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Reducing the abundance of leafhoppers and thrips in a northern California organic vineyard through maintenance of full season floral diversity with summer cover crops

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Abstract

1 Maintenance of floral diversity throughout the growing season in vineyards in the form of summer cover crops of buckwheat (*Fagopyrum esculentum* Moench) and sunflower (*Helianthus annus* Linnaeus), had a substantial impact on the abundance of western grape leafhoppers, *Erythroneura elegantula* Osborn (Homoptera: Cicadellidae), and western flower thrips, *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae), and associated natural enemies.

2 During two consecutive years, vineyard systems with flowering cover crops were characterized by lower densities of leafhoppers and thrips, and larger populations and more species of general predators, including spiders.

3 Although *Anagrus epos* Girault (Hymenoptera: Mymaridae), the most important leafhopper parasitoid, achieved high numbers and inflicted noticeable mortality of grape leafhopper eggs, no differences in egg parasitism rates were observed between cover cropped and monoculture systems.

4 Mowing of cover crops forced movement of *Anagrus* and predators to adjacent vines resulting in the lowering of leafhopper densities in such vines.

5 Results indicate that habitat diversification using summer cover crops that bloom most of the growing season, supports large numbers of predators and parasitoids thereby favouring enhanced biological control of leafhoppers and thrips in vineyards.

Keywords Biocontrol, cover crops, habitat manipulation, leafhoppers, predators, thrips.

Introduction

In California, some researchers have tested the management of resident floor vegetation or planting cover crops as a habitat management tactic in vineyards to enhance natural enemies (Altieri & Schmidt, 1985; Bugg & Waddington, 1994). Reductions in mite (Flaherty, 1969) and grape leafhopper (Daane *et al*., 1998) populations have been observed but such biological suppression has not been sufficient from an economic point of view (Daane & Costello, 1998). Perhaps the problem lies on the fact that most of the above studies were conducted in vineyards with winter cover crops and/or with weedy resident vegetation that dried early in the season or which was mowed or ploughed under at the beginning of the growing season. Therefore, in early summer these vineyards are virtual monocultures without floral diversity. For this reason we hypothesize that there may be a need to maintain a green cover during the entire growing season in order to provide habitat and alternate food for natural enemies. An approach to achieve this is to sow summer cover crops that bloom early and throughout the season, thus providing a highly consistent, abundant and well-dispersed alternative food source, as well as microhabitats, for a diverse community of natural enemies.

A hypothesis tested in this study is that the presence of neutral insects and pollen and nectar from the summer cover crops provide a constant and abundant supply of food sources for natural enemies. This in turn decouples predators and parasitoids from a dependence on grape herbivores, allowing an early build

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up of natural enemies in the system, which in turn regulate pest populations. We tested this hypothesis and examined the ecological mechanisms associated with insect pest reduction when summer cover crops are planted early in the season between alternate vine rows.

The main objectives of this study were:

1. to compare population levels of insect pests (leafhoppers, *E. elegantula,* and thrips, *F. occidentalis*) and natural enemies on vines grown under clean cultivation (monoculture) or diversified with summer cover crops
2. to assess the diversity and abundance of the complex of native predators associated with the summer cover crops
3. to assess the level of parasitism of *E. elegantula* by *A. epos* in cover cropped and monoculture vineyard sections
4. to determine whether cover crop mowing affects the populations of insect pests by forcing movement of natural enemies to adjacent vines.

Materials and methods

Study site

This study was conducted in two identical adjacent Chardonnay vineyard blocks (blocks A and B, 2.5 ha each) from April to September 1996 and 1997. These were located in Hopland, 200 km north of San Francisco, California, in a typical wine-growing region. Total rainfall reached 2035 mm and 1458 mm in both years, respectively, with rains concentrated between November and April. Mean daily temperatures during the growing season were 20 °C in 1996 and 21 °C in 1997. For the last 4 years, both blocks have been under organic management, yearly planted to winter cover crops every other row, receiving an average of 2 tons of compost per hectare and preventive applications of sulphur against *Botrytis* spp. and *Oidium* spp.

One block was kept free of ground vegetation by one spring and one late summer disking (monoculture vineyard). In April, the other block (cover-cropped vineyard) was undersown every alternate row with a 30/70 mixture of sunflower and buckwheat. Buckwheat flowered from late May to July and as the buckwheat senesced, sunflower bloomed from July to the end of the season.

Sampling methods

From April to September of 1996 and 1997, relative seasonal abundance and diversity of phytophagous insects and associated natural enemies were monitored on the vines in both treatment plots. The arthropod fauna of each treatment plot was sampled using three different methods: (1) yellow sticky traps to catch adult leafhoppers, *Anagrus* and general predators, (2) blue sticky traps to estimate densities of thrips and the predator *Orius* sp. (Hemiptera: Anthocoridae), (3) direct count of leafhopper nymphs and eggs on leaves.

Ten yellow and 10 blue sticky traps (10 × 17 cm; Seabright Laboratories, Emeryville, CA, coated with tanglefoot) were placed in each of 10 rows selected at random in the middle area of each block to estimate densities of adult leafhopper, thrips, *Anagrus* wasps, *Orius* sp. and other predators. Traps were orientated perpendicular to the predominant wind direction and positioned above the vine canopy. Traps were deployed at the beginning of April and replaced weekly throughout the 1996–97 growing seasons. All traps were returned to the laboratory and examined under a dissection microscope to count the number of phytophagous insects (including neutral insects i.e. non-pestiferous herbivores) and associated natural enemies on the traps.

In the same rows where sticky traps were placed, grape leaves were visually examined in the field and the number of *E. elegantula* nymphs recorded. Populations of leafhopper nymphs were estimated on 10 randomly selected leaves in each row. This sampling method was carried out in sections with and without cover crops, allowing one to determine quickly and reliably proportion of infested leaves, densities of nymphs and rates of leafhopper egg parasitization by the *Anagrus* wasp (Flaherty *et al*., 1992). Egg parasitism was determined by examining the same 10 grape leaves under a dissection microscope for the presence of parasitized or healthy *E. elegantula* eggs. Unhatched eggs were examined for the presence of a developing *A. epos* or *E. elegantula* (Settle & Wilson, 1990). At the same time, hatched leafhopper eggs were examined to determine the presence or absence of egg scars with a round exit hole, indicating *A. epos* emergence (Murphy *et al*., 1996).

In order to determine whether cover crop mowing forced movement of natural enemies from cover crops to vines, three different selected cover crop rows in block B were subjected to mowing three times each year. Both years, five yellow and five blue sticky traps were placed in the three random rows with cover crops every time they were mowed, and in three random rows that were not mowed.

Because this study was conducted within a working farm and the farmer was not amenable to subdivide blocks to accommodate replicated experimental units, the study may be considered a comparative analysis of an existing on-farm case study, rather than a pseudoreplicated experiment (Hurlbert, 1984). Data on the number of leafhoppers, *Anagrus* and predators found on traps placed in vineyard sections with and without summer cover crop were statistically compared each sampling date and for seasonal means using a t test.

Results

Density responses of the grape leafhopper to summer cover crops

In both years, densities of adult leafhoppers tended to be substantially lower throughout the season (except on 27 June and 18 July in 1996 and early in the summer in 1997) on vines with summer cover crops than in monoculture vines (Figs 1a and b, $t = 2.612$, d.f. = 10, $P < 0.05$).

Comparing the cover-cropped vineyard with the monoculture shows that increasing plant diversity also results in a decrease in the number of leafhopper nymphs. During 1996, nymphal densities were about 15% lower on vines in cover-cropped sections. No interblock differences were detected from 15 August until the end of the season ($t = 2.31$, d.f. = 13, $P < 0.05$). In 1997, lower abundance levels of nymphs on cover cropped vines were evident from 9 July onward ($t = 2.50$, d.f. = 6, $P < 0.05$; Figs 2a and b).

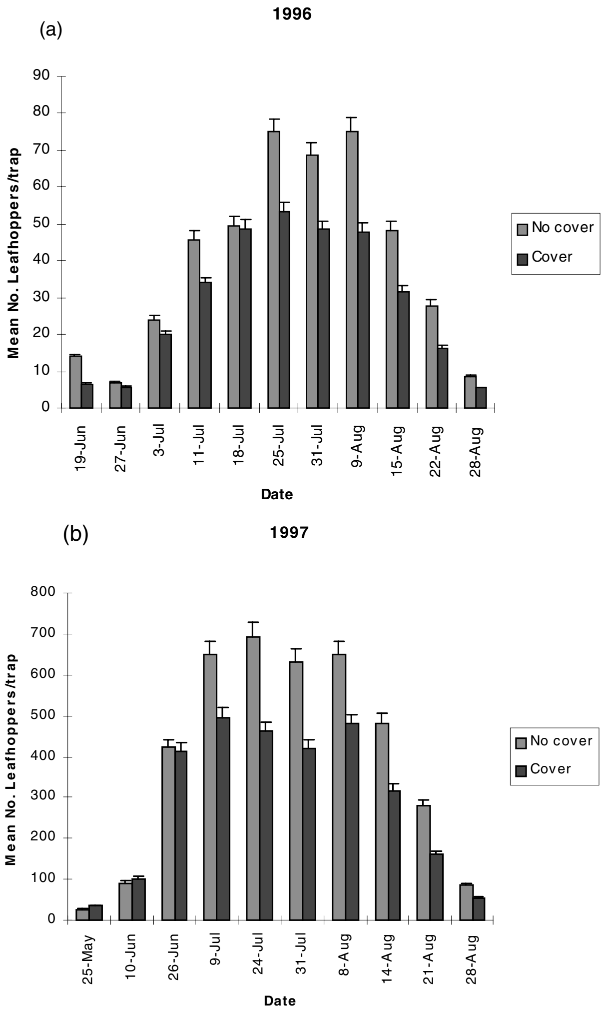

Figure 1 (a) Densities of adult leafhoppers *E. elegantula* in cover cropped and monoculture vineyards in Hopland, California, during the 1996 growing season. Mean densities (number of adults per yellow sticky trap) and standard errors of two replicate means are indicated. In some cases error bars were too small to appear in the figure. (b). Densities of adult leafhoppers *E. elegantula* in cover cropped and monoculture vineyards in Hopland, California, during the 1997 growing season. Mean densities (number of adults per yellow sticky trap) and standard errors of two replicate means are indicated. In some cases error bars were too small to appear in the figure.

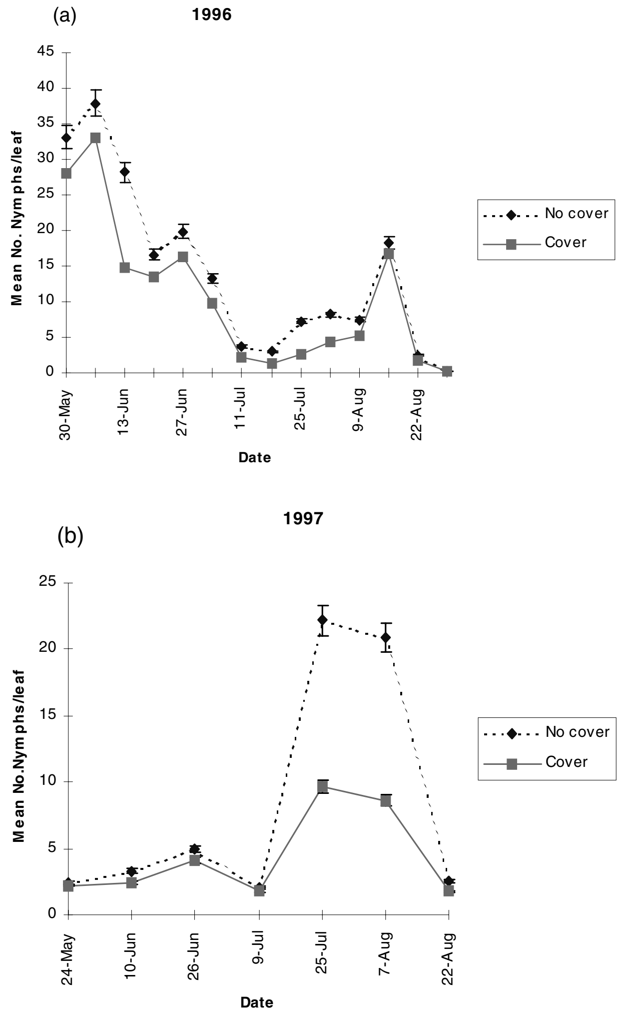

Figure 2 (a) Densities of *E. elegantula* nymphs in cover cropped and monoculture vineyards during the 1996 growing season in Hopland,California. (b) Densities of *E. elegantula* nymphs in cover cropped and monoculture vineyards during the 1997 growing season in Hopland, California.

Effects of cover crops on *A. epos* populations and parasitization rates

During 1996, the mean density of *Anagrus* present on yellow sticky traps placed on cover-cropped and monoculture vineyard sections were similar, although towards the end of the season *Anagrus* attained greater numbers in the monoculture. Similarly, during 1997, a year in which elevated capture rates were evident, sampling revealed higher numbers of *Anagrus* on monoculture vineyards starting in late July (Figs 3a and b, $t = 2.41$, d.f. = 9, $P < 0.05$). Clearly, *Anagrus* was more abundant in the vineyard monocultures associated with higher host densities.

Anagrus differences between yellow sticky trap captures in cover-cropped and monoculture vineyards were not reflected in parasitism records of *E. elegantula*. There was no consistent relationship between leafhopper abundance and the measures of parasitism done in this study. No differences in parasitization rates were detected between treatments in both years, although in July of both years egg parasitization was slightly higher, but not significantly so, in the cover cropped vineyard (Table 1, $t = 3.67$, d.f. = 2, $P < 0.05$).

Effects of summer cover crops on densities of thrips and abundance and diversity of general predators

Densities of thrips as revealed by blue sticky trap captures in 1996 were lower ($t = 2.37$, d.f. = 9, $P < 0.05$) in cover-cropped vineyards than in monocultures, remaining lower throughout the growing season (Figs 4a and b). Such differences were also apparent in 1997, a year of extreme thrips pressure, as thrips numbers were substantially greater in the monoculture starting in

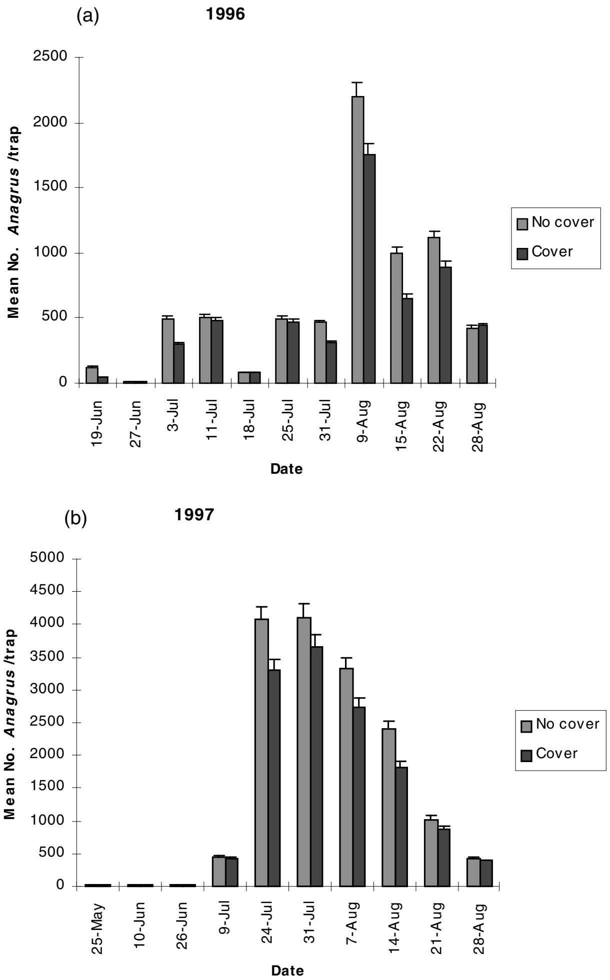

Figure 3 (a) Mean number of *Anagrus epos* per yellow sticky trap and standard errors in cover cropped and monoculture vineyards during the 1996 growing season, in Hopland, California. (b) Mean number of *Anagrus epos* per yellow sticky trap and standard errors in cover cropped and monoculture vineyards during the 1997 growing season, in Hopland, California.

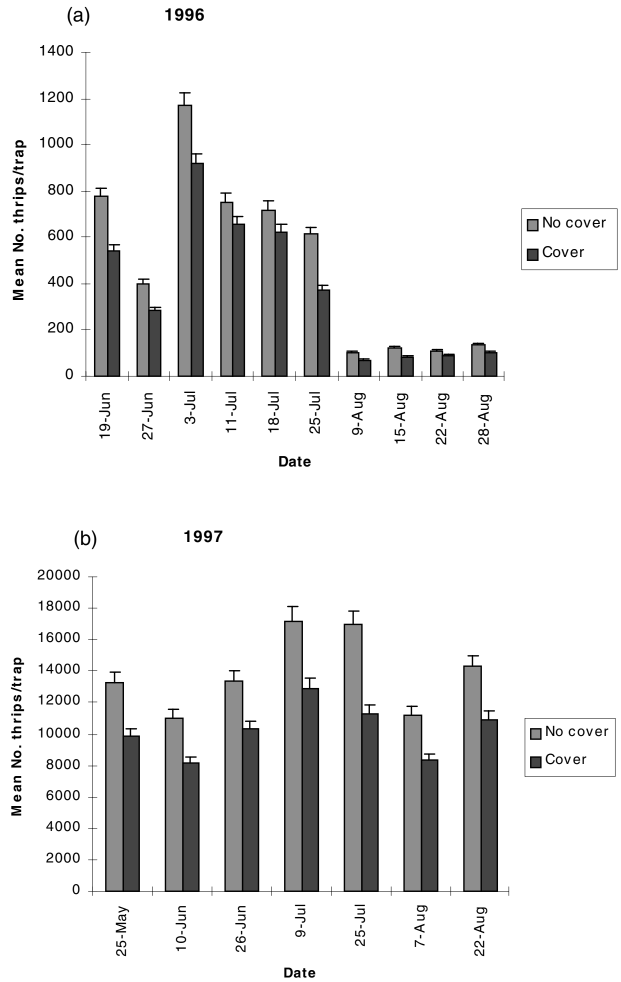

Figure 4 (a) Mean densities of thrips per blue sticky trap placed on cover cropped and monoculture vineyards throughout the 1996 growing season in Hopland, California. (b) Mean densities of thrips per blue sticky trap placed on cover cropped and monoculture vineyards throughout the 1997 growing season in Hopland, California.

Table 1 Mean leafhopper egg percent parasitism by *Anagrus epos* during two growing seasons, in vineyards with and without cover crops (Hopland, California)

	% parasitism	
Year	Cover cropped	No cover crop
1996		
June	48 *a*	49 *a*
July	62 *a*	59 *a*
August	67 *a*	66 *a*
1997		
June	52 *a*	54 *a*
July	64 *a*	55 *b*
August	69 *a*	68 *a*

* Means in each horizontal (monthly) column, followed by the same letter are not significantly different ($P < 0.05$, *t* test)

late July. From these results, it seems clear that the increase in vineyard plant diversity did consistently result in fewer thrips in the cover-cropped vines.

Table 2 gives the numbers of predators from cover-cropped and monoculture systems. The predators include spiders, *Nabis* sp. (Hemiptera: Nabidae), *Orius* sp. (Hemiptera: Anthocoridae), *Geocoris* sp. (Hemiptera: Geocoridae), Coccinellidae and *Chrysoperla* sp. (Neuroptera: Chrysopidae). Generally, the populations were low early in the season and increased, as prey became more numerous as the season progressed. As seen in this table, during both years, general predator populations on the vines tended to be higher in the cover-cropped sections than in the monocultures.

D-Vac sampling of cover crops in both blocks revealed that in 1996 the most abundant predator present on the flowers of buckwheat and sunflowers was *Orius*, followed by several species of Coccinellidae. Among the spiders, members of the family Thomisidae were the most common (Fig. 5). In 1997,

Table 2 Monthly mean densities and standard errors per 25 m D-Vac transect of *Orius* and various predators species on vines with and without summer cover crops (Hopland, California, 1996–97)

		Orius		Spiders		Coccinellidae		Geocoris sp.		Nabis sp.		Chrysoperla sp.	
	Month	1996	1997	1996	1997	1996	1997	1996	1997	1996	1997	1996	1997
Vines with cover crop	June	3 ± 0.7	4 ± 0.3	3 ± 1.3	4 ± 0.4	0	1 ± 0.1	0	0	1 ± 0.3	2 ± 1.1	3 ± 2.2	4 ± 2.2
	July	5 ± 1.9	6 ± 1.2	9 ± 3.4	11 ± 4.1	4 ± 1.0	5 ± 1.2	2 ± 1.7	3 ± 0.3	1 ± 0.6	2 ± 1.3	5 ± 3.1	6 ± 3.1
	August	4 ± 2.0	5 ± 1.8	12 ± 3.7	11 ± 3.4	1 ± 0.8	2 ± 0.3	4 ± 2.3	5 ± 1.7	2 ± 1.1	3 ± 1.5	2 ± 1.0	3 ± 1.7
Vines without cover crop	June	2 ± 1.3	3 ± 1.4	2 ± 1.1	2 ± 0.3	2 ± 0.7	0	0	0	0	0	2 ± 0.7	2 ± 1.7
	July	3 ± 0.9	4 ± 0.9	8 ± 2.6	9 ± 1.5	2 ± 0.4	3 ± 1.3	1 ± 0.5	2 ± 0.7	0	0	4 ± 1.5	4 ± 2.1
	August	2 ± 0.1	4 ± 1.2	9 ± 3.4	10 ± 2.1	1 ± 0.3	1 ± 0.4	2 ± 0.9	3 ± 1.3	1 ± 0.7	2 ± 0.9	2 ± 0.8	1 ± 0.3

Table 3 Abundance of *Erythroneura elegantula*, *Anagrus epos and* predators on vines before and after cover crop mowing (Hopland, California, 1996)

	Before mowing	One week after mowing	*t* stat (d.f. = 4)
Adult leafhoppers	53 ± 7.0 a	45 ± 6.4 b	3.01
Adult *Anagrus epos*	320 ± 88 b	155 ± 37 a	4.53
Predators	2 ± 1.3 a	6 ± 2.1 b	2.80

Means (numbers/yellow sticky trap) in each horizontal column, followed by a different letter are significantly different ($P < 0{,}05$, $t-$test)

Orius was again the most abundant predator on the cover crops, followed by several thomisid spiders and a few species of Coccinellidae, Nabidae and *Geocoris* sp. Most of these predators probably responded to the neutral insects, pollen and nectar present in the cover vegetation.

Effects of cover crop mowing on leafhoppers and *A. epos*

To determine if mowing influenced leafhopper abundance, leafhopper densities were assessed on vines selected before and after mowing compared to numbers on vines where cover crops were not mowed. In 1996, one week after cover crops were subjected to mowing, a two-tailed *t*-test revealed that densities of *Anagrus* and general predators increased in the rows immediately adjacent to the mowed cover crops, when compared to densities on vines with non-mowed cover crops beneath ($t = 2.93$, d.f. = 4, $P < 0.05$). Adult leafhopper densities in turn decreased on vines in rows where cover crops were mowed (Table 3).

In 1997, the same effects of mowing were again detected. Before mowing, leafhopper nymphal densities on vines were similar in the selected cover-cropped rows. One week after mowing, numbers of nymphs declined on vines where the cover crop was mowed, coinciding with an increase in *Anagrus* densities in mowed cover crop rows. During the second week such decline was even more pronounced ($t = 2.93$, d.f. = 4, $P < 0.05$), although by then differences in *Anagrus* numbers between mowed and not mowed rows were not apparent (Figs 6a and b).

Discussion

Our studies showed that cover crops harboured a large number of *Orius*, coccinellid, thomisid spiders and a few other predator species. Comparisons of predator abundance in both blocks showed that the presence of such predators on buckwheat and sunflower produced an increase in the density of predators in the cover-cropped vineyards. This result is consistent with the observations reported by Daane & Costello (1998), who found that cover crops influenced the relative abundance of spiders present in vineyards. The question is whether such enhancements in predator abundance, especially given that *Anagrus* behaved similarly in both systems, explained the lower populations of leafhoppers and thrips detected in the diversified vineyards. Some researchers (Hanna *et al*., 1996) believe that leafhopper reductions may be attributed in part to enhanced activity of certain groups of spiders, which are consistently found at higher densities in the presence of cover crops compared to the clean cultivated systems. Our observations reveal that greater densities of predators is correlated with lower leafhopper numbers and this relationship is much more clear cut in the case of the *Orius*–thrips interaction.

The mowing experiment suggests a direct ecological linkage, as the cutting of the cover crop vegetation forced the movement of the *Anagrus* and predators harboured by the flowers, resulting in both years in a decline of leafhopper numbers on the vines adjacent to the mowed cover crops. These results are consistent with the findings of Sluss (1967), who recommended cutting cover crops in walnut orchards in late April or early May to force movement of *Hippodamia convergens* onto the walnut trees to exert early control of the walnut aphid. Clearly, more research is needed on timing of mowing in relation to the biology of the leafhopper and the phenology of the vine and cover crops.

This evaluation of the effects of summer cover crops as a habitat diversification to reduce insect pest incidence in vineyards satisfies the two general ecological hypothesis that underlie the response of insect pests to diversified systems (Andow, 1991; Altieri, 1994). According to our data, reduced pest numbers in diversified vineyards were apparently due to the impacts of generalist predators. With increased plant diversity, insect pests remained at lower levels than in clean cultivated vineyards, partly because the summer cover crop vegetation offered pollen and nectar and harboured neutral insects that served as alternate food and hosts for important predators along with the *Anagrus* parasitic

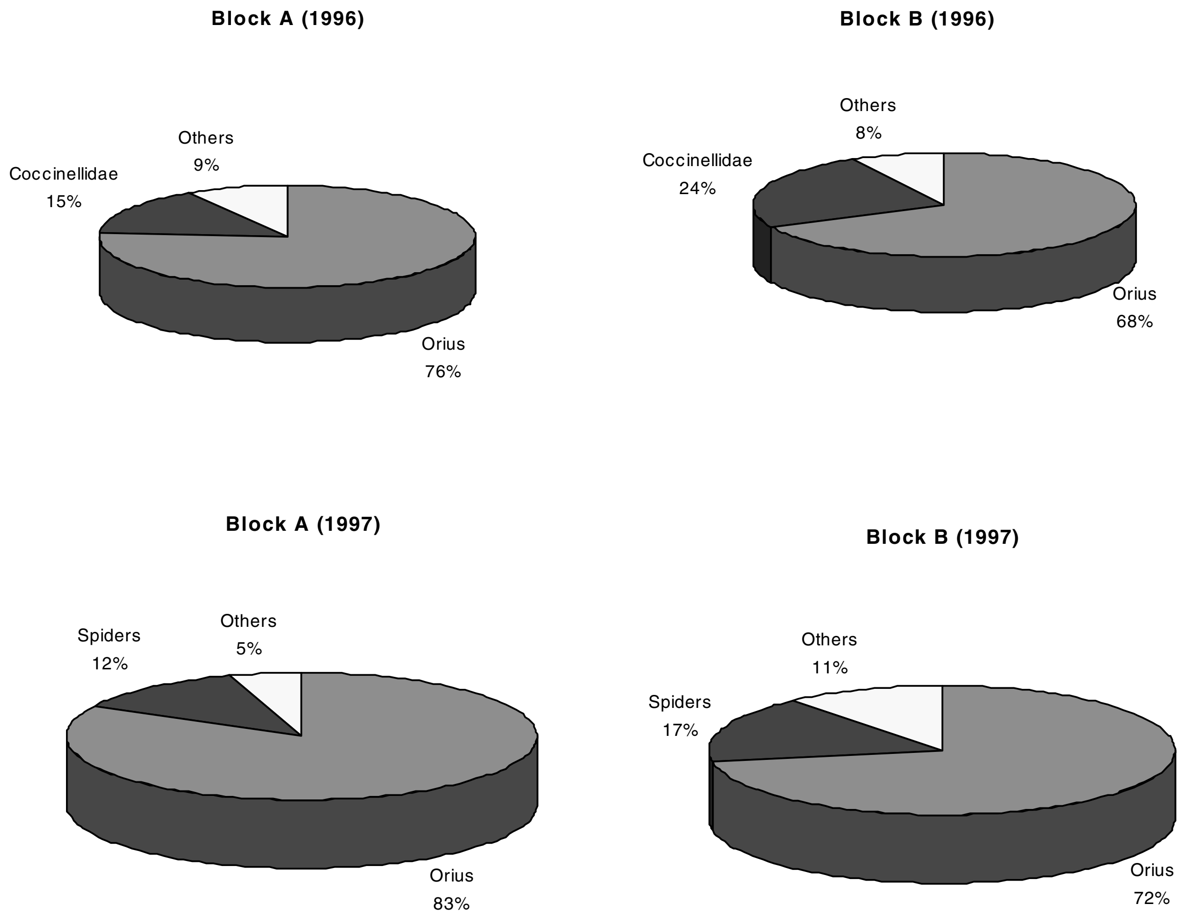

Figure 5 Proportion of predator groups harbored by summer cover crops (1996–97). Others include: *Nabis* sp., *Geocoris* sp., *Chrysoperla* sp., and several spiders.

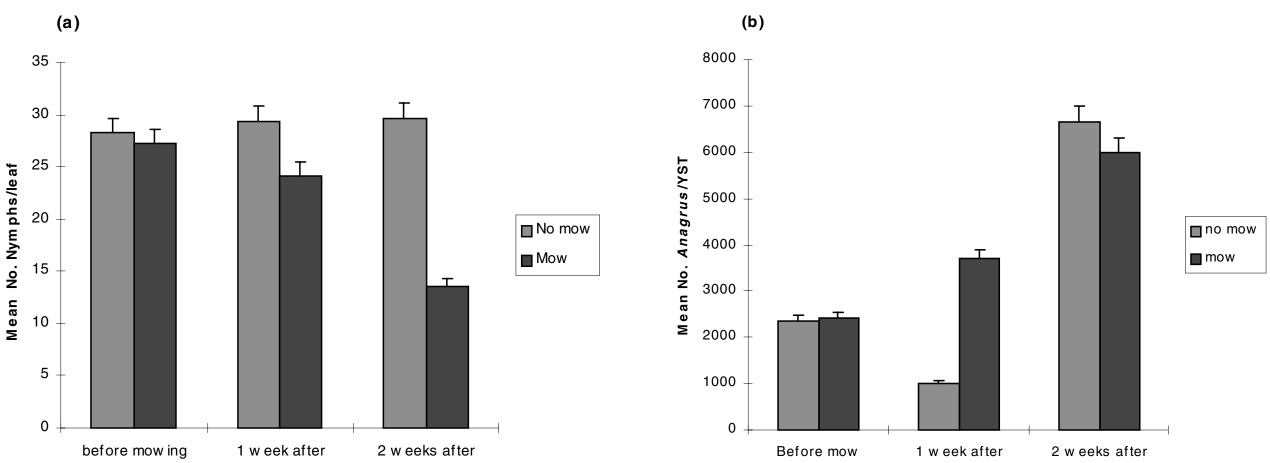

Figure 6 (a) Effects of cover crop mowing in vineyards on densities of leafhopper nymphs during the 1997 growing season in Hopland, California. (b) Effects of cover crop mowing in vineyards on densities of *Anagrus epos* during the 1997 growing season in Hopland, California.

wasp. But, as Root (1973) suggests, leafhoppers and thrips could also have been influenced by the concentration or spatial dispersion of their food plants (vines), and were more likely to find and remain on vines growing as monocultures.

Although it is certainly possible that vines with an undergrowth of cover crops may become 'less apparent' to grape herbivores (*sensu* Feeny, 1976), our data suggest that a critical factor influencing the density of grape herbivores was the abundance and diversity of predators in the cover-cropped vineyards. This indicates that habitat diversification using summer cover crops is a good strategy to support high population of predators, thereby favouring enhanced biological control of leafhoppers and thrips in vineyards. Other farmers of the area adopting summer cover cropping have observed similar trends (D. Koball, personal communication).

This study coincides with Boller (1990), who reported that when understory vegetation is present in the vineyards, a highly complex habitat containing multiple strata is developed. In our case study, the cover crop stratum in vineyards contained various predators species that were also found in the vine canopy, therefore suggesting a continuum of species activity to occur between the vines and the cover crop vegetation.

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