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Impacts of undersowing clover and arugula on insect abundance in broccoli (Brassica oleracea).

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Impacts of undersowing clover and arugula on insect abundance in broccoli
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Abstract

Increasing vegetational diversity has been shown to reduce pest numbers in agroecoystems. To examine the relative effectiveness of undersowing clover (*Trifolium sp.*) and arugula (*Eruca vesicaria subsp. sativa*) in reducing pest numbers, I measured insect abundance on broccoli (*Brassica oleracea var. italica)* plants undersown with either arugula or clover in homogenous or heterogeneous stands compared to a monocrop alternative. Experimental plots showed large variation in covercrop establishment across both farms and replicated blocks within farms. Only aphid abundance was clearly impacted by the background vegetation in replicated 20 x 20 m^2 plots. Overall, plots with a clover background had the fewest number of aphids per plant, followed by those undersown with arugula. The control treatment, kept weed free, had the largest number of aphids per plant. Yield, measured by average head weight, was significantly reduced for plants undersown with clover, but yield for plants undersown with arugula was equal to that obtained from plants in the clean treatment. Increased ladybug (Coleoptera: Coccinellidae) abundance appeared to account for decreased aphid abundance in plots undersown with arugula. These findings indicate that aphid abundance is best explained by the enemies hypothesis. Furthermore, establishing heterogeneous background vegetation results in similar reductions in aphid abundance relative to homogenous backgrounds, with less effect on yield.

Introduction

Utilizing vegetational diversity in agroecosystems as a pest control measure has received increasing attention since Root's (1973) seminal paper. Root hypothesized that increasing the vegetational diversity in a field decreases the abundance of specialist herbivores because it is harder for them to find their resource patch. He called this the resource concentration hypothesis. Alternatively, his enemies hypothesis states that increased vegetational diversity could attract a greater number and diversity of natural enemies resulting in greater control of the herbivores by these natural enemies. The extensive work in this field has received careful review (e.g Risch et al., 1983; Kogan, 1986; Sheehan, 1986; Russell, 1989; Mackauer et. al, 1990; Andow, 1991; Glent et al., 1993; Altieri, 1994, 1995; Jackson, 1997; Barbosa, 1998a; Picket and Bugg, 1998; Collins and Qualset, 1999). Broadly speaking, conclusions have been that vegetational diversity is beneficial in reducing pests most of the time, but the specific conditions under which this is true prove elusive.

One area that has received extensive amounts of research is agronomic systems in which crops of the Brassicaceae family are grown. In support of the resource concentration hypothesis, Schellhorn and Stork (1997) showed that 1) collards had fewer specialist insects when they were interplanted with weeds which were not of the same family compared to interplantings with con-specific weeds, but that 2) there was no associated benefit to the crop when measured by dry weight, proportion leaf area damaged, or number of leaves damaged. When undersown with clover, pest populations on Brassicaceae crops have been reduced (Dempster and Coaker, 1974; Ryan et al., 1980; Theunissen et al, 1995 and Finch and Kienegger, 1997), but yield decreased when measured by weight, apparently due to competition for resources (Theunissen et al., 1995). However, when economic returns were compared, plantings associated with clover had significantly larger monetary returns than plantings with no associated undercover (monocultures) as a result of money saved on pesticide application (Theunissen et al., 1995). Border plantings of *Iberis umbellata* (Brassicaceae) markedly changed the distribution of pest species associated with commercial cabbage fields, but did not significantly reduce overall pest numbers. The border plantings had significantly more natural enemies associated with them, but these beneficial insects failed to move into the crop stands (Bigger and Chaney, 1998).

The Puget Sound region in the state of Washington is currently experiencing explosive growth in the area of direct marketing of organic vegetables. Local consumers are buying produce directly from local farmers at the over 40 different Farmers Markets serving the region (King County DNR, 2001). These local producers commonly grow vegetables from several plant families (e.g. Brassicaceae, Chenopodiaceae, Umbelliferae, Faberaceae, Solanaceae, and Gramineae). To exploit direct marketing opportunities, growers (OR stagger planting dates) plant each crop type in succession (relay planting) to ensure marketable produce throughout the summer. This results in planting crops at less than ideal times for crop growth.

In this paper, I explore how 2 different undersown plantings (clover and arugula) affect overall pest abundance on organic broccoli (*Brassica oleracea* var. *italica*) planted in late summer on several taxonomically diverse farms in the Puget Sound region of Washington. The success of undersowing clover in other regions of the world may be a result of its ability to limit pest abundance while providing an organic nitrogen source and acting as a smother crop to control weeds. Unlike the work by Schellhorn and Stork (1997), I also chose to look at Brassicaceae plants as undersowing candidates because of personal observations indicating that flea beetles (*Phyllotreta sp.*) preferentially fed on wild mustards over broccoli plants. While arugula is not a wild Brassicaceae, it is also known to be a preferred host of flea beetles and has a growth form that is less competitive with broccoli for light. Increasing vegetational diversity can reduce pest numbers; however, increased plant competition often outweighs the benefits gained as a result of reduced pest numbers. One potential way to reduce this competitive effect is to add undersown diversity in strips, rather than evenly throughout the entire field. My experimental design allowed me to test the difference in effect between partial and complete undersowing of a crop. A heterogeneous background was created by having one-half of the area undersown with one of the covercrops, while the other half was planted only to the crop, with no background vegetation.

Methods

Broccoli is a central crop for farms that sell directly to consumers at farmers markets and through Community Supported Agriculture (CSAs). Broccoli is transplanted from starts throughout the summer (April to August) in the Puget Sound region. The primary pests associated with crucifers in this region are a suite of aphids *Brevicoryne brassicae*, *Myzus persicae* and *Aphis fabae)* (Homoptera: Aphididae); flea beetles (*Phyllotreta cruciferae,* (Chrysomelidae: Alticidae)); (and a lepidopteran complex consisting of *Pieris rapae* (Pieridae), *Plutella xylostella* (Plutellidae) and *Trichoplusia ni* (Noctuidae).

Replicated experimental plots were establish at 2 farms in the Puget Sound region of Washington: Rent’s Due Ranch (RD: 48º14’N, 122º22’W), an organic farm located near Stanwood, Washington, and a Washington State University extension system farm located near Puyallup (Puy: 47º12’N, 122º20’W). A block consisted of 5 treatments (4 experimental and 1 control) that manipulated the makeup of the background vegetation. Experimental treatments consisted of homogenous backgrounds of either a clover mixture (Cv) (50:50 of *Trifolium repens* and *Trifolium fragiferum*, broadcast seeded at approximately 62.5 lbs/hectare) or arugula (Br) (*Eruca vesicaria subsp. sativa*, direct seeded into 2 rows between each row of broccoli) or a heterogeneous background of half clean and either half clover (CvCn) or half arugula (BrCn) (see Figure 1). I kept the control treatment (Cn) weed free by hand hoeing and mowed the covercrops with a push lawnmower as needed to keep them below the level of the broccoli crop. Broccoli plants (RD: Southern Comet F1, Puy: Green Valiant F1, West Coast Seeds Ltd.) were transplanted into the fields approximately 5 weeks after initial planting (Table 1) at ½m intervals with 1m spacing between rows.

Each farm had 2 experimental blocks for a total of 4 blocks with 5 treatments per plot (except for block 2 at RD where the arugula failed to germinate and the Br and BrCn treatments were abandoned (a total of 18 experimental plots). To accommodate production needs, block 1 contained 20 rows while block 2 contained 17 rows. I randomly selected a total of 16 plants from each treatment, 8 each from 2, 3-row groups (rows 2-4 and 12-14 to isolate them from another experiment). In heterogeneous backgrounds treatments I chose 8 plants from each type of background for a total of 16 for the entire treatment. Selected plants were flagged for repeated sampling.

Mechanical and weather problems resulted in non-uniform establishment of both the broccoli and the covercrops. At Puyallup (Puy) the covercrops were planted prior to transplanting the broccoli starts, to act as a trap crop (Table 1). However, an unusually hot and dry spell occurred shortly after planting causing poor germination of both clover and arugula. The arugula that did come up bolted very quickly. At Rent's Due Ranch (RD), mechanical and production problems resulted in the fields not being tilled until immediately prior to broccoli transplanting, resulting in the covercrops being seeded after transplanting (Table 1). For both blocks at Puy and the first block at RD, the weather was unusually hot and dry during the critical early establishment stage for the transplants. Blocks at the Puy site were watered, but no water was available at RD (see Table 2 for a summary of the differences between blocks and farms in crop establishment).

I visually sampled entire plants for insects and damage. All insects observed were recorded, including the percent of aphids parasitized by hymenopteran wasps based on the number of mummies counted. Damage was measured based on the percent of vegetative matter consumed using the following categories: 0: 0%, 1: 1-10%, 2: 11-25%, 3: 26-50%, and 4: >50% of vegetation eaten. Once plants began developing heads (heading stage), head diameter was recorded and scored for marketability using the following categories: 1: no damage, 2: some damage, or head not compact but still marketable, 3: physical blemishes, aphids or frass in the head, not marketable, or 4: extensive damage, not marketable. Aphids do not remove tissue from plants but their feeding reduces head size and can cause distortions in the shape of the broccoli head. This damage was accounted for by scoring the marketability of the head. At RD, sampled plants were individually harvested and head diameter, marketability scores and weight were recorded. In addition, total yield weights were collected at RD based on background vegetation, not the treatment vegetation, i.e. clover, arugula, or clean).

Sampling of block 1 on RD was unique from the other blocks in 2 ways. It was sampled 4 times during the season instead of 3 times, as were the other blocks. In addition, during the season it became apparent that larger numbers of ladybug adults and larvae were present in this block compared to other plots. To quantify this difference, a single ladybug census was made by walking 3 randomly chosen transects through each treatment. Each transect was walked between 2 rows at a constant pace (4 minutes to cover the 8-meter length of each treatment block) recording the number of ladybug larvae and adults, including the vegetational type they were located on (crop, weed, arugula, ground, or other). Only ladybugs found on either of the two rows of broccoli or the area between rows were recorded. I used a fixed amount of time to cover a single transect to ensure that all vegetational types received an equal sampling effort, discussed more thoroughly in Banks (1999).

Because sampling intervals were sporadic across both Julian date and days after transplant, averages were taken across the number of samples per plot, yielding an average load for each plant. The 3 primary lepidopteran pests were merged into a single value of cabbage looper equivalents (IPM[1]) based on economic threshold models developed by Harcourt et al (1955) and modified by Stewart & Sears (1988) and King and Olkowski (1991). One cabbage looper equivalent equals 1 cabbage looper, 1.5 imported cabbageworms, or 5 diamondback moths. I analyzed the abundance of each primary insect separately with a nested ANOVA, with farm and treatment as fixed effects and plot within farm as a random effect. To better meet the assumptions of ANOVA analysis, per plant average insect abundance was transformed as follows: log(aphid +1),   (IPM+0.5), and arcsin((fraction aphids parasitized)). Treatment effects were determined significant by using the treatment by plot within farm error term for the denominator in F tests. Significant ANOVA results were followed by Fisher's least significance difference test (LSD) to test *a priori* contrasts between each treatment (Br, BrCn, Cv, CvCn) versus the control group (CN). Fisher's LSD test was also used to analyze yield data.

Results

Overall cover crop establishment was poor due to poor germination at Puy and late planting at RD. As a result, clover treatments were dominated by background weeds in each field (see Table 2 and Figure 2). Experimental plots were paired by farm to control for expected inter-farm variation. The 2 blocks at the Puy site responded similarly; however, there was significant difference between the 2 blocks at RD in plant growth and insect distributions. Regardless of background vegetation, all broccoli plants in block 2 at RD grew to 2 to 3 times the volume of the plants in block 1, closing the canopy between rows. This growth resulted from additional fertilizer incorporated into the field at initial tilling and increased moisture at the initial establishment phase (M. McIntyer, pers. comm.). Growth did not occur to this extent in any other block in the experiment.

Insect Abundance

Flea beetles were not present in significant numbers at either farm, although at RD flea beetles were present but remained primarily on kale about 300m away from experimental blocks. In past years, flea beetles were the primary pest of all brassica crops at RD (pers. obs.). Flea beetles were present in large numbers at Puy during the establishment of arugula prior to broccoli transplanting. This adult population disappeared shortly after transplanting, either because of within season generational dynamics or because they moved to a newly planted commercial cabbage field next to the research plots.

The virtual absence of flea beetles at both fields and the highly variable pattern of aggregate lepidopteran abundance resulted in only the mean number of aphids per plot showing a significant difference between treatments (P=0.011) along with significant blocking terms (Farm and block within farm, $P < 0.0005$ for each) (Table 3). *A priori* contrasts for differences between each treatment compared to the clean treatment (control) were significant for all treatment effects (Figure 3). The pattern indicating the clean treatment had the most number of aphids per plant was consistent as an overall effect (averaged across farms) (Figure 3) and for each plot within farm (Table 4).

The seasonal pattern of insect abundance in block 1 at RD (the only block sampled 4 times) also merits further discussion. At sample number 3 (43 days after transplanting), treatments were indistinguishable from one another in terms of insect abundance. Yet by sample 4 (54 days after transplanting) there was

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[1] IPM is used as the abbreviation for counting the lepidopteran complex because it is used to develop IPM thresholds in cabbage, so we use this abbreviation.

an observable difference between treatments (Figure 4). The separation of lepidopteran abundance between treatments was greater when measured by IPM value than by any single lepidopteran species. (Lepidopteran abundance in the homogenous background treatments (Br and Cv) decreased while abundance in all treatments containing bare-ground (Cn, BrCn, and CvCn) continued to increase throughout the season. Aphid abundance changed less than lepidopteran abundance between sample number 3 and sample number 4 and which treatments experienced a decrease in abundance differed. Aphid abundance decreased the most in the heterogeneous treatments (BrCn and CvCn) with the clean treatment having the greatest abundance.

The results of this single estimate of ladybug abundance are presented in Table 5. Nearly 60% of the observed individuals were associated with the 2 arugula treatments (Br and BrCn). The two treatments with the fewest number of ladybugs were Cn and CvCn. Of those observed in the arugula treatments, only 11% occurred on broccoli plants while over half were observed on the arugula plants themselves. If the numbers observed on weeds and arugula are combined to represent non-crop vegetation, then nearly 90% of the observed ladybugs were on this non-crop vegetation. For the two clover treatments (Cv and CvCn), 56% of the observed individuals were on non-crop vegetation and about a third were on broccoli plants.

Yield

Measurements of yield at the RD farm were taken at two levels, the treatment level and background vegetation level (clover, arugula, or clean). The growth differences between plots resulted in vastly different yield patterns between plots (Figure 5). As a result, I analyzed yield data separately by block[2]. At the treatment level, yield represented head weight for each of the repeatedly sampled plants that obtained marketable head size and quality. A one-way ANOVA for yield weight was marginally significant (P= 0.092, Table 6). *A priori* contrasts between the clean treatment and each other treatment revealed that for treatments where clover was the covercrop, average head weight was significantly reduced (Table 4). Total yield weight by background vegetation (the sum of all harvested heads from a given background treatment), summing across harvest dates, cannot be analyzed statistically, but the data (Figure 5) suggest that a undersowing with clover resulted in a decrease in overall yield in block 1, but had no influence on yield in block 2. This lack of influence in block 2 likely was the result of the overall vigorous broccoli growth in all treatments (see Results above).

Discussion

As the establishment of uniform replicate block treatments proved difficult (see Table 2), results should be interpreted cautiously. The only insects showing a response to the treatments were aphids. Aphids were consistently more numerous on plants with no associated background vegetation (Table 4 and Figure 3). Even though there was no difference in the number of mummies (a sign of parasitism) present per treatment; there was no observed difference in the rate of parasitism (measured as the per cent of aphids parasitized), which might be expected since aphid numbers were different between treatments. This is unexpected because if the rates of parasitism are equal (e.g. 20%) and the number of aphids differs between treatments (e.g. 100 versus 1000), the number of mummies should be larger in the treatment with

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[2] Results of this analysis should be viewed with caution. In this analysis, each plant is viewed as an independent sample of the effect of background vegetation. However, the treatment (background vegetation) was applied to the *entire* block, therefore the assumption of independence may not be valid.

more aphids (e.g. 1000 x 20% = 200) than the treatment with fewer aphids (e.g. 100 x 20% = 20). This observation indicates that background vegetation did not alter the interaction between herbivore and parasitoid populations, rather another process, such as increased immigration rate, resulted in larger populations of adult parasitoids. However, this is a very tentative conclusion as neither number of parasitoids nor parasitism rate were measured directly.

It is more likely that the reduction in aphid number is attributable to the presence of predators, such as ladybugs. At the single census taken in plot 1 at RD, treatments with arugula as background vegetation (Br and BrCn) had dramatically higher ladybug populations (Table 5). This circumstantial evidence is consistent with the enemies hypothesis. Arugula treatments were flowering at the time of the census, providing nectar and pollen resources for the adult ladybugs. The large number of ladybugs observed on arugula plants relative to on broccoli plants (Table 5) further supports the enemies hypothesis. The increased ladybug population coincides with the large drop in aphid numbers between the third and fourth sampling points (Figure 4). However, in treatments with background clover vegetation, the distribution of ladybugs in the field cannot be correlated with the lower aphid abundance observed. The extent to which the enemies hypothesis explains these results is limited by the observation that aphid abundance was lowest in the homogeneous clover treatment which had an intermediate population of ladybugs.

When compared in land area equivalents, total combined yield achieved in an intercrop system is often greater than yields achieved when component crops are grown as monocrops (see Vandemeer, 1989). This is an important concept when considering the advantages to increasing system diversity with the intent of reducing pest numbers. Each component crop must have economic yield value if the overall benefits of intercropping are to be realized above potential plant-plant competition (e.g. Dempster, 1969; Dempster and Coaker, 1974; Altieri et al., 1985; Theunissen et al, 1995). The experiments reported in this paper were conducted during the late summer when plants often experience water stress. Therefore, it is likely that broccoli plants grown during this period would show the greatest competitive interaction between the main crop and the undersown vegetation, a scenario for which the benefits of intercropping are least likely to be realized. Reduced yields were not observed for treatments with a homogeneous background of added vegetation (Br and Cv). Yield for treatments with heterogeneous vegetative background consisting of arugula (BrCn) was intermediate to yields of Br and Cn treatments. Because the heterogeneous treatments were divided into two halves (clean or background vegetation) instead of a less dense or random application of the treatment, the intermediate brassica result (for the heterogeneous arugula treatment) may indicate an additive model for the impact arugula has (OR may indicate arugula has an additive influence) on overall yield. Conversely, the heterogeneous background with clover (CvCn) exhibited the lowest yield of all (Figure 5), suggesting clover has a non-additive competitive effect when planted with broccoli. The large yield reduction in the CvCn treatment for RD block 1, is qualitatively supported by the pattern of overall aphid abundance (Figure 3). The pattern of reduced aphid abundance with no measurable decrease in yield for treatments with an arugula background is a tentative indication that arugula may be intercropped with broccoli as a control strategy.

Although aphid numbers were reduced for arugula treatments, only a small overall gain in broccoli yield was associated with this reduction (relative to treatments with other plant associations). Small increases in yield such as observed here may not justify additional costs that might be associated with using a particular background vegetation as a control strategy. In this experiment, arugula was seeded at a relatively high density, two rows between each broccoli row with a 6 inch within row spacing. Seed and labor costs are relatively high at the rates planted for this experiment ($16 for seed plus 1 hour labor to plant per block), and since a market for large harvests of arugula does not exist (J. McIntyre, pers. comm.) it is likely to remain a minor secondary crop. For intercropping to be an economically viable control strategy, a lower density of arugula plants would need to be planted with the same control effectiveness or another low-cost or economically profitable plant would need to be substituted in the system.

One potential way to reduce the costs and competitive effects of undersowing (or intercropping) is to undersow in strips across the field instead of over the entire field. This technique of establishing ecological compensation areas is being used in Switzerland (Nentwig, et al., 1998; Wratten, et al., 1998). The establishment of heterogeneous background vegetation is a similar technique that needs to be explored. Arugula as background vegetation appears to offer a level of protection extending beyond the area in which it is planted. The mean number of aphids per plant was not different between the homogeneous and heterogeneous arugula treatments with differences in yield being minor. This pattern of aphid abundance is consistent across farms and within each plot. Similarly, clover had no affect on aphid abundance, although the heterogeneous treatment with clover (CvCn) at RD block 1 had the lowest overall yield, suggesting a possible negative, non-additive effect on yield. Aggregate lepidopteran abundance was not affected by any treatment, except (CvCn treatments in) block 1 at RD). In this singular case, both heterogeneous treatments exhibited dramatic decreases in overall abundance compared to any homogeneous background treatment. The particular composition of these strips and their arrangement within the field merits further investigation (see Banks, 1998 for a thorough discussion of how scale and heterogeneity interact to influence insect abundance and behavior in weedy culture[3]).

One goal of these experiments was to determine if arugula could serve as an effective trap crop, luring specialist herbivores (especially flea beetles) away from the broccoli crop with out attracting additional pests into the crop. The resource concentration hypothesis would predict that by adding a con-specific to the field there would be an overall increase in specialist pests as a result of the larger, more concentrated resource. Due to the extremely low abundance of flea beetles during the experiment, no conclusions can be drawn. However, aphids, which are generalist herbivores, should have increased in abundance in all treatments with additional vegetation in accordance with the resource concentration hypothesis (Andow, 1991). The decrease in aphid abundance and the associated increase in ladybug abundance on plants with undersown vegetation suggest the enemies hypothesis may better explain the results of these experiments. Without knowing rates of immigration and emigration for the predators and the herbivores and actual predation rates, a definitive conclusion cannot be reached.

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[3] Weedy culture is another term used when native vegetation or weeds are allowed to grow within the field.

Table 1. Planting and sampling dates for each farm and plot.

	RD		**Puy**	
	Plot 1	**Plot 2**	**Plot 1**	**Plot 2**
Clover sown	**7/13/01**	**7/26/01**	**6/1/01**	**6/1/01**
Arugula seeded	**7/13/01**	**7/28/01**	**6/9/01**	**6/9/01**
Broccoli Transplanted	**7/12/01**	**7/26/01**	**7/17/01**	**7/19/01**
Sample 1	**7/21/01**	**8/1/01**	**8/23/01**	**8/23/01**
Sample 2	**8/15/01**	**8/15/01**	**9/15/01**	**9/15/01**
Sample 3	**8/24/01**	**9/14/01**	**9/22/01**	**9/22/01**
Sample 4	**9/4/01**	**x**	**x**	**x**
Harvest dates	**9/8, 9/11, 9/14**	**9/21, 9/25, 9/28**		

Table 2. Establishment of crop plants and background vegetation.

	RD		Puy	
	Plot 1	Plot 2	Plot 1	Plot 2
Crop Establishment	Good growth, but some water stress.	Excellent	Moderate growth due to heat and water stress.	Moderate growth due to heat and water stress.
Arugula Establishment	Excellent growth, choked out weeds by mid experiment.	No plants established nor background vegetation, experimental plots abandoned.	Moderate growth, bolted due to heat and water stress. Significant amounts of *Equisetum arvense* (L.).	Poor growth, bolted due to heat and water stress. Significant amounts of *Equisetum arvense* (L.).
Clover Establishment	Moderate levels of cover by late season, but significant amount of background weeds.	No plants established, consisted entirely of background weeds.	Good, choked out most weeds by mid experiment.	Patchy growth and cover, dominated by background weeds.
Dominant Weeds Present	Chenopodium album (L.) and Polygonum lapathifolium (L.).		Equisetum arvense (L.), with lesser amounts of Chenopodium album (L.) and Polygonum lapathifolium (L.).	
Supplemental Irrigation	None.		Sporadic during weeks 2 though 5.	

Table 3. Nested ANOVA results for mean aphid number per plant (log (x+1)). Hypothesis test is for the treatment effect using the treatment by block (referred to as plot in the table) with in farms MES (Mean Error Square).

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Number of Aphids per Plant   Multiple R: 0.658   Squared multiple R: 0.433


                             Analysis of Variance

Source             Sum-of-Squares   df  Mean-Square     F-ratio       P

FARM                    117.449     1      117.449      66.463       0.000
Treatment                63.433     4       15.858       8.974       0.000
PLOT(FARM)               46.841     2       23.420      13.253       0.000
Treatment*PLOT(FARM)     18.947     8        2.368       1.340       0.223

Error                    480.655   272        1.767


Test of Hypothesis

       Source       SS         df        MS             F             P

  Hypothesis       63.433     4       15.858          6.696          0.011
  Error            18.947     8        2.368
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Table 4. Mean and Standard Error of the Mean (SEM) of aphid numbers (log(x+1)) per plant, by farm, block and treatment. See Figure 1 for designation of treatment categories.

Farm	**Puy**				**RD**			
Block	**1**		**2**		**1**		**2**	
Treatment	**Mean**	**SEM**	**Mean**	**SEM**	**Mean**	**SEM**	**Mean**	**SEM**
Br	**1.803**	**0.332**	**1.972**	**0.332**	**4.265**	**0.332**	**X**	**X**
BrCn	**1.421**	**0.332**	**2.308**	**0.332**	**4.171**	**0.332**	**X**	**X**
Cn	**2.296**	**0.303**	**3.357**	**0.303**	**5.076**	**0.303**	**3.705**	**0.303**
CvCn	**1.263**	**0.303**	**2.743**	**0.303**	**4.059**	**0.303**	**3.075**	**0.303**
Cv	**1.645**	**0.303**	**1.251**	**0.303**	**3.609**	**0.303**	**2.415**	**0.303**

Table 5. Observed frequencies of ladybugs in RD plot 1 by treatment and location for (a) all locations and (b) when arugula and weeds are classified as non-crop.

a.

	Arg	Crop	Ground	Other	Weed	Totals
Br	20	1	0	0	4	25
BrCn	4	4	0	0	12	20
Cn	0	5	0	0	4	9
Cv	0	6	1	1	7	15
CvCn	0	2	0	0	6	8
Totals	24	18	1	1	33	77

b.

	Crop	Ground	Non Crop	Other	Totals
Br	1	0	24	0	25
BrCn	4	0	16	0	20
Cn	5	0	4	0	9
Cv	6	1	7	1	15
CvCn	2	0	6	0	8
Totals	18	1	57	1	77

Table 6. ANOVA table for yield weight of individual broccoli heads at RD, plot 1 and a priori contrasts for treatments versus clean treatment. See Figure 1 for description of treatment codes.

Source	**Sum-of-Squares**	**df**	**Mean-Square**	**F**	**P**
Treatment	0.137	4	0.034	2.139	0.092
Error	0.688	43	0.016		

Treatment	**Mean log(x+1) difference**	**P value for Fisher's LSD**
Br	0.092	0.112
BrCn	0.040	0.495
CvCn	-0.158	0.010
Cv	-0.100	0.064

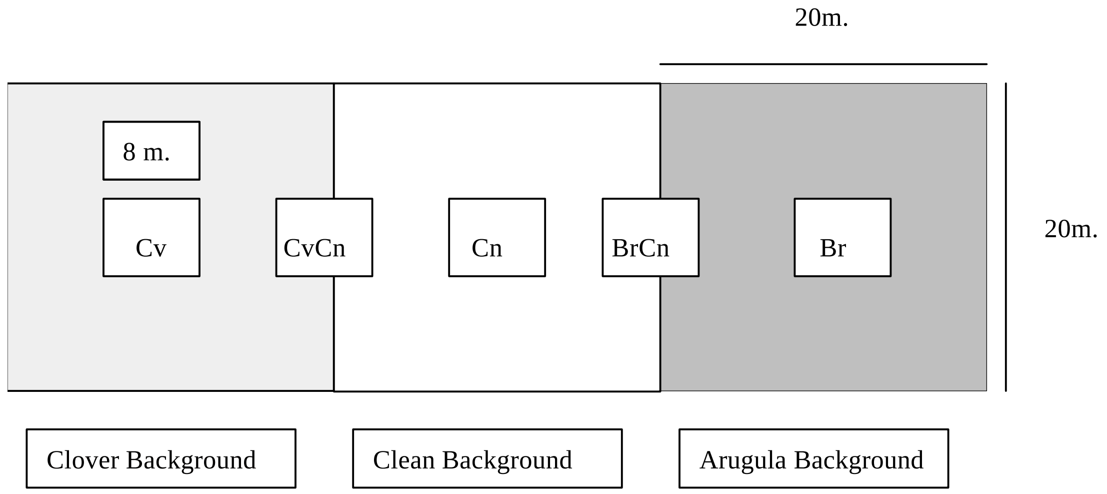


Figure 1. Schematic of how treatments within plot was arranged; with background (i.e. clover, clean or arugula) as a whole plot and treatments are split plots within the whole plots. Treatments are designated by the background vegetation as Cv: clover, CvCn: clover and clean, Cn: clean, BrCn: arugula and clean, and Br: arugula. Plants sampled for insects and yield were randomly selected within the split-plot treatments (see Methods)

Figure 2.

Mean value of covercrop vegetation by farm, block, and sample number. Solid lines represent total cover, long dashes represent arugula cover and short dashes represent clover cover. Total cover is a measure of all plant material, inlcuding weeds, crop, and background vegetation. See text for definitions of cover classes.

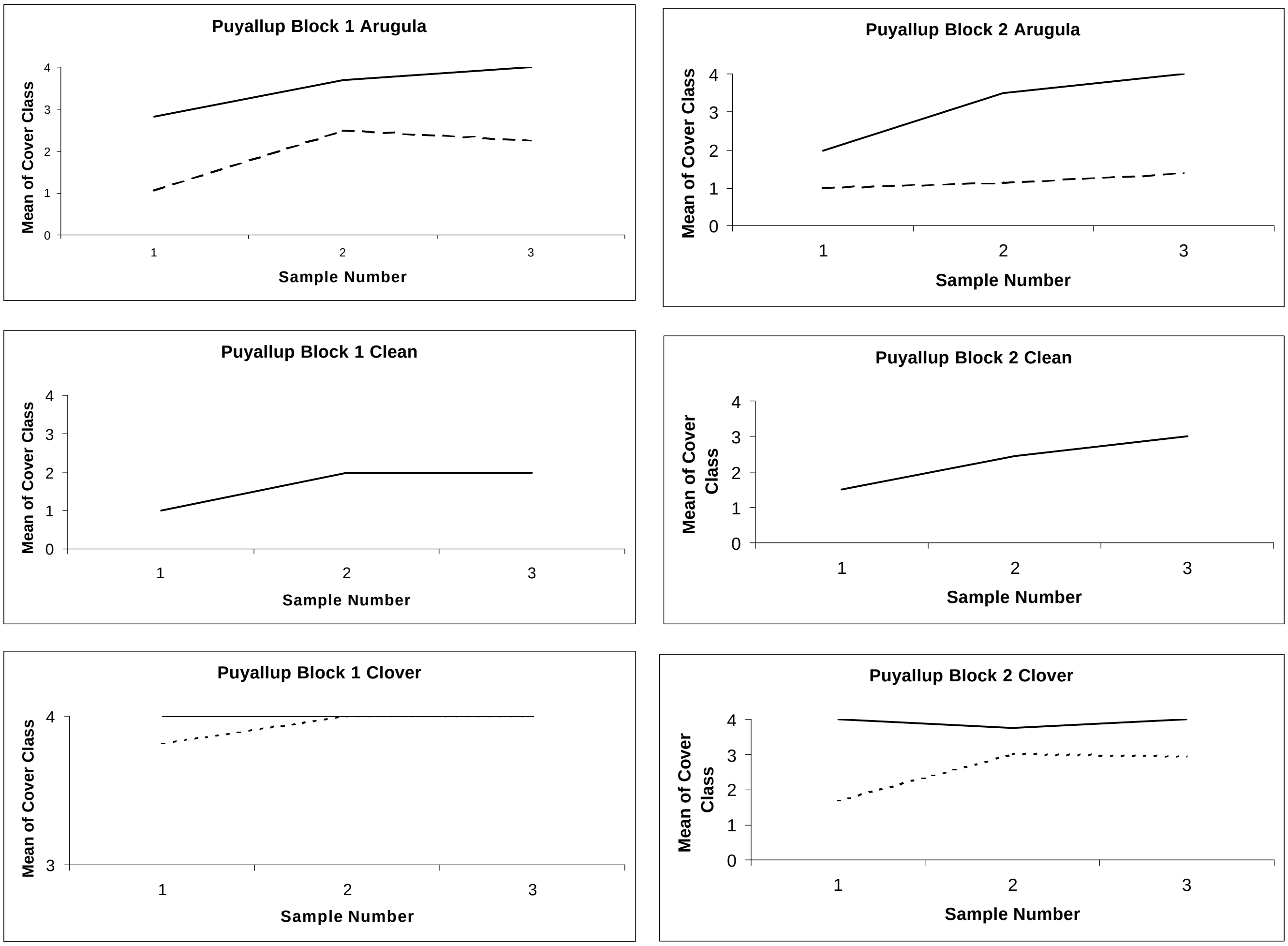
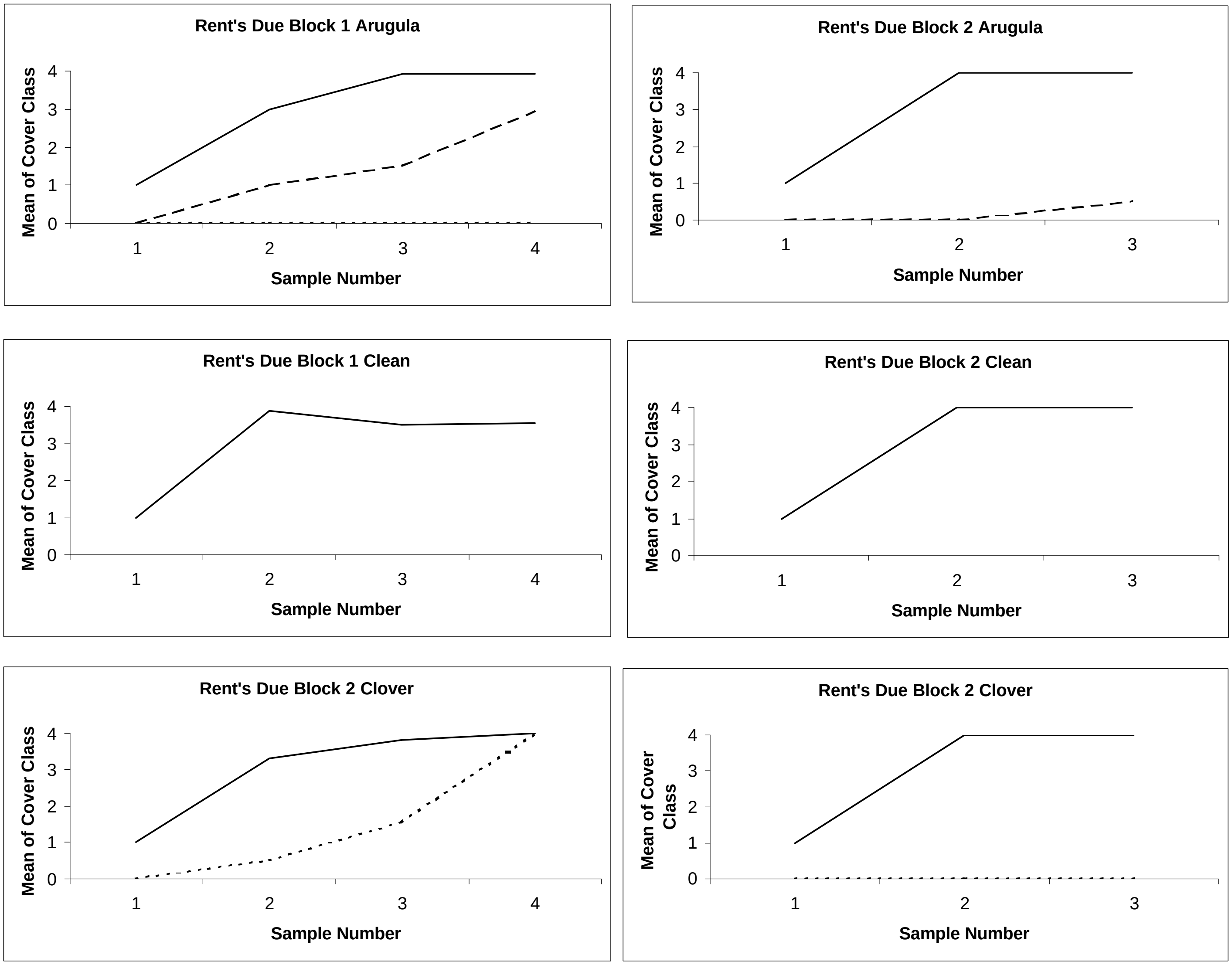


Figure 2, cont'd.



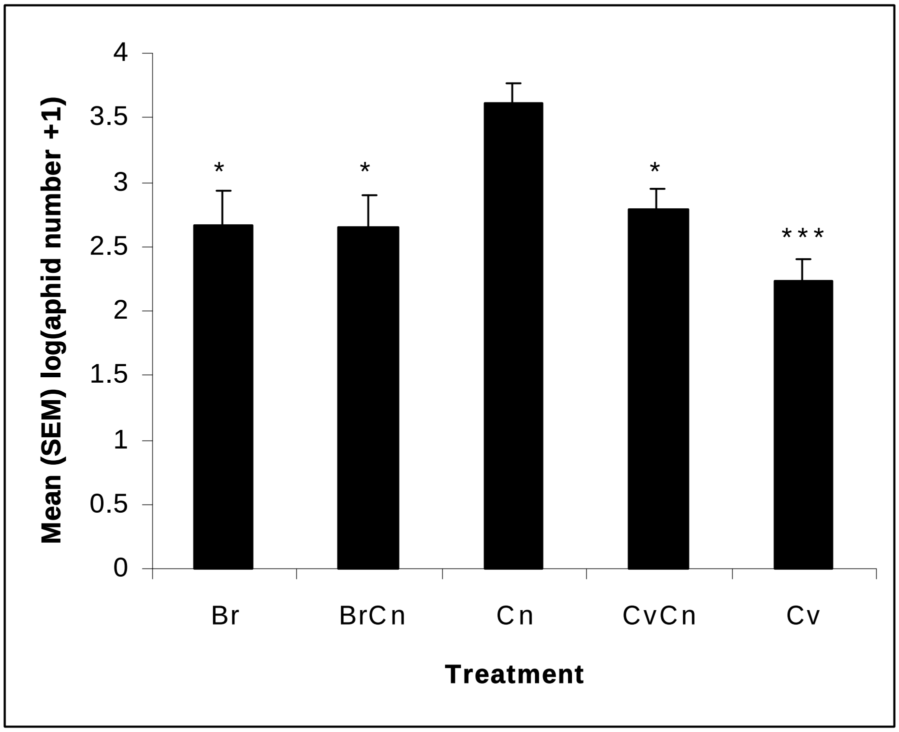


Figure 3. Mean (+1 SEM) aphid number per plant (log(x+1)) averaged across all farms. See Figure 1 for designation of treatment categories. Treatments with an * are significantly different from the control group (Cn) at p<0.05, those with * at the p<0.001 by Fisher's least significant difference.**

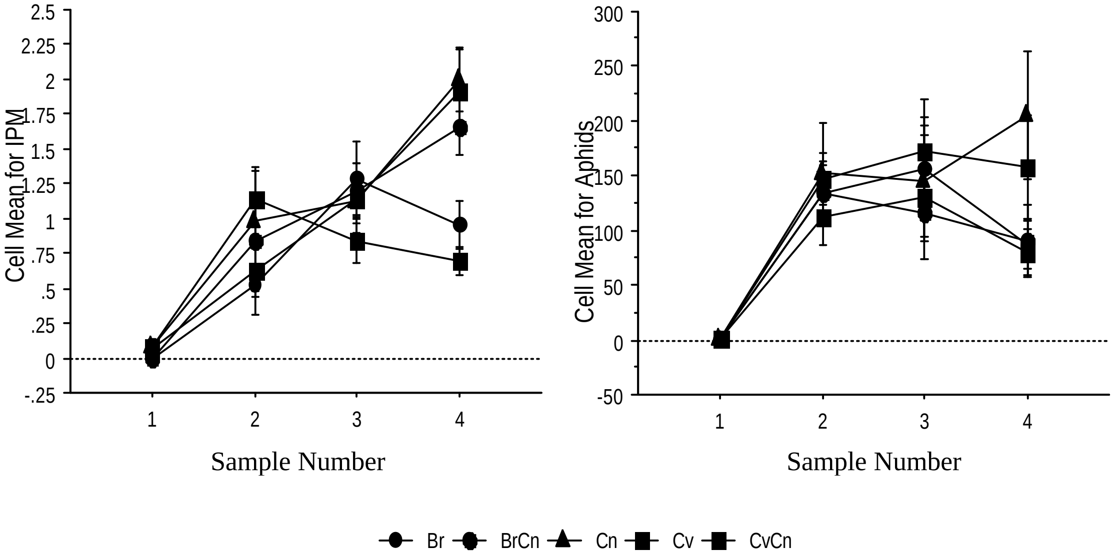


Figure 4. Mean insect numbers per plant at RD plot 1. See Figure 1 for treatment classifications.

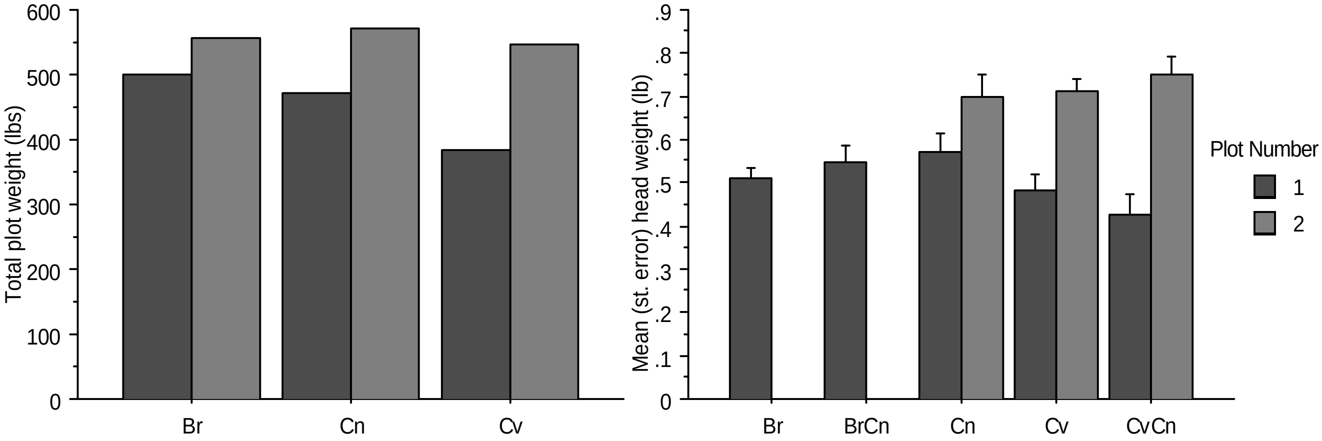


Figure 5. Yield data for RD by plot by overall background vegetation and treatment.

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