, its usefulness has been widely discussed (e.g. Topping and Sunderland, 1992; Spence and Niemälä, 1994; Sunderland et al., 1995). Since pitfall captures depend on carabid density but also on their activity, which may be enhanced by hunger (Chiverton, 1984) or habitat

Table 3

Effect of groundcover management systems on species richness, Shannon–Wiener's diversity index and evenness (mean values in eight traps \pm standard deviation are given)

Groundcover management	Richness	Diversity	Evenness
Herbicide	3.75 \pm 1.16 a	0.91 \pm 0.30 a	0.71 \pm 0.10 ab
Tillage	3.62 \pm 0.74 a	0.67 \pm 0.37 ab	0.70 \pm 0.12 ab
Plastic mulch	2.37 \pm 0.74 b	0.57 \pm 0.37 bc	0.74 \pm 0.33 a
Pine-bark mulch	2.37 \pm 0.52 b	0.34 \pm 0.19 cd	0.40 \pm 0.22 c
Natural soil	2.12 \pm 0.35 b	0.34 \pm 0.17 cd	0.46 \pm 0.24 bc
Straw mulch	1.75 \pm 0.71 b	0.17 \pm 0.22 d	0.24 \pm 0.32 c

Within each column, mean values followed by the same letter are not significantly different (Duncan's multiple range test).

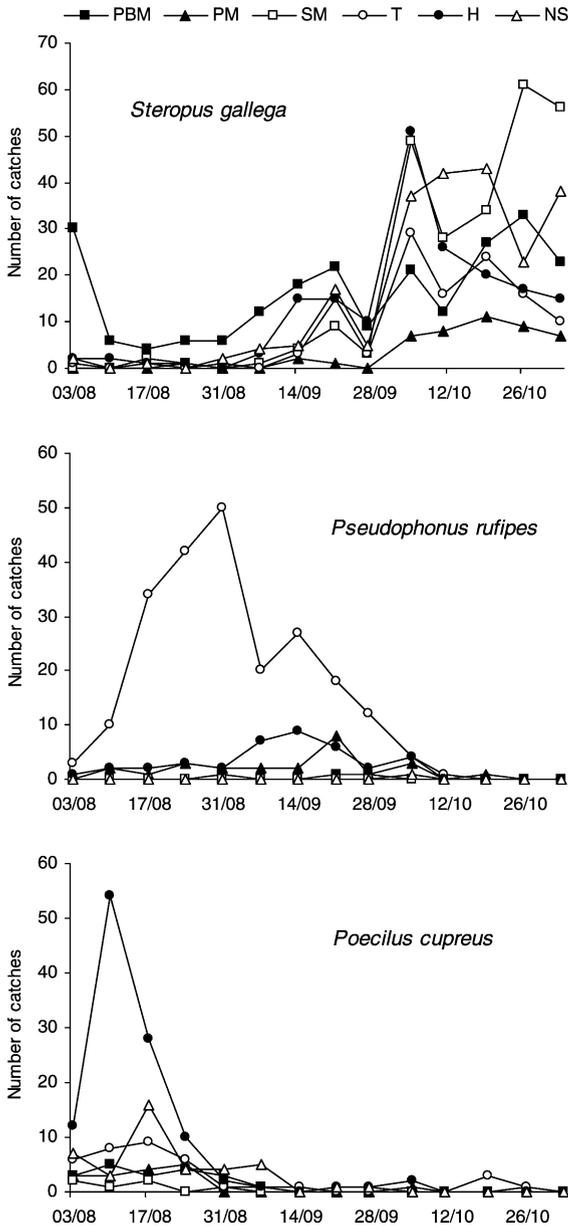


Fig. 2. Seasonal activity of the three commonest carabids *Steropus gallega*, *Pseudophonus rufipes* and *Poecilus cupreus* in each groundcover management (PBM: pine-bark mulch; PM: plastic mulch; SM: straw mulch; T: tillage; H: herbicide; NS: natural soil). Number of catches in eight traps per treatment in each sampling date.

alteration (Holliday and Hagley, 1984), carabid catches are considered as an estimate of the activity density. The present study represented a real situation in which the tree rows treated for preventing weed competition were separated by frequently-mowed and -shredded alleys. As carabids could move freely between plots or from the alley into the plots, differences in pitfall trap captures were used as an indication of the suitability of a groundcover management system for the ground beetles.

Research on the impact of tillage on ground beetles has been extensive with inconsistent results depending on the crop or the carabid species (Barney and Pass, 1986; House and Alzugaray, 1989; Cárcamo, 1995; Cárcamo et al., 1995; Symondson et al., 1996; Baguette and Hance, 1997; Andersen, 1999). Soil samples in an apple orchard reflected lower carabid abundance in tilled than in non-tilled plots although this difference was not observed in pitfall trap catches (Holliday and Hagley, 1984). The type of orchard management system also affected carabid fauna (Pearsall and Walde, 1995). For instance, *P. rufipes* was relatively much scarcer in abandoned than in organic or conventional apple orchards, although no differences were established between organic and conventional management systems. Nevertheless, since management differences were not restricted to the soil surface, carabid differences cannot be strictly attributable to the groundcover management systems.

In our study, the groundcover–carabid interaction resulted in significant differences in the overall carabid catches, the individual species preference and the structure of the carabid community. Carabids were significantly scarcer under the plastic cover and were collected in greatest abundance in the tilled and herbicide plots. This tendency was mainly attributable to the strong preference shown by *P. rufipes* and *P. cupreus* for the tillage and herbicide treatments, respectively. *S. gallega* did not show such a clear preference. With respect to richness, diversity and evenness indices, the herbicide and the tilled plots presented the most diverse carabid community and the straw cover the poorest.

Every agronomic practice may influence environmental parameters, such as substrate temperature or humidity, availability of organic matter, food or shelter, etc. and consequently carabid captures may fluctuate in accordance with their own needs. Carabids have

ecological requirements related to size, shape, food preferences, temperature, humidity, life history and season (Lövei and Sunderland, 1996, and references therein). According to those requirements, a ground beetle species may display a differential response depending on the groundcover suitability. Environmental factors such as temperature, substrate moisture as well as the quality and quantity of food affected fecundity, growth and survival of two carabid species in laboratory experiments (Van Dijk, 1996). In an apple orchard, air temperature was positively correlated with the capture of *Pterostichus melanarius* Illiger although it did not affect other species (Holliday and Hagley, 1978). Soil moisture negatively affected carabid catches in cultivated fields (Cárcamo et al., 1995). This could explain the significantly lower diversity reported in the straw mulch plots since humidity in this cover would be likely to be the highest. The use of herbicides, apart from altering the habitat structure or carabid prey availability, may also directly influence carabids through toxicity (Laub and Luna, 1992; Cárcamo et al., 1995). However, in our research the herbicide application on 30 August did not seem to affect the population dynamics of carabids in those plots (Fig. 2). Brust (1990) also found little direct effect of herbicides on carabids. Species interactions may also have a strong influence on the structure of the carabid community. Currie et al. (1996) concluded from a laboratory experiment that intraguild predation and interspecific competition for food may affect the dynamics and thus the structure of carabid communities. Cárcamo et al. (1995) suggested a similar influence in field experiments. Some of the factors mentioned may have affected the immigration–emigration balance as well as the mortality, fecundity or recruitment rates of the overall carabids and of particular species, explaining differences in the activity density between habitats (Hawthorne et al., 1998).

In apple orchards, carabids are natural enemies of pests, preying on aphids (Hagley and Allen, 1990), apple maggot (Hagley et al., 1982), and potentially on other pests that have a life cycle stage in the soil, such as apple sawfly, apple twig cutter or apple leaf midge. Ground beetles have also been cited as preying on fifth-instar codling moth when the larvae seek a cocooning site on the ground (Glen and Milsom, 1978; Hagley et al., 1982; Hagley and Allen, 1988; Riddick and Mills, 1994), and some species could even feed

on larvae in their cocooning shelters in the tree since they are able to climb plants in order to prey on pests (Dixon and McKinlay, 1992). Although few studies have focused on the efficiency of carabid predation on codling moth, ground beetles seem to have only a slight effect in regulating this pest populations (Glen and Milsom, 1978; Hagley and Allen, 1988; Riddick and Mills, 1994). Nevertheless, as the presence of natural enemies is compatible with the use of control techniques of low impact, such as granulosis virus (CpGv) or mating disruption, carabids may contribute to diminish the infestation pressure in sustainable production programs.

In such programs, where non-residual herbicides are prohibited or not recommended, alternatives to the common use of herbicides to avoid vegetation competition with trees are required. The results of our study showed that, apart from affecting tree growth, fruit yield or soil structure, moisture or temperature, the type of orchard groundcover management also affected the activity density and diversity of ground beetles.

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