

 Open access • Journal Article • DOI:10.1016/0167-8809(94)00535-M

Abundance, growth rate and parasitism of *Brevicoryne brassicae* and *Myzus persicae* (Homoptera : Aphididae) on broccoli grown in living mulches — [Source link](#)

Michael J. Costello, Miguel A. Altieri

Institutions: University of California, Berkeley

Published on: 01 Feb 1995 - Agriculture, Ecosystems & Environment (Elsevier)

Topics: Brevicoryne brassicae, Myzus persicae, Diaeretiella rapae, Aphid and Aphididae

Related papers:

- [Vegetational Diversity and Arthropod Population Response](#)
- [Organization of a Plant-Arthropod Association in Simple and Diverse Habitats: The Fauna of Collards \(Brassica Oleracea\)](#)
- [Habitat Management to Conserve Natural Enemies of Arthropod Pests in Agriculture](#)
- [Incidence of pests and arthropod natural enemies in zucchini grown with living mulches](#)
- [Varying responses of insect herbivores to altered plant chemistry under organic and conventional treatments](#)

Share this paper:    

View more about this paper here: <https://typeset.io/papers/abundance-growth-rate-and-parasitism-of-brevicoryne-27tpow4sxd>

Abundance, growth rate and parasitism of *Brevicoryne brassicae* and *Myzus persicae* (Homoptera: Aphididae) on broccoli grown in living mulches

Michael J. Costello*, Miguel A. Altieri

Laboratory of Biological Control, University of California, Berkeley, CA 94706, USA

Abstract

In 1990 and 1991, populations of the cabbage aphid, *Brevicoryne brassicae*, and the green peach aphid, *Myzus persicae*, were monitored on broccoli interplanted with three leguminous cover crops (the living mulches) and compared with broccoli without cover crop (clean cultivation). The cover crops used were white clover (*Trifolium repens* L.), strawberry clover (*Trifolium fragiferum* L.) and a mixture of birdsfoot trefoil (*Lotus corniculatus* L.) and red clover (*Trifolium pratense* L.). Fertilizer was applied as compost or synthetic fertilizer crossed with cropping system regime. *Brevicoryne brassicae* can reach pest status in *Brassica* cropping systems, whereas *M. persicae* is generally innocuous. Both aphids are attacked by the parasitoid *Diaeretiella rapae*. Seasonal aphid abundance, parasitism and population growth rates were analyzed.

No significant effect of fertilizer was found for any of the parameters analyzed. The living mulches had lower aphid populations overall, although differences with clean cultivation were greatest early in the season for *M. persicae* and diminished over time. No effect of cropping system on population growth rate was seen for *Brevicoryne brassicae*, but for *M. persicae* growth rates were higher in living mulches compared with clean cultivation. Parasitism was highest on clean cultivated broccoli for both aphid species in 1990 and for *M. persicae* in 1991, but no differences were found for *Brevicoryne brassicae* in 1991. This suggests that differential population growth rates and parasitism seen for *M. persicae* are a result of inhibition of *D. rapae* in the living mulches. Possible reasons for differences in parasitism between the two aphid species in living mulches and clean cultivation are discussed.

Keywords: *Brevicoryne brassicae*; *Myzus persicae*

1. Introduction

Increasing vegetational diversity in agroecosystems, either by intercropping or by interplanting a crop with non-crop vegetation, has

frequently been tested as a method of insect pest population control, but with variable results (see recent reviews by Russell, 1989; Andow, 1991). This variability can in part be attributed to differences in natural enemy feeding ranges (generalist vs. specialist) and methods of host finding (visual, olfactory or random), as well as differences in herbivore response to changes in host plant quality in diverse plantings.

* Corresponding author at: Laboratory of Biological Control, UC Berkeley, Kearney Agricultural Center, 9240 S. Riverbend Ave., Parlier, CA 93648, USA.

The enemies hypothesis states that populations of insect natural enemies will be more abundant in vegetationally diverse cropping systems because of the variety of microhabitats or food resources (Root, 1973). However, results from studies which have tested this hypothesis with respect to parasitism have varied. Parasitism in vegetationally diverse cropping systems has been enhanced (Letourneau, 1987; Horn, 1988), decreased (Smith, 1976b; Andow and Risch, 1987) or has shown no change (Altieri, 1984; Letourneau, 1990) compared with crop monocultures. Sheehan (1986) argued that vegetational diversity may interfere with specialist parasitoid searching abilities because of masking of chemical cues used to orient to their hosts or inability to recognize patch boundaries. Andow (1991) suggested that the increased plant structural complexity (the way that plant surface area is connected together, see Andow and Prokrym, 1990) inherent in diversified cropping systems may interfere with parasitoid host-finding. In addition, vegetational diversity may cause parasitoids which search randomly to spend more time on vegetation which does not harbor their insect hosts, which would lead to less frequent host encounters and/or decreased patch tenure times.

In addition to effects on natural enemies, vegetational diversity can affect plant quality. When plant species are mixed there is a high probability of changes in host plant quality because of increased competition for resources such as light, nutrients and water (Andow, 1991). This can lead to higher rates of herbivore emigration (Kareiva, 1982) or lower rates of herbivore population growth (Finch, 1988) compared with single species plantings.

Aphid populations on annual crops have been consistently lowered by interplanting with weedy vegetation or cover crops (Dempster and Coaker, 1974; O'Donnell and Coaker, 1975; Altieri et al., 1985; Andow et al., 1986; Horn, 1988; Cartwright et al., 1990). The lower numbers of aphids in these systems is often attributed to a decrease in numbers of immigrant alates, which are known to be affected by crop background (Costello, 1995). However, less is known about

the effects of interplanted non-crop vegetation on the post-colonization development of aphids, which is affected by biotic mortality agents and host plant quality. Studies of the cabbage aphid, *Brevicoryne brassicae* (L.), in *Brassica* cropping systems have found variable rates of parasitism in interplantings compared with clean cultivated monocultures (Smith, 1976b; Altieri et al., 1985; Horn, 1988; Kloen and Altieri, 1990). Main crop growth parameters are often lower when interplanting with non-crop vegetation (Dempster and Coaker, 1974; O'Donnell and Coaker, 1975; Altieri et al., 1985; Andow et al., 1986; Horn, 1988), making it difficult to determine whether effects seen on aphid populations are the results of parasitism or changes in plant quality.

Brassica crops are cultivated year round in the moderate climatic zones of the central California coast, and are colonized by *Brevicoryne brassicae* and the green peach aphid, *Myzus persicae* (Sulzer). *Brevicoryne brassicae* is a specialist on the Brassicaceae and prefers feeding on younger plant tissues, which makes it the aphid of economic importance on broccoli as it can move into the developing floral buds and render the head unmarketable. *Myzus persicae* is a generalist which feeds on a wide range of plants in several families, but is generally not of economic importance on *Brassica* crops. Both aphids are attacked by the parasitoid *Diaeretiella rapae* M'Intosh (Hymenoptera: Braconidae), which tends to specialize on crucifer-feeding aphids, but has also been reported attacking numerous other aphids species on a range of plant families (Sheehan and Shelton, 1989a).

At the University of California Agricultural Experiment Station in Albany, early-season populations of *Brevicoryne brassicae* and *M. persicae* on broccoli were lower when interplanted with clover (a living mulch) compared with clean cultivation (Costello, 1992). However, by season's end no differences in aphid abundance remained among treatments, suggesting that aphid growth rates in living mulches were higher. Further studies were therefore undertaken at a site in the Salinas Valley, California, to determine whether aphid abundance followed a similar pattern and if so, to identify the mechanisms in-

volved. Included in the study was a comparison of organic vs. conventional fertilizers to ascertain if this had any effect on host plant quality and, consequently, aphid abundance.

2. Materials and methods

Experiments were conducted at the Rural Development Center farm from September to December 1990 and May to July 1991. The experiment was a 4×2 factorial, in a randomized complete block/split plot design, with blocks replicated four times and plot size $10 \text{ m} \times 10 \text{ m}$. The main plot factor consisted of four cropping system levels: three cover crops interplanted with broccoli (the living mulches, hereafter denoted LM) and a clean cultivated (no cover crop) control. The cover crops used were white clover (*Trifolium repens* L.), strawberry clover (*Trifolium fragiferum* L. cv. 'O'Connors') and a mixture of birdsfoot trefoil (*Lotus corniculatus* L. cv. 'Kalo') and red clover (*Trifolium praetense* L.). Two fertilizer levels comprised the sub-plot factor: synthetic fertilizer or chicken manure/rice hull compost. Nitrogen availability in the plots given compost was low, which meant that plots given compost had lower crop growth parameters than those given synthetic fertilizer (Costello, 1994). Crop growth, however, was not negatively affected in the living mulches (Costello, 1994). Broccoli was transplanted at an intra-row spacing of 22 cm with 0.6 m between rows (approximately $72\,000 \text{ plants ha}^{-2}$). Cover crops in the living mulch plots covered 83% of the inter-row area. Further methodology is described in Costello (1994).

Aphids were sampled by taking 50 broccoli leaves from 50 separate plants in each sub-plot, excluding the two outer rows. Sampling was stratified according to plant stratum (upper, $n=15$; middle, $n=25$; lower, $n=10$; subplot row, $n=10$ per row). Samples were taken every 2 weeks in 1990 and every 10 days in 1991. Sampling dates are presented as days after planting (DAP).

Aphids were heat-extracted using a combination of the methods described by Hughes (1963)

and Pielou (1961). Aphids and mummies (parasitized fourth instar and adult aphids) were segregated according to species and counted by instar using the keys of Raworth et al. (1984) and Dodd (1976). Third instar aphids containing parasitoids which had undergone considerable development but which had not yet mummified were noted and scored as parasitized.

2.1. Statistical analysis

Aphid abundance data were \log_{10} transformed and analyzed by repeated measures ANOVA (Statistical Analysis Systems Institute Inc. (SAS Institute Inc.), 1988), using leaf area as a covariate to partition any variation due to plant size. If plant size was found not to be significant ($P > 0.05$), then the data were reanalyzed without the covariate. The mean aphid abundance from each living mulch was compared with clean cultivation using orthogonal contrasts. No contrast was declared significant unless the overall ANOVA was significant at $P < 0.05$.

Parasitism was determined as: % parasitism = total parasitized aphids (instars III–IV and apterous adults) $\times 100$ / (parasitized and non-parasitized aphids (instars III–IV and apterous adults)). Parasitism values (those with zero aphid counts removed) were arcsin transformed and analyzed by ANOVA (PROC GLM, SAS Institute Inc., 1988), averaging across sampling dates for each treatment. Means were separated by Tukey's honestly significant difference (HSD).

Aphid population growth rates (r —the \log_e aphids per sample per aphid instar period) were estimated using the method of Hughes (1963) for observed rates of increase. Values of r were analyzed by ANOVA (PROC GLM, SAS Institute Inc., 1988), averaging across sampling dates for each treatment, with means separated by Tukey's HSD.

Determination of broccoli leaf nitrate-nitrogen is described in Costello (1994). Linear regression analysis was used to determine the association between aphid population growth rates and broccoli leaf nitrate-nitrogen, using samples from strawberry clover LM and clean cultivation

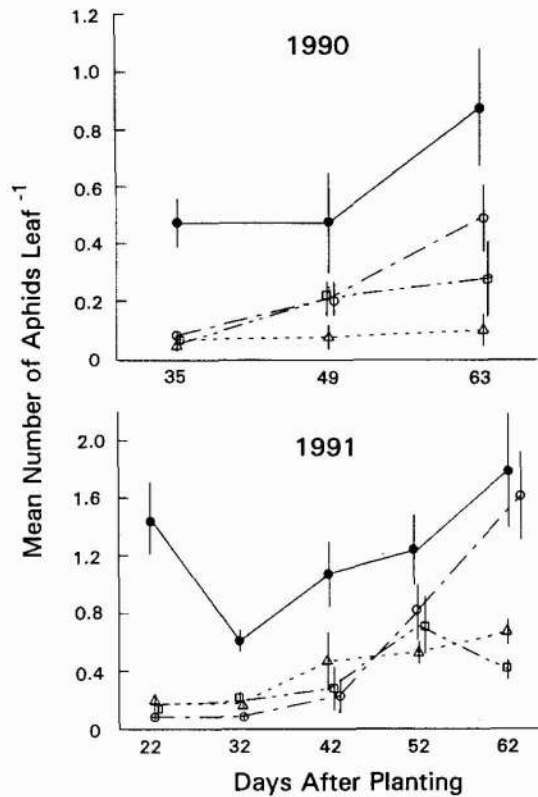


Fig. 1. Mean apterous *M. persicae* abundance on broccoli in living mulches (LM) and under clean cultivation, in 1990 and 1991. Error bars are standard error of the mean. ○, white clover LM; △, strawberry clover LM; □, trefoil/red clover LM; ●, clean cultivation.

which was the result of reduced alate aphid colonization (Costello, 1995).

All living mulches significantly reduced *M. persicae* abundance in both 1990 and 1991 compared with clean cultivation (Fig. 1; Table 2). In addition, there was significant date by cropping system interaction in 1991; compared with clean cultivation, numbers were significantly lower on 22, 32, 42 and 62 DAP in strawberry clover LM (contrast $F=52.13, 63.46, 11.61,$ and $8.18,$ respectively; d.f. = 1, 12; $P=0.0001, 0.0001, 0.008$ and $0.02,$ respectively) and trefoil/red clover LM (contrast $F=53.25, 59.13, 18.54$ and $15.38,$ respectively; d.f. = 1, 12; $P=0.0001, 0.0001, 0.002, 0.004,$ respectively) but not on 52 DAP. The population in white clover LM was lower on 22, 32 and 42 DAP (contrast $F=65.54, 99.57, 21.10,$ respectively; d.f. = 1, 12; $P=0.0001, 0.0001$ and $0.0013,$ respectively), but not on 52 or 62 DAP.

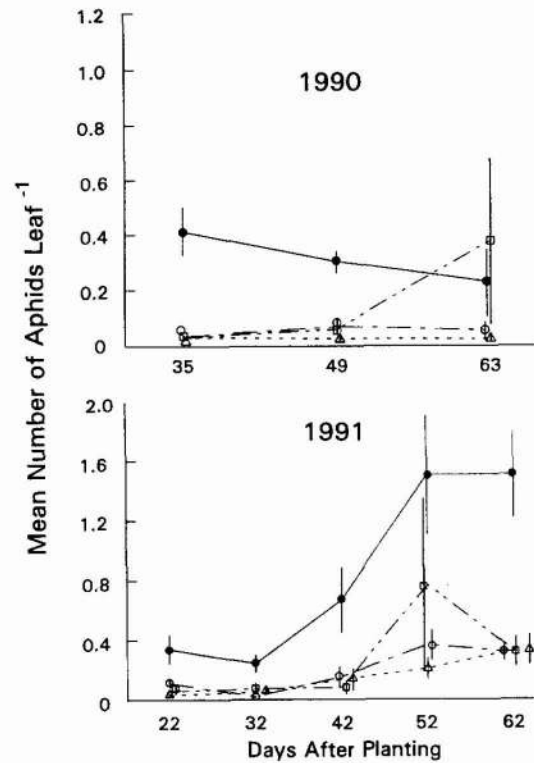


Fig. 2. Mean apterous *Brevicoryne brassicae* abundance on broccoli in living mulches (LM) and under clean cultivation, in 1990 and 1991. Error bars are standard error of the mean. ○, white clover LM; △, strawberry clover LM; □, trefoil/red clover LM; ●, clean cultivation.

Aphid numbers were 82%, 56% and 44% lower in white clover LM than clean cultivation on the three sampling dates, respectively, in 1990, and 95%, 86%, 78%, 34% and 10% lower on the five sampling dates in 1991, respectively. This pattern of diminishing differences over the course of the season is similar to that seen for combined populations of *M. persicae* and *Brevicoryne brassicae* on broccoli in clover living mulches (Costello, 1992), and for *M. persicae* on bell peppers in rye living mulches (Cartwright et al., 1990). The population of *M. persicae* in strawberry clover LM was most consistently lower than in clean cultivation in 1990 (85%, 84% and 88% on the sampling dates, respectively), but in 1991 differences narrowed somewhat between early-season (88% lower in strawberry clover LM) and mid- to late-season (57–63% lower) in 1991.

Living mulches also significantly reduced *Brevicoryne brassicae* abundance in both 1990

Table 2

Estimated season-wide population growth rates (r —the \log_e aphids per sample per instar period \pm SEM) for *Myzus persicae* and *Brevicoryne brassicae* in living mulches (LM) and clean cultivation

Season	Aphid sp.	Cropping system	r (\pm SEM)	n
1990	<i>M. persicae</i>	White clover LM	1.20(0.08)a	44
		Trefoil/red clover LM	1.13(0.13)ab	30
		Strawberry clover LM	0.92(0.14)ab	33
		Clean cultivation	0.86(0.10)b	44
	<i>B. brassicae</i>	White clover LM	0.75(0.14)a	25
		Trefoil/red clover LM	0.85(0.15)a	31
		Strawberry clover LM	0.85(0.18)a	21
		Clean cultivation	0.78(0.08)a	48
1991	<i>M. persicae</i>	White clover LM	1.45(0.11)a	93
		Trefoil/red clover LM	1.26(0.10)a	92
		Strawberry clover LM	1.33(0.09)a	91
		Clean cultivation	0.97(0.08)b	95
	<i>B. brassicae</i>	White clover LM	1.25(0.13)a	73
		Trefoil/red clover LM	1.37(0.14)a	67
		Strawberry clover LM	1.39(0.14)a	66
		Clean cultivation	1.33(0.09)a	92

Means within a group followed by the same letter are not significantly different ($P > 0.05$).

and 1991 compared with clean cultivation, with no interaction (Fig. 2; Table 2). The population of *Brevicoryne brassicae* in white clover LM displayed a weak pattern of decreasing differences with clean cultivation in 1990 (numbers lower by 92%, 81% and 78% on 35, 49 and 63 DAP, respectively) but in 1991 no such consistent diminution over time was seen (differences of 67% on 22 DAP and 79% on 62 DAP). The sharp rise in numbers of *Brevicoryne brassicae* in trefoil/red clover LM on 63 DAP in 1990 was due to a very high count on just one leaf. Numbers of *Brevicoryne brassicae* in 1990 were most consistently lower on strawberry clover LM compared to clean cultivation (94%, 93% and 92% on the three sampling dates, respectively).

3.3. Population growth rates

The rate of population increase of *Brevicoryne brassicae* did not differ between any of the living mulches and clean cultivation in either season (Table 2). However, r for *M. persicae* was significantly greater in white clover LM compared with clean cultivation in 1990 (Table 2), and was

greater for all living mulches vs. clean cultivation in 1991 (Table 2). This finding corresponds with that of Helenius (1989), who observed higher rates of increase for the bird cherry/oat aphid (*Rhopalosiphum padi* L.) on oats interplanted with field beans compared with a pure stand of oats. The higher r values for *M. persicae* in the white clover living mulch compared with clean cultivation corresponds to the observed patterns of abundance, i.e. late-season populations levels approaching those found in clean cultivation. Growth rates in the other living mulches, although statistically equivalent with white clover LM on a season-wide basis, did not result in aphid densities approaching that in clean cultivation at the end of the season.

3.4. Parasitism

Percent parasitism in 1990 for both aphid species was significantly higher in clean cultivation compared with all living mulches (Table 3). No parasitism was recorded in strawberry clover LM. In 1991 parasitism in clean cultivation was significantly greater compared with all living

Table 3

Season-wide percent parasitism (\pm SEM) of *Myzus persicae* and *Brevicoryne brassicae* in living mulches (LM) and clean cultivation

Season	Aphid sp.	Cropping system	% parasitism	<i>n</i>
1990	<i>M. persicae</i>	White clover LM	1.34(0.95)a	31
		Trefoil/red clover LM	3.03(2.09)a	22
		Strawberry clover LM	0.00(0.00)a	18
		Clean cultivation	10.05(2.18)b	39
	<i>B. brassicae</i>	White clover LM	3.33(3.33)a	6
		Trefoil/red clover LM	7.20(3.29)a	16
		Strawberry clover LM	0.00(0.00)a	12
		Clean cultivation	17.83(2.37)b	45
1991	<i>M. persicae</i>	White clover LM	2.54(1.20)a	53
		Trefoil/red clover LM	2.27(0.97)a	50
		Strawberry clover LM	2.83(1.06)a	55
		Clean cultivation	13.84(1.49)b	83
	<i>B. brassicae</i>	White clover LM	12.19(2.27)a	47
		Trefoil/red clover LM	11.35(2.29)a	42
		Strawberry clover LM	13.04(2.67)a	33
		Clean cultivation	15.38(1.45)a	84

Means within a group followed by the same letter are not significantly different ($P > 0.05$).

mulches for *M. persicae*, but no differences were found between clean cultivation and any of the living mulches for *Brevicoryne brassicae* (Table 3).

These results show a trend toward lower parasitism by *D. rapae* where crops are associated with non-crop vegetation and support the hypothesis that vegetational diversity can provide a barrier to parasitoid searching ability (Sheehan, 1986; Andow and Risch, 1987). Given the evidence that *D. rapae* is attracted to host plant odor (Read et al., 1970; Akinlosotu, 1977; Sheehan and Shelton, 1989b), it seems likely that the barrier in the living mulches was an olfactory one, though the contribution of increased plant structural complexity cannot be ruled out. Reduced parasitism in living mulches was consistent on *M. persicae*, but was found on *Brevicoryne brassicae* only in 1990. Results from previous studies with *Brevicoryne brassicae* have also been mixed. Smith (1976b) found lower parasitism by *D. rapae* on *Brevicoryne brassicae* in a weedy Brussels sprouts compared with monoculture in only 1 of 3 years, whereas Altieri et al. (1985) and Horn (1988) found higher parasitism in weedy vs.

monoculture *Brassica* crops. No change in parasitism of *Brevicoryne brassicae* was found when interplanted vegetation was fava bean (*Vicia fava* L.) (Altieri, 1984), vetch (*Vicia sativa* L.) (Altieri et al., 1985), or mustard (*Brassica hirta* Moench; Kloen and Altieri, 1990). It is possible that the non-crop vegetation weeds in some of these studies provided a nectar source which contributed to increased *D. rapae* longevity, tenure time and/or fecundity. Evidence of visitation to nectariferous plants has been found for some aphidiines (braconid parasitoids of aphids), including *D. rapae* (Jervis et al., 1993), but only if patch tenure time were increased would the availability of nectar offset any olfactorial or plant structural inhibition of parasitoid searching ability. However, when aphids are the primary pest, the presence of nectariferous plantings may be of little consequence because of the availability of aphid-produced honeydew as a food source for aphidiines (N.J. Mills, personal communication, 1994).

The evidence suggests that the lower rates of parasitism in the living mulches contributed to higher *M. persicae* population growth rates in

1991. Differential rates of parasitism, however, do not consistently explain differences in r values in 1990. In that season the population of *M. persicae* in white clover LM was the only one with a significantly higher r value compared with clean cultivation, whereas all living mulches had lower rates of parasitism than clean cultivation. In addition, r did not differ between any of the living mulches and clean cultivation for *Brevicoryne brassicae*, but percent parasitism was significantly higher under clean cultivation compared with all living mulches. These inconsistencies may be due to the low number of samples with aphids or mummies in 1990 compared with 1991 (Tables 2 and 3).

It cannot be ruled out that parasitism in these studies is merely a response to aphid density. In both seasons *M. persicae* densities were higher in the clean cultivated plots, which had consistently higher rates of parasitism compared with living mulches. Densities of *Brevicoryne brassicae* in living mulches were very low in 1990, when parasitism was lower compared with clean cultivation. However, the higher rates of parasitism found by Smith (1976b) in a Brussels sprouts monoculture were at equivalent aphid densities as the weedy Brussels sprouts (Smith, 1976a), and Helenius (1990) found a higher rate of parasitism in an oat monoculture despite finding a higher aphid density in mixtures of oats and fava beans. Thus, further studies on parasitism with control of aphid density would be helpful in separating the effects of host density from crop diversity.

It is uncertain why, in 1991, parasitism was negatively affected in the living mulches for *M. persicae* but not *Brevicoryne brassicae*, given that the same parasite attacks both aphid species. This contradicts the findings of Horn (1988), who found no differences in parasitism by *D. rapae* on *Brevicoryne brassicae* and *M. persicae*. One possible explanation lies in the different ways that the aphids distribute themselves on the leaf. *Brevicoryne brassicae* nymphs remain close to their stem mother and therefore populations have an aggregated distribution, whereas *M. persicae* nymphs tend to disperse at birth and maintain a more uniform distribution. It may be that the in-

hibitory effect of the living mulch on parasitoid searching ability caused *D. rapae* to increase tenure time at colonies of *Brevicoryne brassicae* compared with the more widely dispersed *M. persicae*. Interesting, Lopez et al. (1990) found that scattered *Brevicoryne brassicae* are more likely to be attacked by *D. rapae* than *Brevicoryne brassicae* in colonies. Clearly, there is no such preference for scattered *M. persicae* over colonial *Brevicoryne brassicae*. It is also possible that the preference of *D. rapae* for *Brevicoryne brassicae* (Hafez, 1961) played a role in differential parasitism, but it is difficult to see why this preference would be exhibited in the living mulches but not in clean cultivation.

These studies corroborate earlier findings that aphid populations can be lowered on crops grown with interrow vegetation, although this advantage was strongest in the early part of the growing season, and declined thereafter for *M. persicae*. However, because it is *Brevicoryne brassicae* and not *M. persicae* which causes economic damage on *Brassica* crops, the living mulches were successful as a cultural method of pest control, and contributed to lower pest damage levels (see Costello, 1994).

Acknowledgments

Thanks are expressed to Mike Gonzales and Teo Gonzales at the Rural Development Center in Salinas for their cooperation, to Foster Farms and PureGro Fertilizer Co. for their donation of the fertilizers, and to Martin Johnson at Bud of California for donating most of the broccoli plants. Partial support was provided by grants to M. A. Altieri by the Jesse Smith Noyse Foundation and the California Energy Commission. Dr. Kenneth Hagen made available his laboratory facilities for processing the field samples and Linda Schmidt helped coordinate field assistance. Dr. Nicholas Mills provided helpful comments and suggestions to the manuscript.

References

- Akinlosotu, T.A., 1977. Some aspects of the host finding behaviour of the female *Diaeretiella rapae* McIntosh (Hy-

- menoptera: Aphidiidae). *Nigerian J. Entomol.*, 1: 11–18.
- Altieri, M.A., 1984. Patterns of insect diversity in monocultures and polycultures of brussels sprouts. *Prot. Ecol.*, 6: 227–232.
- Altieri, M.A., Wilson, R.C. and Schmidt, L.L., 1985. The effects of living mulches and weed cover on the dynamics of foliage- and soil-arthropod communities in three crop systems. *Crop Prot.*, 4: 201–213.
- Andow, D.A., 1991. Vegetational diversity and arthropod population response. *Ann. Rev. Entomol.*, 36: 561–586.
- Andow, D.A. and Risch, S.J., 1987. Parasitism in diversified agroecosystems: phenology of *Trichogramma minutum* (Hymenoptera: Trichogrammatidae). *Entomophaga*, 32: 255–260.
- Andow, D.A. and Prokrym, D.R., 1990. Plant structural complexity and host-finding by a parasitoid. *Oecologia*, 82: 162–165.
- Andow, D.A., Nicholson, A.G., Wien, H.C. and Willson, H.R., 1986. Insect populations on cabbage grown with living mulches. *Environ. Entomol.*, 15: 293–299.
- Cartwright, B., Roberts, B.W., Hartz, T.K. and Edelson, J.V., 1990. Effects of mulches on the population increase of *Myzus persicae* (Sulzer) on bell peppers. *Southwest. Entomol.*, 15: 475–479.
- Costello, M.J., 1992. Covering the soil between rows: canopy reflectance, aphid ecology, and crop growth in broccoli/legume living mulches. Ph.D. Dissertation, University of California, Berkeley, 184 pp.
- Costello, M.J., 1994. Broccoli growth, yield and level of aphid infestation in leguminous living mulches. *Biol. Agric. Hortic.*, 10: 207–222.
- Costello, M.J., 1995. Spectral reflectance from a broccoli crop with vegetation or soil as background: influence on immigration by *Brevicoryne brassicae* and *Myzus persicae*. *Ent. Exp. Appl.*, in press.
- Culliney, T.W. and Pimentel, D., 1986. Ecological effects of organic agricultural practices on insect populations. *Agric. Ecosyst. Environ.*, 15: 253–266.
- Dempster, J.P. and Coaker, T.H., 1974. Diversification of crop ecosystems as a means of controlling pests. In: D. Price-Jones and M.E. Solomon (Editors), *Biology in Pest and Disease Control*. Blackwell, Oxford, pp. 106–114.
- Dodd, G.D., 1976. Key for the identification of the instars of the cabbage aphid (*Brevicoryne brassicae* (L.)). *Plant Pathol.*, 25: 84–86.
- Finch, S., 1988. Entomology of crucifers and agriculture-diversification of the agroecosystem in relation to pest damage in cruciferous crops. In: M.K. Harris and C.E. Rogers (Editors), *The Entomology of Indigenous and Naturalized Systems in Agriculture*. Westview Press, Boulder, CO, pp. 39–71.
- Helenius, J., 1989. The influence of mixed intercropping of oats with field beans on the abundance of spatial distribution of cereal aphids (Homoptera: Aphididae). *Agric. Ecosyst. Environ.*, 25: 53–73.
- Helenius, J., 1990. Incidence of specialist natural enemies of *Rhopalosiphum padi* (L.) (Hom., Aphididae) on oats in monocrops and mixed intercrops with fava bean. *J. Appl. Entomol.*, 109: 136–143.
- Horn, D.J., 1988. Parasitism of cabbage aphid and green peach aphid (Homoptera: Aphididae) on collards in relation to weed management. *Environ. Entomol.*, 17: 354–358.
- Hughes, R.D., 1963. Population dynamics of the cabbage aphid, *Brevicoryne brassicae* (L.). *J. Anim. Ecol.*, 32: 393–424.
- Jansson, R.K. and Smilowitz, Z., 1986. Influence of nitrogen on population parameters of potato insects: abundance, population growth, and within-plant distribution of the green peach aphid, *Myzus persicae* (Homoptera: Aphididae). *Environ. Entomol.*, 15: 49–55.
- Kareiva, P.M., 1982. Experimental and mathematical analyses of herbivore movement: quantifying the influence of plant spacing and quality on foraging discrimination. *Ecol. Monogr.*, 52: 261–282.
- Kloen, H. and Altieri, M.A., 1990. Effect of mustard (*Brassica hirta*) as a non-crop plant on competition and insect pests in broccoli (*Brassica oleracea*). *Crop Prot.*, 9: 90–96.
- Letourneau, D.K., 1987. The enemies hypothesis: tritrophic interaction and vegetational diversity in tropical agroecosystems. *Ecology*, 68: 1616–1622.
- Letourneau, D.K., 1990. Abundance patterns of leafhopper enemies in pure and mixed stands. *Environ. Entomol.*, 19: 505–509.
- Lopez, E.R., Van Driesche, R.G. and Elkinton, J.S., 1990. Rates of parasitism by *Diaeretiella rapae* (Hymenoptera: Braconidae) for cabbage aphids (Homoptera: Aphididae) in and outside of colonies: why do they differ? *J. Kans. Entomol. Soc.*, 63: 158–165.
- O'Donnell, M.S. and Coaker, T.H., 1975. Potential of intra-crop diversity for the control of brassica pests. *Proc. 8th British Insecticide and Fungicide Conference 1975*, 1: 101–107.
- Pielou, D.P., 1961. Note on a volumetric method for the determination of numbers of apple aphid, *Aphid pomi* DeG., on samples of apple foliage. *Can. J. Plant Sci.*, 41: 441–443.
- Raworth, D.A., Frazer, B.D., Gilbert, N. and Wellington, W.G., 1984. Population dynamics of the cabbage aphid, *Brevicoryne brassicae* (Homoptera: Aphididae) at Vancouver, British Columbia I. Sampling methods and population trends. *Can. Entomol.*, 116: 861–870.
- Read, D.P., Feeny, P.P. and Root, R.B., 1970. Habitat selection by the aphid parasite *Diaeretiella rapae* (Hymenoptera: Braconidae) and hyperparasite *Charips brassicae* (Hymenoptera: Cynipidae). *Can. Entomol.*, 102: 1567–1578.
- Russell, E.P., 1989. Enemies hypothesis: a review of the effect of vegetational diversity on predatory insects and parasitoids. *Environ. Entomol.*, 18: 590–599.
- Sheehan, W., 1986. Response by specialist and generalist natural enemies to agroecosystem diversification: a selective review. *Environ. Entomol.*, 15: 456–461.

- Sheehan, W. and Shelton, A.M., 1989a. The role of experience in plant foraging by the aphid parasitoid *Diaeretiella rapae* (Hymenoptera: Aphidiidae). *J. Insect Behav.*, 2: 743–759.
- Sheehan, W. and Shelton, A.M., 1989b. Parasitoid response to concentration of herbivore food plants: finding and leaving plants. *Ecology*, 70: 993–998.
- Smith, J.G., 1976a. Influence of crop background on aphids and other phytophagous insects on Brussels sprouts. *Ann. Appl. Biol.*, 83: 1–13.
- Smith, J.G., 1976b. Influence of crop background on natural enemies of aphids on Brussels sprouts. *Ann. Appl. Biol.*, 83: 15–29.
- Statistical Analysis Systems Institute Inc., 1988. SAS User's Guide: Statistics. SAS Institute, Cary, NC.
- Van Emden, H.F., 1966. Studies on the relations of insect and host plant III. A comparison of the reproduction of *Brevicoryne brassicae* and *Myzus persicae* (Hemiptera: Aphididae) on brussels sprout plants supplied with different rates of nitrogen and potassium. *Entomol. Exp. Appl.*, 9: 444–460.
- Van Emden, H.F. and Bashford, M.A., 1969. A comparison of the reproduction of *Brevicoryne brassicae* and *Myzus persicae* in relation to soluble nitrogen concentration and leaf age (leaf position) in the brussels sprout plant. *Ent. Exp. Appl.*, 12: 351–364.