FINAL REPORT TO THE ORGANIC FARMING RESEARCH FOUNDATION:
Two Year Activities and Results
"Enhancing Biological Control of Insect Pests Using Flowering Intercrops in Wine Grape Agroecosystems"

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PROJECT SUMMARY

The purpose of this ongoing project is to provide a thorough scientific evaluation of on-farm habitat management strategies in order to develop cost-effective biological control options for managing important arthropod pests of California vineyards. Working collaboratively with ten commercial growers (see list above) from 2008-2009, the project served to evaluate the impact of the conservation biological control strategy of Floral Resource Provisioning (FRP) via several flowering plants on soil quality and population dynamics of *Erythroneura* leafhoppers (Homoptera: Cicadellidae) and *Planococcus* mealybugs (Homoptera: Pseudococcidae) in key California wine producing regions. The project measured the impact of intercropping with five flowering plant species, including Annual Buckwheat (*Fagopyrum esculentum*), 'Lacy Phacelia' (*Phacelia tanacetifolia*), 'Sweet Alyssum' (*Lobularia maritima*), 'Bishops Weed' (*Ammi majus),* and 'Wild Carrot' (*Daucus carota*) on the enhancement of biological control of leafhoppers and vine mealy bugs in Napa, Sonoma, and Fresno County vineyards. The research project was designed to contribute scientific data for use in developing new ecologically based pest management strategies that meet or exceed USDA national standards (USDA NOP) for certified organic production.

In 2008 and 2009, we compared insect population and soil parameters (2008) between selected vineyard blocks under agroecological management and under normal farmers management (FM). Erratic fall/winter rains and wet spring conditions negatively affected cover crop treatment establishment in 2008. At most research sites, the cool and wet spring conditions in both 2008 and 2009 resulted in low overall pest densities. In 2008, population densities were extremely low, thus isolating a treatment effect was difficult. Nevertheless in vineyards where flowering plants established a reasonable cover that year, leafhopper reductions were apparent in treatment plots. Despite such environmental conditions and setbacks in 2008, the study produced the following results: 1. in 2009, peak leafhopper nymph densities were found to be significantly lower (when compared to control plots) when there was good treatment establishment and high overall leafhopper pressure at the site; 2. no significant differences were found in early-season *Anagrus sp.* (a key biological control agent) density when comparing treatment and control plots; 3. where assessed, no significant difference in leafhopper egg parasitism rates were observed between treatment and control plots; 4. significantly higher abundance and diversity of arthropod natural enemies (especially predators) were found in all treatment plots in 2008 and 2009; 5. the diversity and abundance of arthropod natural enemies varied in treatment plots over each growing season; 6. laboratory and field studies showed enhanced longevity of *Anagyrus psuedococci* (biocontrol agent of vine mealybug) under controlled conditions and enhanced rates of parasitism/mortality in the field with FRP compared to control. Although the findings of the study support the hypothesis that incorporating flowering cover crops in vineyards can support diverse and abundant populations of natural enemies and contribute to the regulation of arthropod pests and the maintenance of soil fertility, additional research is necessary. Ongoing research in the 2010 season (data still being analyzed) will provide additional longer-term

data on the effects of various types of flowering species in multiple sites on the biological control of grapevine pests.

INTRODUCTION

Pest management in wine grape production frequently depends upon the use of synthetic chemical control strategies. Many of the commonly used insecticides are known to have significant and negative environmental quality and human health risks. In addition, the long-term viability of pesticide use is uncertain due to decreased pesticide effectiveness resulting from the development of genetic resistance to pesticides by arthropod pests, increasing pesticide costs for growers, and an increasingly restrictive regulatory environment. To systemically address these pressing social and environmental issues, new approaches to pest management must be continuously tested and developed.

The project (outlined below) was developed in response to the expressed interest of California growers for new ecologically based pest management strategies for wine grapes, many of which are responding to increased consumer demand for wines made from organically grown grapes. Building upon prior research in conservation biological control, this project has been the first comprehensive study of the effects of annual flowering intercrops in multiple sites in Napa and Sonoma County wine grapes.

OBJECTIVES STATEMENT:

In 2008, the Agroecology Research Group at the University of California Berkeley initiated a two-year participatory and on-farm research and extension project involving 10 vineyards and nine separate research sites in Napa and Sonoma County. The project involved three (3) Certified Organic, two (2) Certified Biodynamic, and two (2) IPM-managed/integrated production systems of multiple scales within a wide diversity of growing environments. The project was designed assess the effectiveness of specific agroecological management strategies, including treatments of non-crop vegetation (e.g., winter and summer cover crops) on soil quality improvement and the enhancement of functional biodiversity for insect pest suppression in California vineyards. The objective of the research was to further define the key ecological design components (e.g., landscape structure, species composition, management inputs, and timing) that serve to successfully stimulate soil biological activity, enhance and sustain soil quality, and sponsor cost-effective biological control of key wine grape pests.

The study intended to provide detailed qualitative and quantitative assessments of the specific ecosystem management practices responsible for the internal regulation of important arthropod pests and the maintenance of soil fertility without the use of synthetically compounded materials and a minimum of externally derived OMRI-listed pest control inputs. Knowledge derived from this research will provide the scientific basis for the widespread adoption of agroecological management practices consistent with the highest standards of Certified Organic and Biodynamic production. Extensive grower involvement was organized throughout the development, implementation, assessment, and outreach components of the project. Results derived from the study will be published in industry periodicals and newsletters most commonly read by wine grape producers. A manual of agroecological vineyard diversification will be produced along with informational brochures and a website to assure the widespread distribution and accessibility of the findings. The three-year goal of the proposed research is to test this suite of agroecological viticulture practices in a wide range of grape varietals and within a diversity of growing conditions throughout Napa and Sonoma Counties. By 2011, our aim is to have a minimum of one hundred California vineyards experimenting with or fully adopting these strategies. With the supporting scientific data and comparative cost-benefit analyses, our objective is to encourage the collaborative promotion of these counties through various regional producer organizations as *the* premiere region for agroecological fine wine production. Once fully tested, these agroecological production strategies may be effectively adapted to other wine-producing regions, nationally and internationally.

Changes in objectives as the project unfolded. With additional funding from The California Department of Food and Agriculture (CDFA) in 2009, we added a fully replicated research site at the UC Kearney Agriculture Research Center in Fresno County. The addition of this research site allowed researchers to study the impact of FRP on biological control of vine mealybug and to conduct a series of related laboratory and mechanistic studies to measure the ecological processes theorized to be enhanced through FRP. In 2010, the research project expanded further to include a fully replicated research design in Lodi, California.

MATERIALS AND METHODS

Treatment establishment: Experimental treatments were established each fall and spring by participating growers. The flowering species tested included 'Annual Buckwheat' (*Fagopyrum esculentum*), 'Lacy Phacelia' (*Phacelia tanacetifolia*), 'Sweet Alyssum' (*Lobularia maritima*), 'Bishops Weed' (*Ammi majus),* and 'Wild Carrot' (*Daucus carota*) (see Appendix, photos 1-4).

Plot design: In 2008 we established split-block Grower Trials (GT) in 8 vineyards (see Figure 1 for an example plot design in farmers' fields). In 2009, in addition to the 10 Grower Trials designed to provide outreach and assess the effects of flowers in farmers' conditions compared to their normal management, the research project included one Primary Research Block (PRB). PRB are replicated experiments designed to test four floral resource provisioning (FRP) plant species that bloom in an overlapping sequence (see Figure 2a and b for the replicated experimental design). The PRB, located at the UC Kearney Agricultural Center (KAC), consisted of a fully replicated randomized block design and similar sampling methodologies to those used in the Grower Trial plots. In the GT trials in Napa and Sonoma County we used on-farm research techniques to evaluate whole-farm trials, utilizing a split-block design at each site, having each function as a single treatment replicate. Due to the geographic distribution of pest species, monitoring at the GT sites in Napa and Sonoma County focused exclusively on assessing densities of *Erythroneura elegantula*, *Anagrus* wasps, and generalist predator species. At the KAC site we evaluated the impact of FRP on population densities of vine mealybug and *Erythroneura* leafhoppers and their key generalist and specific natural enemies, *Anagyrus* *pseudococci* and *Anagrus sp*., respectively. Sites were selected for their uniform cultivar and rootstock combinations, vine age, soil and fertilization conditions, irrigation infrastructure, and pest management history. FRP plant species were selected based on their ability to influence pest densities or enhance the longevity, fecundity, or sex ratios of parasitoids in previous studies (Begum et al. 2006; Berndt et al. 2006; English-Loeb et al. 2003; Irvin et al. 2007; Lee and Heimpel 2008; Nicholls et al. 2000; Winkler et al. 2006).

Sampling:
All sampling was conducted from April 15 – October 1 (2008-2009) using standard methods developed for *Erythroneura* leafhoppers and *Planococcus* mealybug and their key natural enemies (Daane and Costello 1998; Costello and Daane 2003; Nicholls et al. 2004; Walton et al. 2006; Daane et al. 2004, 2006, 2007; UC IPM 2008).

Monitoring of both the GT sites and the PRB occurred every 15 days and consisted of the following assessments:

1. To measure the relative population densities of insect fauna in ground covers and control plots, five 30-sweep sweep net samples were conducted in each experimental plot every 15 days.
2. 5 yellow sticky traps were placed on vines selected at random within the sampling universe of each treatment and control plot to estimate densities of adult leafhoppers and to assess population densities of generalist and specific predators and parasitoids (Nicholls et al. 2000).
3. To assess densities of non-flying arthropods in the vine canopy, samples were conducted using the canopy shaking method following protocols outlined by Costello and Daane (2003).
4. Following methods described by Costello and Daane (2003) and Nicholls et al. (2004), 60 vine leaves were examined in each experimental plot every 15 days to determine the density of leafhopper nymphs.
5. To assess rates of parasitism of leafhoppers by *Anagrus* spp., 60 individual grape leaves were collected from each plot after the emergence of the first or second brood of adult leafhoppers and examined under a dissecting microscope for the presence of parasitized or healthy leafhopper eggs following Daane and Costello (1998) and Nicholls et al. (2004).

Monitoring of the PRB also included the following:

6. To calculate the influence of FRP treatments on vine nutrient status and vine vigor, petiole nitrogen and cane biomass samples were taken each year following protocols outlined by Costello and Daane (2003).
7. Measurements of the relative densities of vine mealybugs were conducted 3 times/season using 1-minute categorical ratings (July and September) and one cluster damage rating at harvest time (August/September) following protocols outlined by Daane et al. (2006).
8. Measurements of the influence of FRP on parasitism rates of vine mealybugs by *Anagyrus pseudococci*, was conducted following protocols outlined by Daane et al (2004).

In a controlled laboratory setting:

9. Measurement of the impact of FRP on the longevity of *Anagrus spp.* and the longevity, fecundity, and sex ratios of *Anagyrus pseudococci* was conducted using protocols outlined by English-Loeb et al. 2003, Irvin et al. 2007, Jervis et al. (2004), Lee and Heimpel (2008), Vattala et al. (2006), and Winkler et al. (2006).

Statistical analysis. All sampling data taken to evaluate seasonal changes in pest and beneficial population densities are being analyzed through repeated measures ANOVA. All annual sampling data taken to analyze single sample occurrences will be calculated using a linear regression model ANOVA. Data will be transformed for any abnormalities.

PROJECT RESULTS

Introduction

Most growers informed us that the 2008 growing season was marked by very unusual weather – low winter rainfalls, early frosts and cool spring temperatures are all thought to have contributed to reduced or delayed vine development and lower overall pest densities. This resulted in a number of field trials in which pest and natural enemy densities were so low that they could not be meaningfully compared. Weather in the 2009 growing season followed more typical patterns and insect densities were high enough to provide useful comparisons of pest and natural enemy populations between treatment and control plots.

Data collection in 2008 was further limited by growers' inexperience with establishing and managing flowering ground covers in their vineyards. For many growers, this was their first time sowing these flowers in a vineyard. This resulted in a number of participating vineyards with poorly established stands of flowering ground covers and subsequently reduced the total number of field sites with a functional treatment to monitor over the growing season. A total of 8 split-block trials were planned; out of these, only 4 established well enough to constitute a flowering ground cover treatment. While this was detrimental to certain research objectives, both growers and researchers gained valuable knowledge about the use of flowering ground covers in vineyards.

The Public Field Days and Grower Cross-Visits held throughout this project helped to facilitate grower exchange of information about the use of flowering ground covers in vineyards. For instance, those growers that successfully established the flowers in the 2008 season were able to provide other participants with information about their practices (e.g., timing of sowing, seed rates, equipment used). As a result, growers had a much higher rate of successful treatment establishment in 2009. Our research group continues to hold these outreach and extension events every year as part of our ongoing work with growers to better develop and refine the use of flowering ground covers in vineyards.

2008 Season Results

Leafhopper nymphs

In the 2008 growing season, leafhopper densities were unusually low in most vineyards, reaching less than 2 nymphs per leaf which is far below normal pest thresholds (the recommended treatment threshold for grape leafhoppers is 20 nymphs/leaf [UC IPM 2008]). Given these low numbers, it was not possible to detect significant differences on nymphal densities between agroecological and farmer management blocks.

Figure 3 shows the seasonal means of grape leafhopper nymphs in all 8 agroecological and farmer management (control) vineyard plots, highlighting those 4 blocks in which flowering cover crops were successfully established. All other blocks exhibited erratic germination or late establishment of the flowers. As seen in Figure 3, in most vineyards seasonal densities were exceptionally low and rarely reached above 0.5 nymphs per leaf. Although differences are not statistically significant, the trends suggest that nymphal densities in agroecological blocks were lower (but not significantly) in three vineyards and in the other four reached greater numbers than in the farmer's management blocks. In the vineyards where this latter trend was observed, leafhopper abundance was low in control plots because farmers sprayed either chemical pesticides (Wappo Ranch) or organically allowed pesticides such as Pyganic (Robert Sinskey and Quintessa). This highlights the fact that agroecological treatments were successful in maintaining low numbers of leafhopper nymphs (far below the economic threshold) comparable to those reached in conventionally sprayed vineyards (Figure 4) and to those sprayed with organic products (Figure 5).

Natural enemies in the vine canopy

Such regulation in the agroecological blocks may be attributed in part to the early colonization and abundance of spiders and other predators in the blocks diversified with flowering cover crops. In five out of 8 vineyards we found higher numbers of predators per sticky trap in the plots with flowers than in the monocultures void of cover crops (Figure 6).

Natural enemies on the ground covers

At one site (Quintessa), flowering summer ground covers were found to attract a greater overall diversity and abundance of generalist predators than the resident vegetation (overwintering cover crops and spring-summer weeds) found in the control plots (Figures 7a and 7b). Many of these predators readily moved from the flowers to the vines.

Early-season* Anagrus *densities and Leafhopper egg parasitism rate

In 2008, there were no significant differences in early season *Anagrus* densities (coinciding with peak 1st generation leafhopper oviposition) at all sites regardless of treatment. A parasitism study was conducted at one of the field sites with a well-established treatment (Quintessa). There was no difference in leafhopper egg parasitism by *Anagrus* wasps between the treatment and control plots (Table 1).

Table 1. Leafhopper egg parasitism rate (Quintessa, 2008)

Treatment	Control
24%	21%

Soil Quality

After we applied the methodology developed by Nicholls et al. (2004) to assess soil quality in July 2008, we built amoeba graphs to display soil quality indicators which allowed us to compare on each farm the soil quality indicators in the agroecological block and in the adjacent block under farmer's management (control). In the case of Oakville Ranch, an organic vineyard, it can be observed that the agroecological block exhibited higher values in most indicators than the FM block (Figure 8). Similar trends could be observed in the biodynamic vineyard Quintessa where the agroecological treatments seem to exert fast and substantial effects in improving soil structure, biological activity, compaction, and amounts of organic residues (Figure 9). Winter cover crops and flowering treatments also rapidly improved soil quality indicators at Wappo (conventional farm). At this site, the FM block clearly requires improvements in soil cover and in other edaphic conditions to optimize root development and activate soil biological activity (Figure 10).

As observed in Figure 11, which exhibits the mean soil quality indicators for all surveyed farms, with the exception of Saintsbury (a conventional farm), seven out of eight agroecological blocks exhibited higher soil quality values than the blocks under farmer's management, suggesting that winter and flowering cover crops enhance soil quality to levels above the threshold value of 5 (except for Quintessa and Sainstbury).

2009 Season Results

Grower Trials (Napa and Sonoma County)

Leafhopper nymph densities

In the 2009 Grower Trials, leafhopper nymph densities were found to be lower in 6 of 7 blocks with the flowering ground cover plots (when compared to farmer management/control), and these differences were especially noticeable at three separate research sites where pest densities reached greater than 2 nymphs per leaf (Figure 12).

Early-season **Anagrus** *densities*

At two sites, early season Anagrus densities were higher in the diversified plots, but in the other 5 sites there were no significant differences in early season *Anagrus* densities coinciding with peak 1st generation leafhopper oviposition (Figure 13).

Natural enemies on the ground covers

At two sites, sweep netting of the flowering covers showed that the flowering plant treatments attracted a great diversity of generalist predators reaching substantial abundandance levels when compared to resident vegetation. The predator species guilds changed with the phenology of flowers as the season progressed (Figures 14a, 14b, and 15).

Natural enemies in the vine canopy

As shown in Figure 16, in four of seven vineyards many predators reached higher densities on the canopy in blocks with flowers than in control plots. These predators detected in the vine canopy of the treatment plots were also found in the flowers, suggesting that these arthropods move from the covers to the vines.

Primary Research Block (KAC)

Leafhopper nymph densities

In 2009, overall leafhopper densities were very low and therefore no differences were detected between treatments.

Vine mealybug parasitism

Mealybug parasitism by *Anagyrus pseudococci* was found to be higher in the flowering treatment plots than in the control monoculture plot (Figure 17). Laboratory tests revealed that *Ammi majus* and *Fagopyrum esculentum* extended the longevity of *A. pseudococci* relative to other flowers and the control (water) (Figure 18).

Spiders in the vine canopy

Spider abundance in the vine canopy increased over the growing season in the flowering treatment plots when compared to control plots (Figure 19)

CONCLUSIONS AND DISCUSSION

The addition of flowering ground covers to vineyard plots did not produce a consistent trend in pest densities over the course of this two-year study. Apparently these effects were associated with erratic weather patterns which led to poor establishment of flowering cover crops in many of the sites. In 2008, leafhopper nymph densities were lower only in plots where flowering ground covers were well established, while in 2009 all flowering ground cover plots were found to have *lower* nymph densities than control plots. At research sites with the highest pest pressure and good treatment establishment, there appears to be a significant treatment effect.

Early season abundance of *Anagrus* wasps did not appear to be influenced by FRP. Our data indicate that the *Anagrus* population is most likely influenced by leafhopper abundance itself, suggesting a density-dependent relationship which has been previously suggested by other researchers (Wackers et al. 2005).

Flowering ground cover treatments did attract and retain a significantly greater diversity and abundance of generalist natural enemies over the course of both growing seasons. Clearly these predators move from the covers to the vines impacting early and mid season leafhopper abundance. More detailed analysis of this data should reveal species specific relationships (e.g., *Orius* predominantly found on *D. carota* but rarely on *P. tanacetifolia*) and how these could be further manipulated to increase biological control. Late-season adult leafhoppers, which can interfere with harvest activities as a nuisance pest, were not significantly influenced by FRP over the two-year study.

Unusually low insect pest abundance observed in both years of the study along with poor or inconsistent treatment establishment in multiple vineyards limited the amount of useful data obtained through this project. Consistently lower leafhopper densities were observed in all cases where flowering ground covers were established at research sites with high overall leafhopper pressure. However the lack of a consistent response across all research plots suggests the need for both longer-term replicated research and a range of mechanistic studies to substantiate the causes of observed changes in pest population densities. In addition, recently published studies in the conservation biological control literature suggest that the non-crop vegetation surrounding vineyards and other cropping systems may influence the effects of FRP at the field scale. Such landscape level analyses have been integrated into our research during the 2010 and 2011 growing seasons.

The data obtained from this project provides some level of confidence on the use of flowering ground covers in vineyards to enhance biological control. Perhaps more importantly, the project allowed researchers to establish the foundation (e.g. increase grower contacts, interest and participation, FRP species selection, increased knowledge of treatment implementation and management) for more comprehensive studies of FRP in vineyards. Appendix I depicts the treatment establishment guidelines for farmers interested in incorporating flowers into their vineyards, with practical recommendations on seeding rates, planting times, spatial distribution in the field, etc.

Ongoing and future research on the impact of FRP for biological control in California wine grapes.

Building upon this OFRF-funded research as well as prior field- and landscape-scale studies in conservation biological control in vineyards (Begum et al. 2006; Berndt et al. 2002, 2006; Daane and Costello 1998, 2003; English-Loeb et al. 2003; Hanna et al. 1996; Ingels et al. 1998; Irvin et al. 2007; Nicholls et al. 2000), our research group has recently initiated the first comprehensive, multi-scale study of the impact of floral resource provisioning (FRP) and landscape diversity in Napa, Sonoma, San Joaquin, and Fresno County wine grape systems. The project will assess both influence of field and landscape level heterogeneity and the role of chemical ecology (e.g. pheromones) on enhancing biological control in vineyards.

OUTREACH

An important component of this 2-year study was the outreach and extension efforts. Throughout the duration of this OFRF project, Public Field Days and Grower Cross-Visits played a central role in educating both growers and researchers on the use of flowering ground covers in North Coast vineyards. This project has led to the development of a grower network that continues to collaborate with researchers to develop and refine the use of flowering ground covers in vineyards. Grower input has led to improved design of flowering ground cover treatments, which has led to increased grower adoption of these practices. Growers have been responsible for the identification and selection of new species of flowering plants that can be more readily adopted by vineyard managers (i.e., seed that is inexpensive, flowers that can be sown in the fall and do not require additional irrigation). They have also played a large role in advising growers new to the project that are sowing flowering ground covers in their vineyard for the first time – as mentioned, this is what led to a greater rate of successful treatment establishment in the 2009 growing season. A similar pattern was seen in this past 2010 season, in which we again had 7 sites with well-established flowering ground covers. At present, for the 2011 season, 14 growers will be establishing a total of 17 split-block trials. Further, some growers have now been collaborating with researchers over 4 growing seasons and attending our outreach events every year. After participating for two consecutive years, most farmers have gained confidence in our research group and this has helped us to continue experimenting in their fields to further refine diversification strategies for enhanced biological control which ultimately benefits farmers by lowering their dependence on external inputs.

Dissemination of Project Results

By exhibiting their experimental blocks to the wider wine grape grower community, growers are serving as disseminators of best management practices and provide technical information to other growers interested in adopting similar management practices. In order to assure the relevancy and accessibility of educational and extension literature developed in association with the project, growers are helping us gather information and review/edit written materials produced by us for wide-scale distribution. Much of this information will soon be available on our website (http://agroecology.berkeley.edu). In addition to publication in technical journals, findings derived from this study will be published in industry periodicals and newsletters most commonly read by wine grape producers (e.g. Practical Winery and Vineyard, California Agriculture, etc). Finally, in order to assure the widespread distribution and accessibility of the findings and practices used in the study, a manual of agroecological vineyard diversification is being produced.

Grower Cross-Visits (Photo 5)

These events provide growers participating in this project with an opportunity to share information and experiences related to the implementation and management of flowering ground covers in vineyards. At each site visit, the vineyard manager explained the establishment and management of the treatment to other growers and researchers. Researchers also discussed in more detail their approaches to evaluating the experimental treatments and elaborated on the theory informing the research design.

The objective of the Grower Cross-Visit is to facilitate social learning amongst growers as well as receive feedback and assess the potential of the experimental practices to fit within current vineyard management practices and to evaluate the relative costs of this pest management strategy. Such participatory discussions enable researchers to better define research objectives that address grower concerns and reflect realistic management constraints.

Public Field Days

Growers have also played a central role in the outreach and extension field days organized in association with this project. As part of our efforts to encourage grower involvement, we hold an annual Public Field Day in which the wider wine grape growing community is invited to visit an experimental block in order to see the flowering ground covers. These Field Days provide an opportunity for people outside of the project to learn about the research that is being conducted and the experiences of participating growers with the use of these practices.

Farmworker training (Photos 6-7)

These training sessions allowed researchers and growers to collaborate in the monitoring and assessment of insect populations as well as soil and crop health parameters throughout the duration of the study. These training sessions allow growers and workers to make better observations of insect populations in their vineyards and thereby provide valuable feedback to researchers.

Outreach Activities in 2008

We held 3 insect monitoring training sessions (February 28, May 5, and July 22, 2008) that introduced both growers and selected farm laborers to some of the more common insect sampling methods used in this research. Researchers also gave a lecture (in Spanish) on the principles of agroecology and conservation biological control.

A Grower Cross-Visit took place on June 3, 2008, at Saintsbury vineyards and Constellation – Wappo Hill. Growers discussed establishment of the flowering ground covers with particular attention paid to the sowing of sweet alyssum underneath the vine row. Researchers provided growers with information on the biology of *Anagrus* spp. and how floral resource provisioning could potentially improve biological control of leafhoppers by this wasp.

Following harvest, a public presentation was held on October 11, 2008, at the Napa Public Library. Preliminary findings from the 2008 research were presented to the larger wine grape grower community and additional growers were recruited for the ongoing study.

As a result of all these efforts, 4 additional growers joined the project and established experimental blocks at their properties for the 2009 growing season. Many other growers requested that they be invited to future public field days held by our research group.

Outreach Activities in 2009

We conducted training (in Spanish) of farm workers from participating vineyards on February 25 and June 10, 2009. These training sessions were held at 2 participating vineyards in Oakville, CA. The intention was again to provide workers with the overall logic for the research being done in their vineyards and further train them in insect identification and data collection.

We held a Grower Cross-Visit on May 15, 2009, at a participating vineyard in Sonoma County. Researchers and growers came together to view treatment establishment at one of the participating vineyards and discuss implementation and management of the flowering ground covers. A summary of the data from the 2008 study was also presented to growers. Growers provided researchers with feedback about criteria for future selection of new flowering ground cover species.

A Public Field Day was held on June 29, 2009. At this event the larger wine grape growing community was invited to visit one of the on-farm trials in Rutherford, CA. With over 30 growers in attendance, researchers presented project goals and objectives while participating growers shared information about their experience and involvement with the project to date. This field day was reported in the Napa Valley Register:
http://www.napavalleyregister.com/news/local/article_27172757-b858-5293-899e-7fae98850c3b.html

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Photo 1. *Phacelia tanacetifolia* and *Lobularia maritima*

Photo 2. *Fagopyrum esculentum* and *Lobularia maritima*

Photo 3. *Ammi majus*

Photo 4. *Daucus carota*

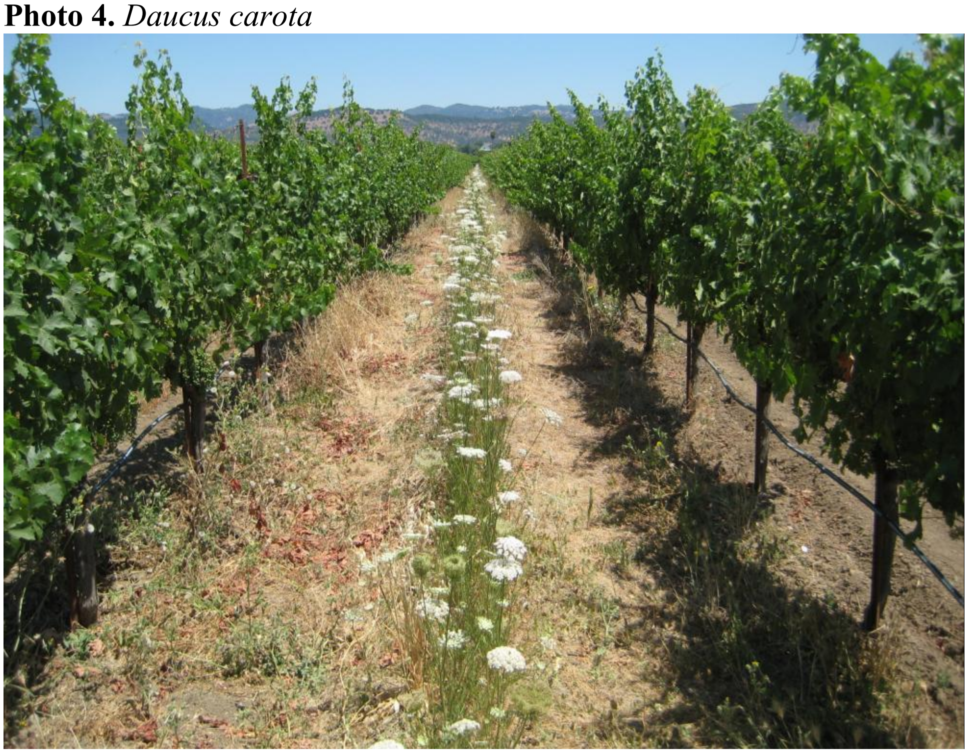


Photo 5. Grower Cross-Visit

Photo 6. Farmworker Training Session

Photo 7. Farmworker Training Session

Figure 1. Grower Trial split-block design

Figure 2a. Primary Research Block

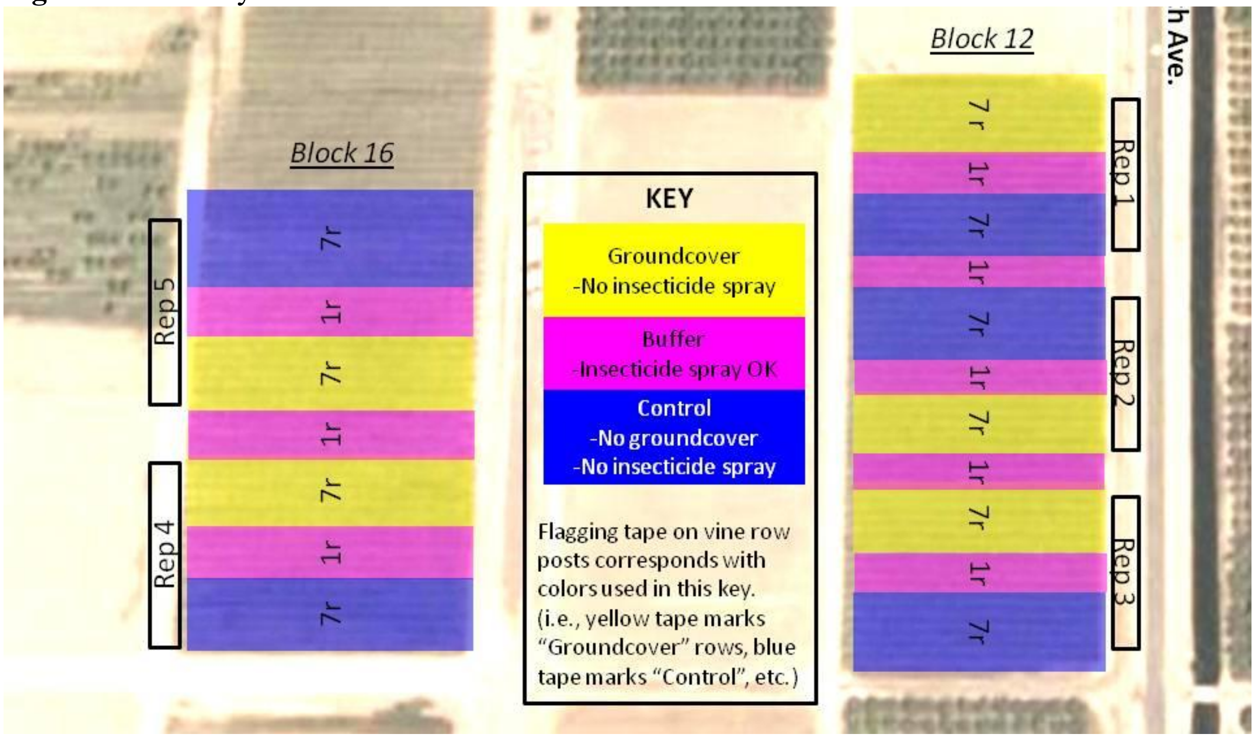


Figure 2b. Detailed view of Primary Research Block

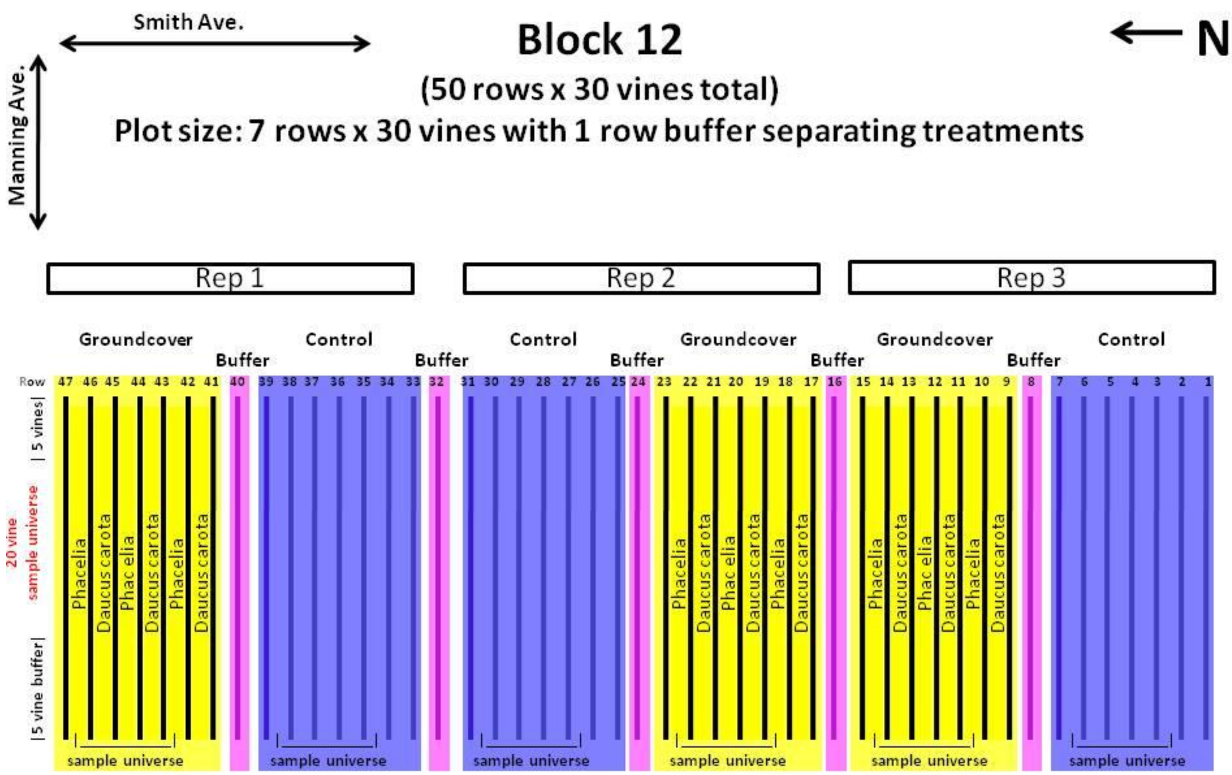


Figure 3. Seasonal mean of leafhopper nymph densities in 2008

(* Non-significantly higher population densities of leafhoppers found in treatment plots at Quintessa in 2008 resulted from a well-established geographic distribution of leafhopper densities across the landscape.)

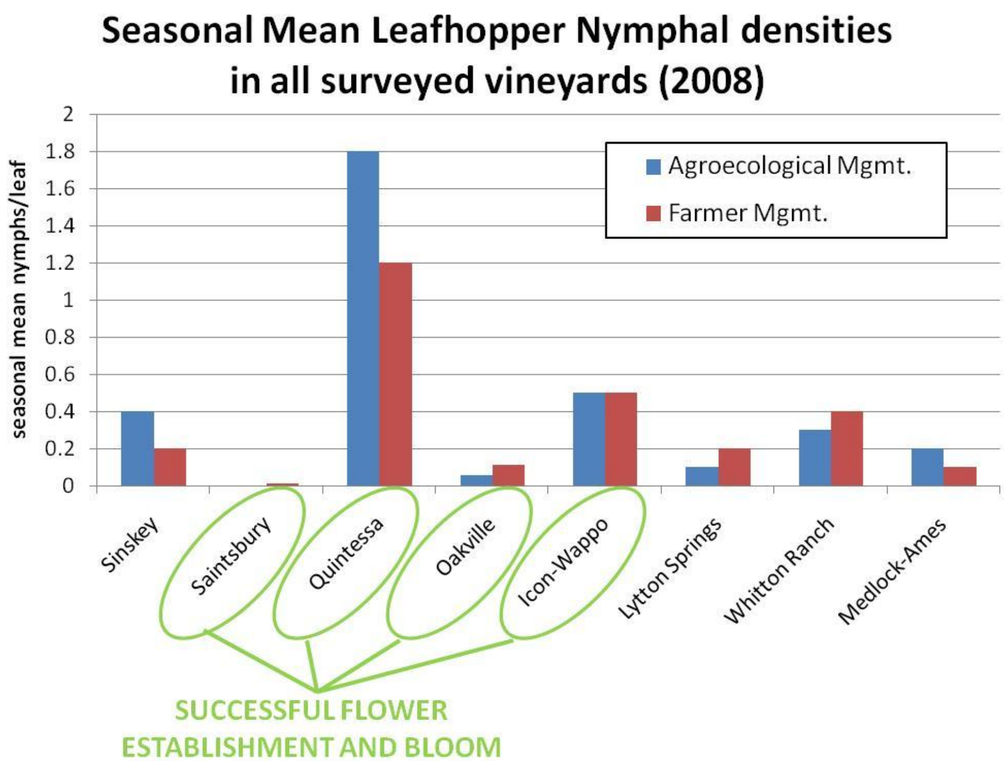


Figure 4. Leafhopper nymph densities in 2008 at Wappo

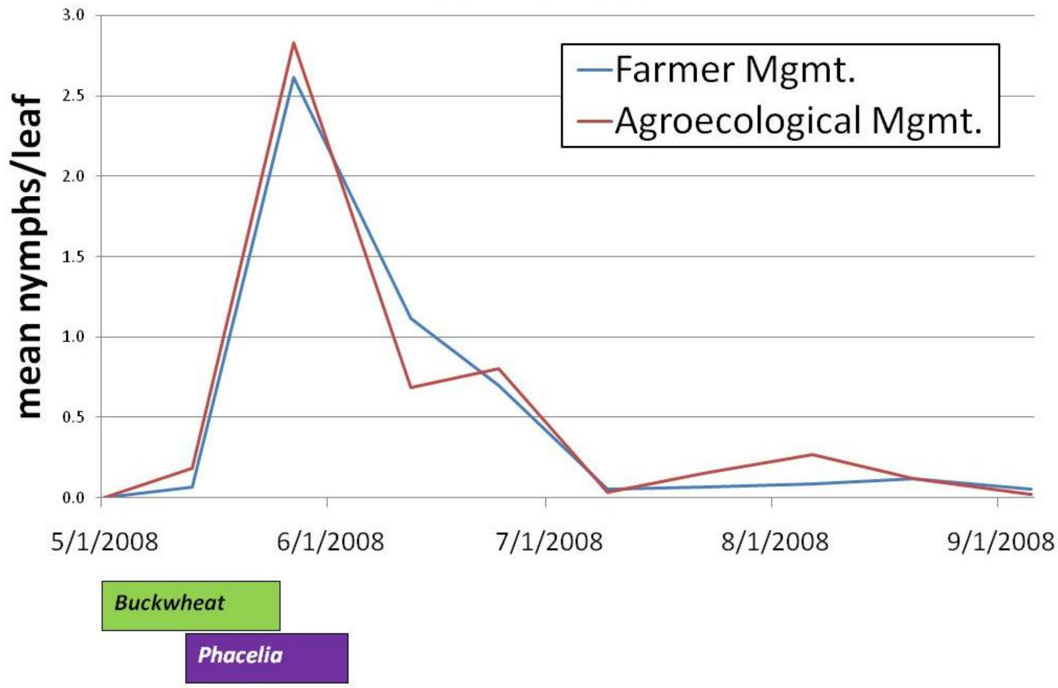


Figure 5. Leafhopper nymph densities in 2008 at Quintessa

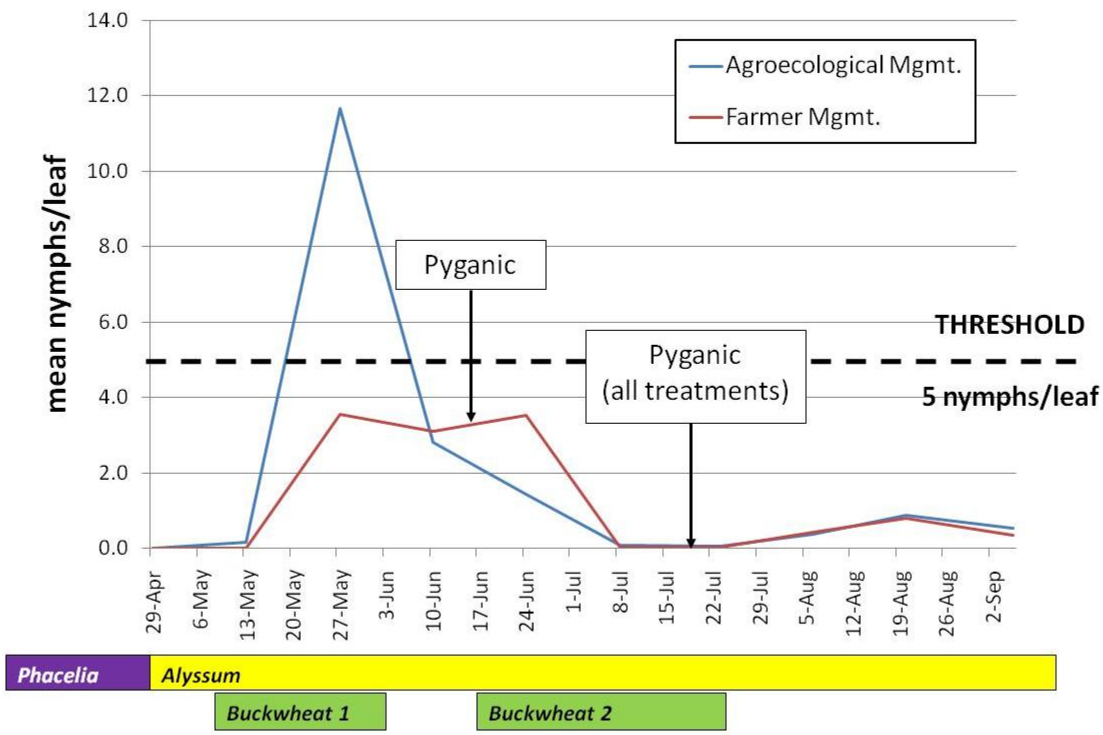


Figure 6. Predator abundance in the vine canopy (2008).

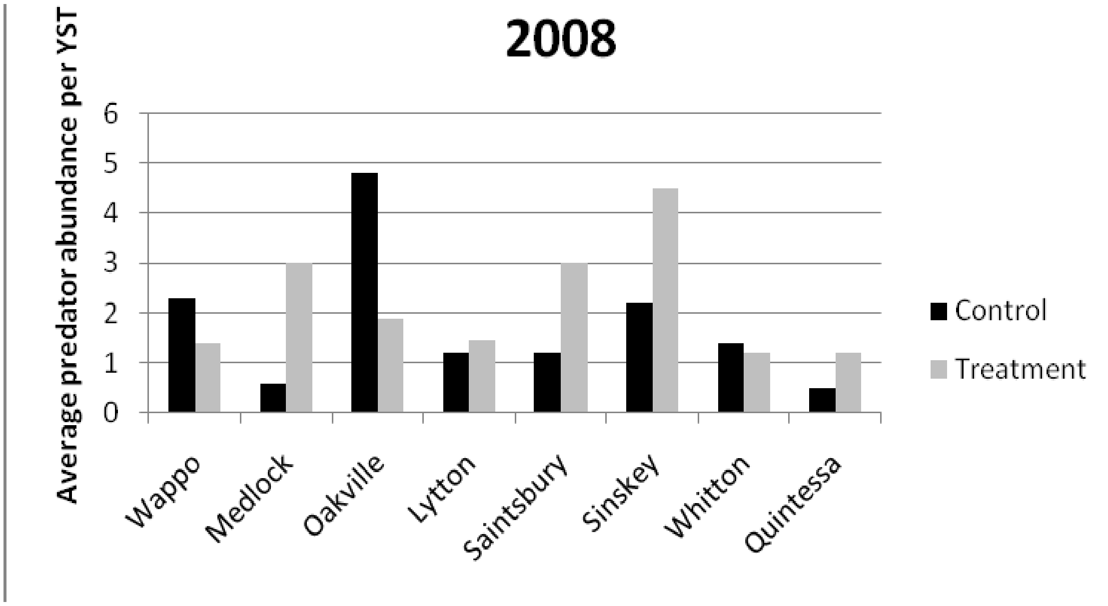


Figure 7a. Natural enemy abundance on the flowering ground covers at Quintessa (2008)

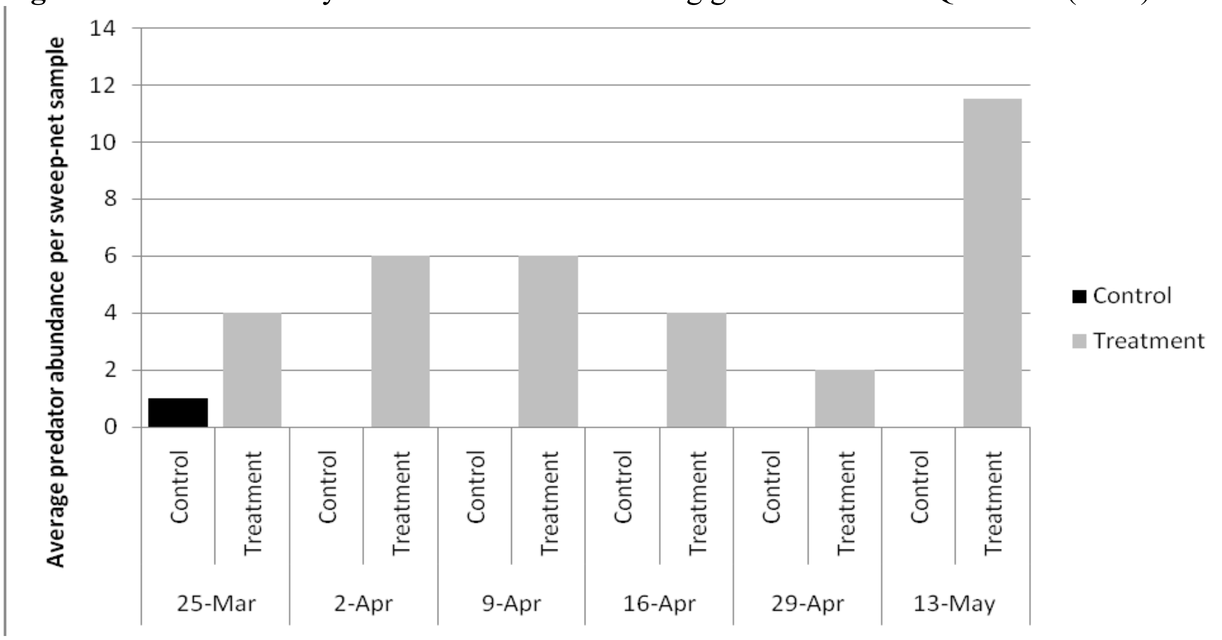


Figure 7b. Natural enemy abundance on the flowering ground covers at Quintessa (2008)

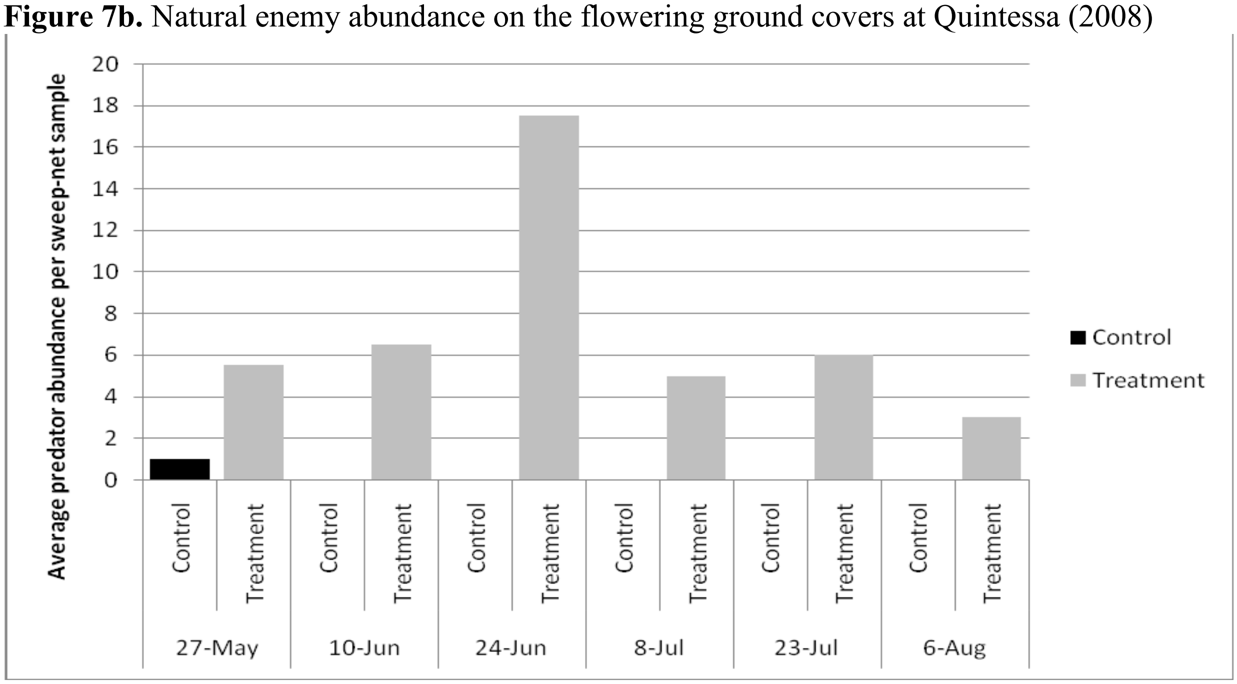


Figure 8. Comparative assessment of soil quality indicators in the agroecological plot and the farmer's management control plot at Oakville Ranch (Napa County)

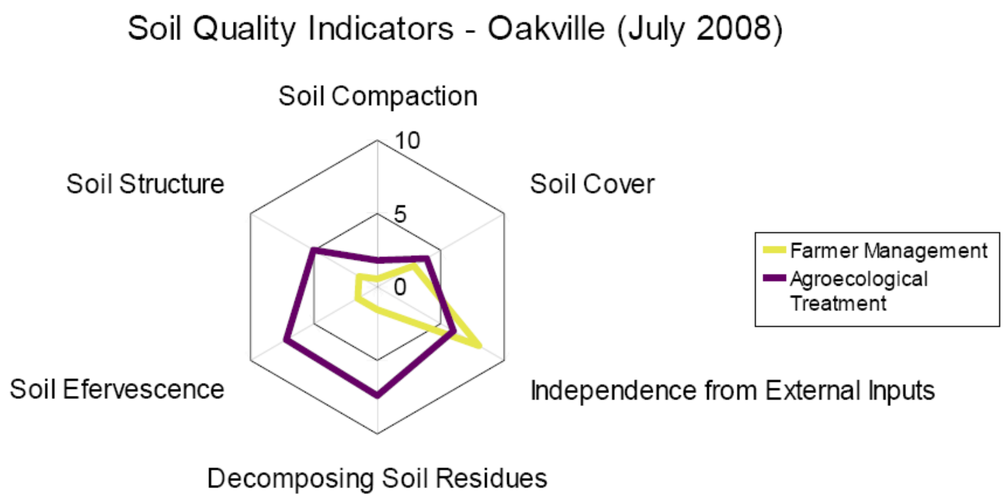


Figure 9. Comparative assessment of soil quality indicators in the agroecological block and under biodynamic farmer management at Quintessa (Napa County)

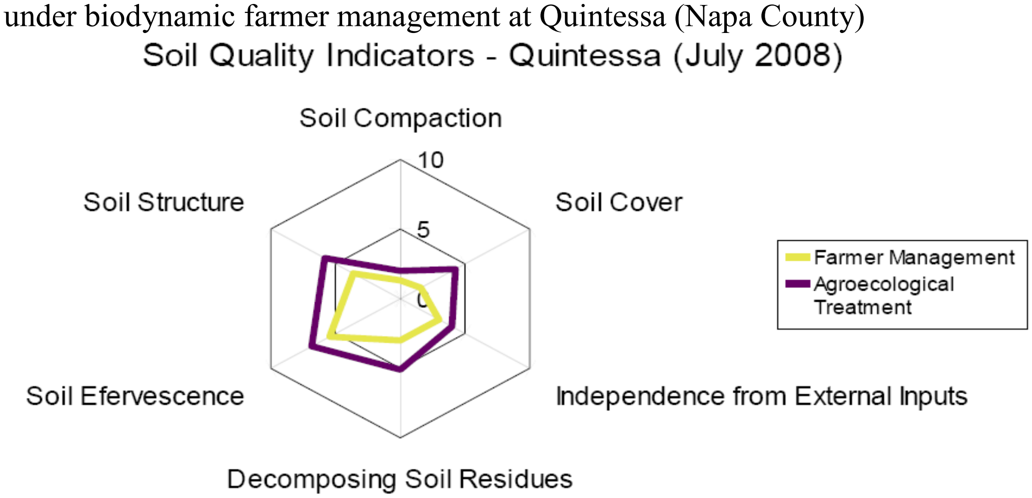


Figure 10. Comparative assessment of soil quality indicators in the agroecological block and under conventional farmer management at Wappo (Napa County)

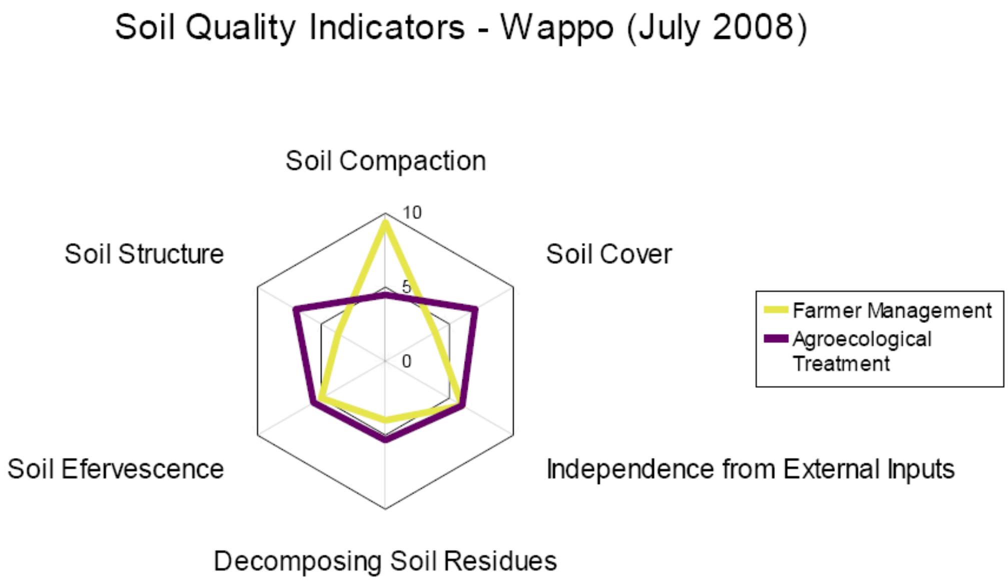


Figure 11. Mid-summer mean soil quality indicator values across all agroecological and farmer management plots at all surveyed vineyards in Napa and Sonoma County.

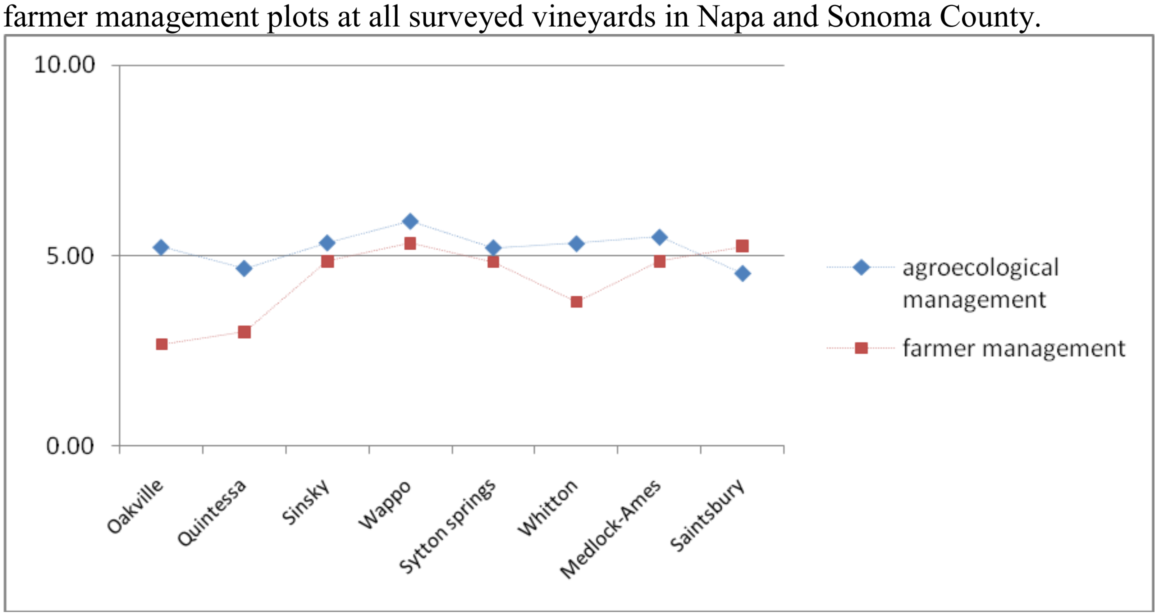


Figure 12. Peak leafhopper nymph density at all Grower Trial sites in 2009

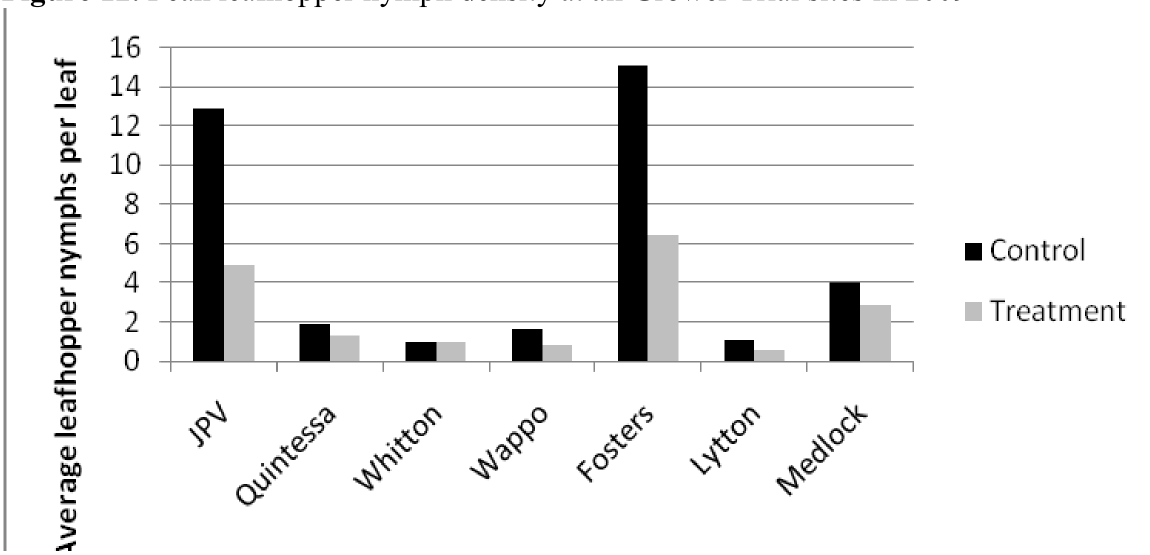


Figure 13. Early-season *Anagrus* densities at all Grower Trial sites in 2009

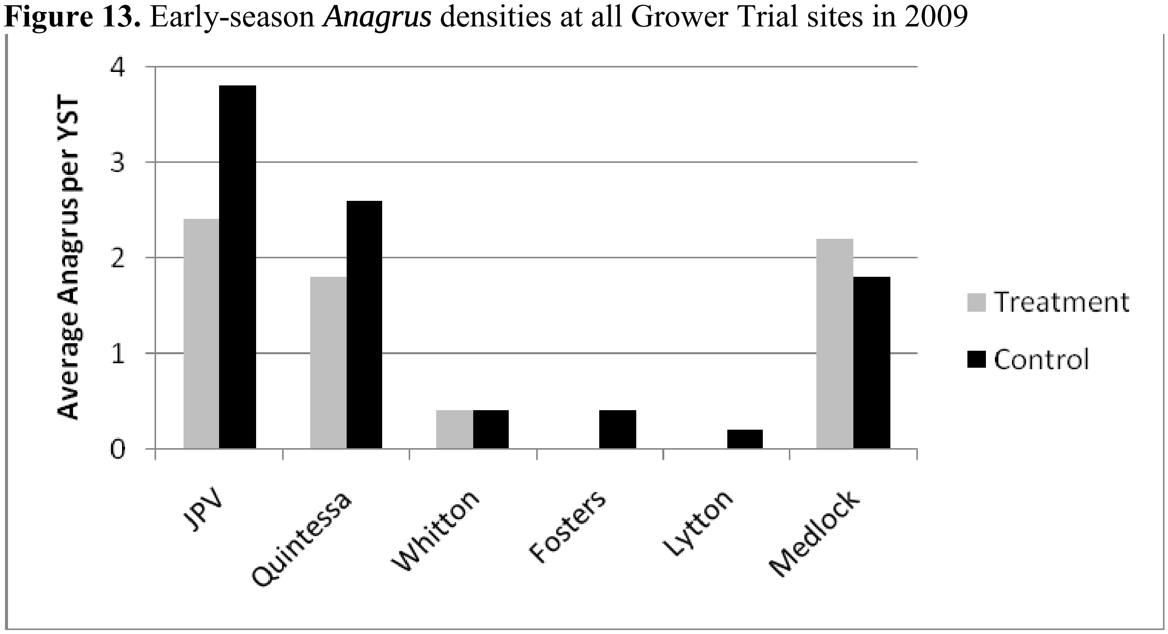


Figure 14a. Predator diversity and abundance on ground covers at Joseph Phelps (2009)

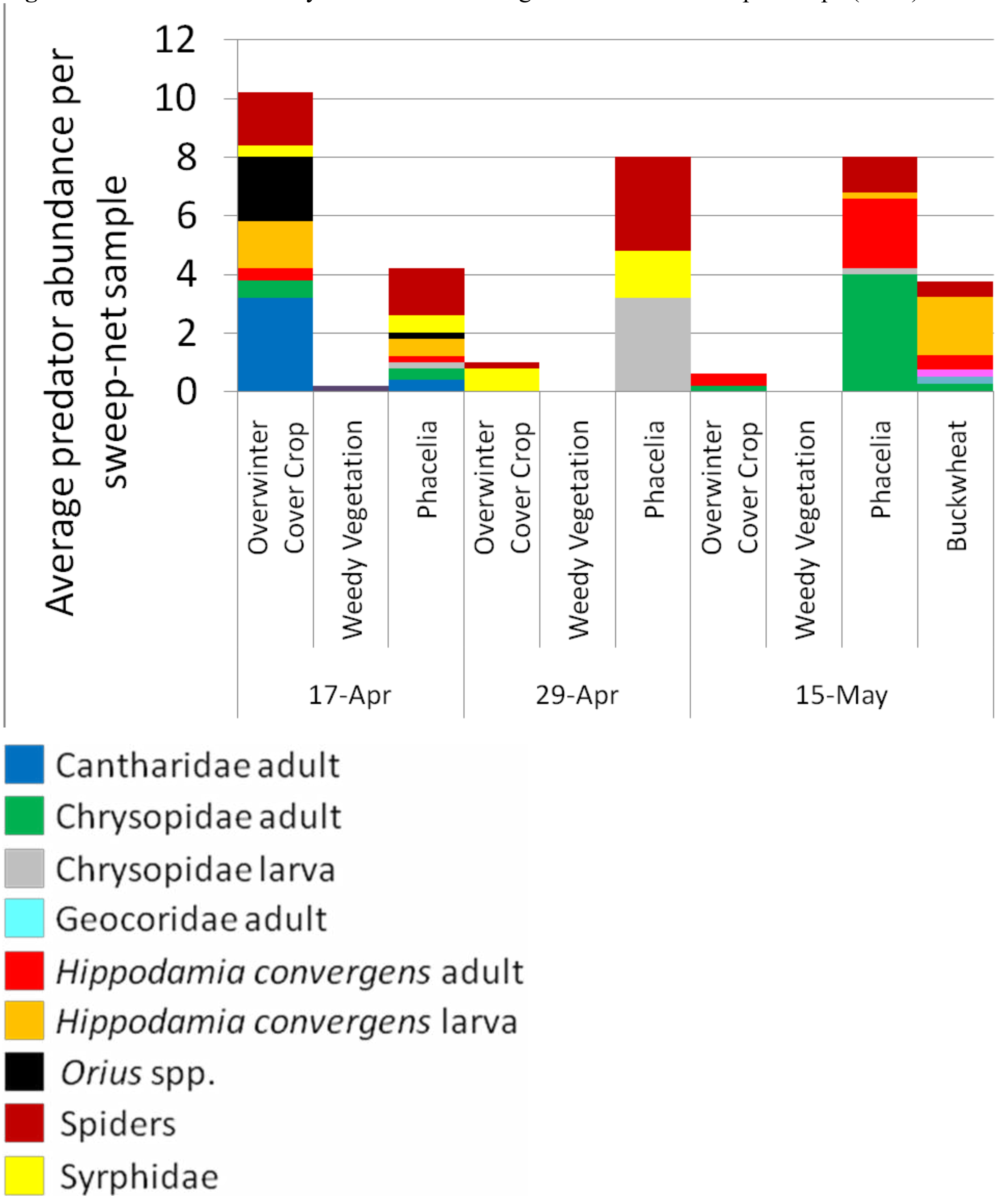


Figure 14b. Predator diversity and abundance on ground covers at Joseph Phelps (2009)

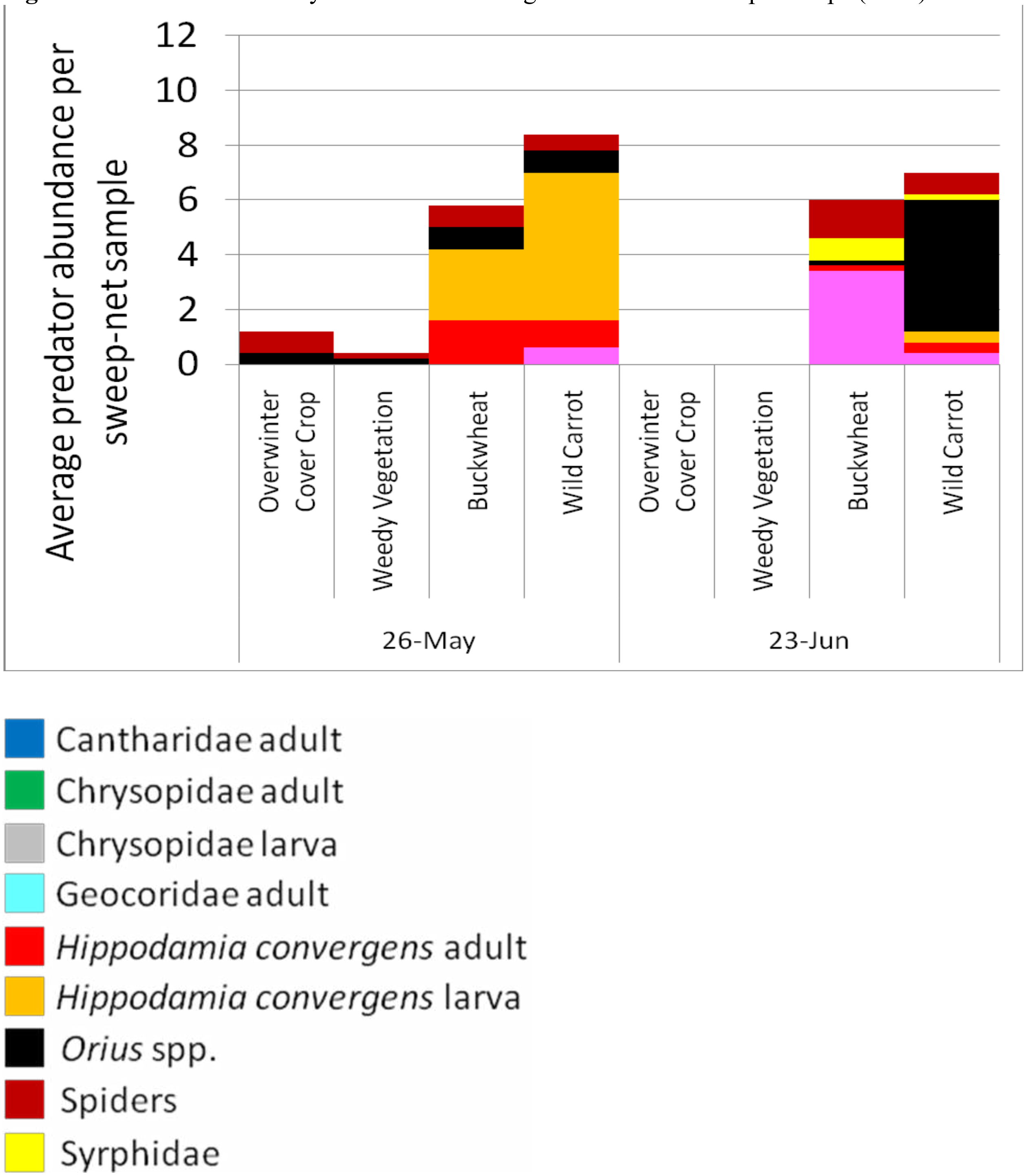


Figure 15. Predator diversity and abundance on ground covers at Fosters Grace (2009)

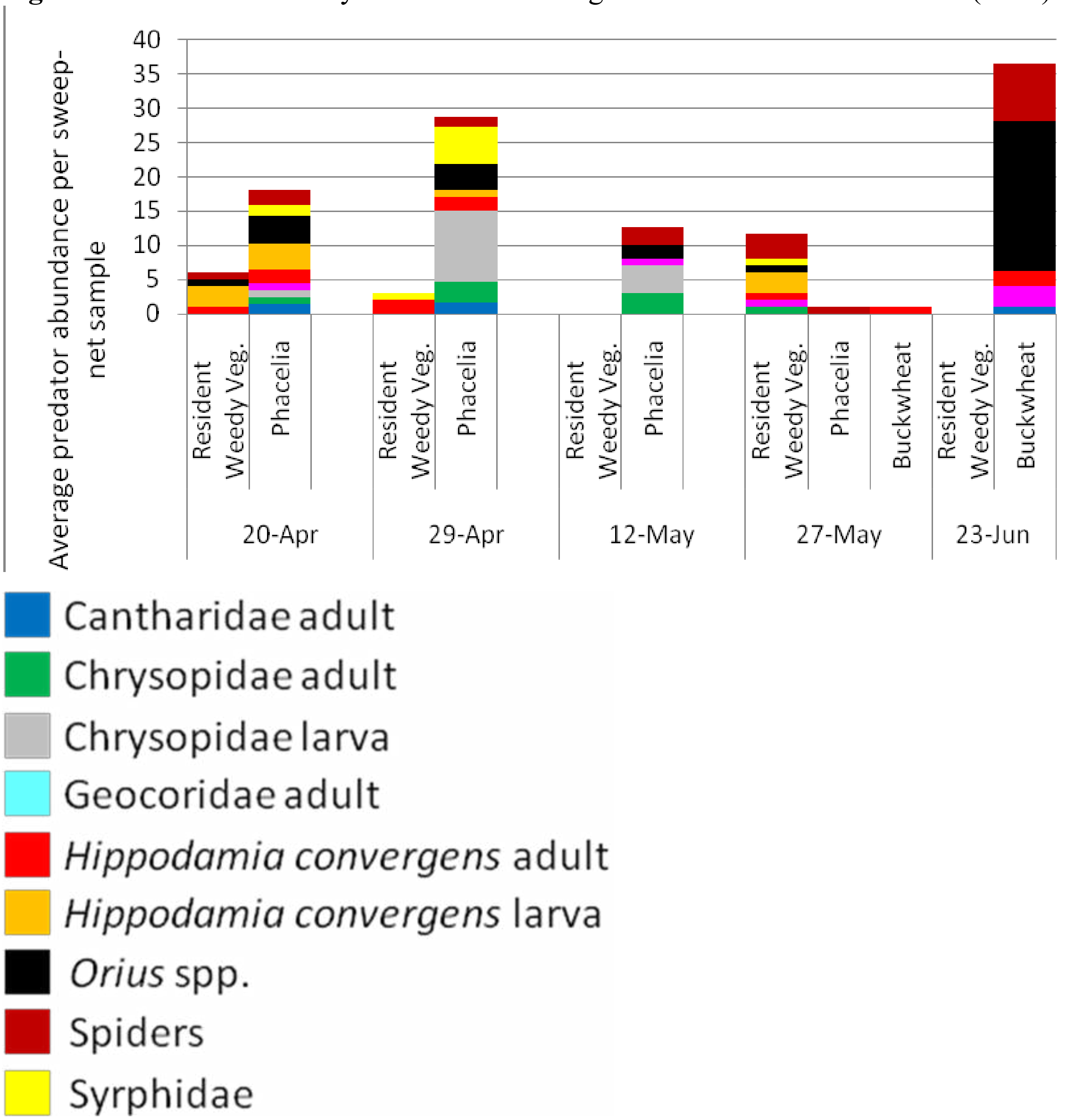


Figure 16. Predator abundance in the vine canopy.

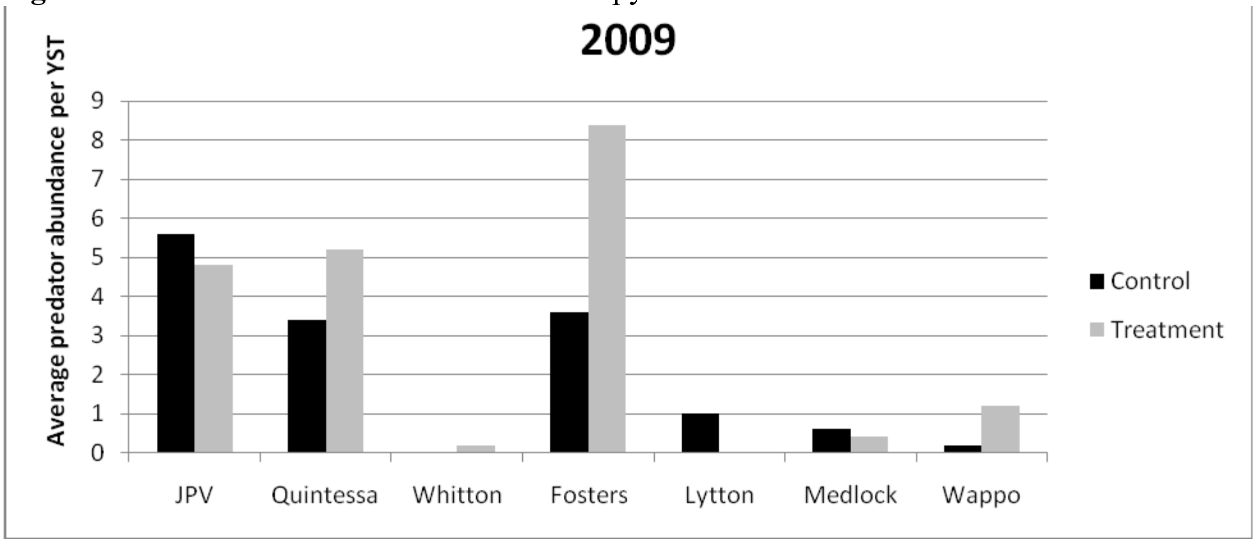


Figure 17. Field parasitism rate of vine mealybug (*Planococcus ficus*) at KAC (2009).

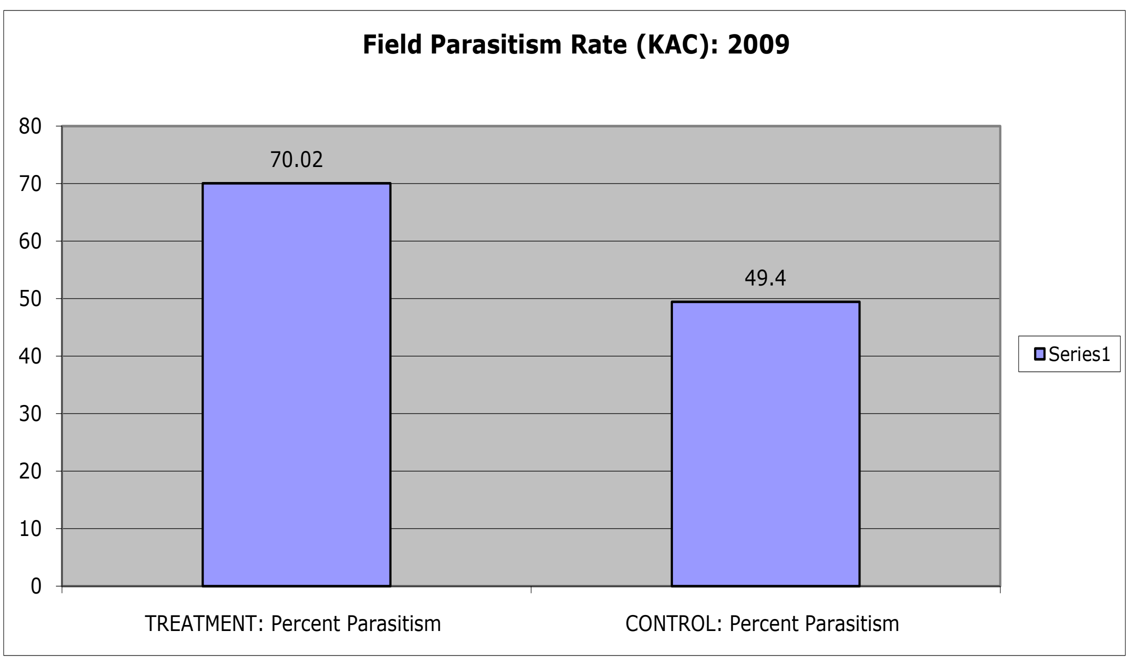


Figure 18. Impact of different floral nectar provision treatments on longevity of *Anagyrus pseudococci*

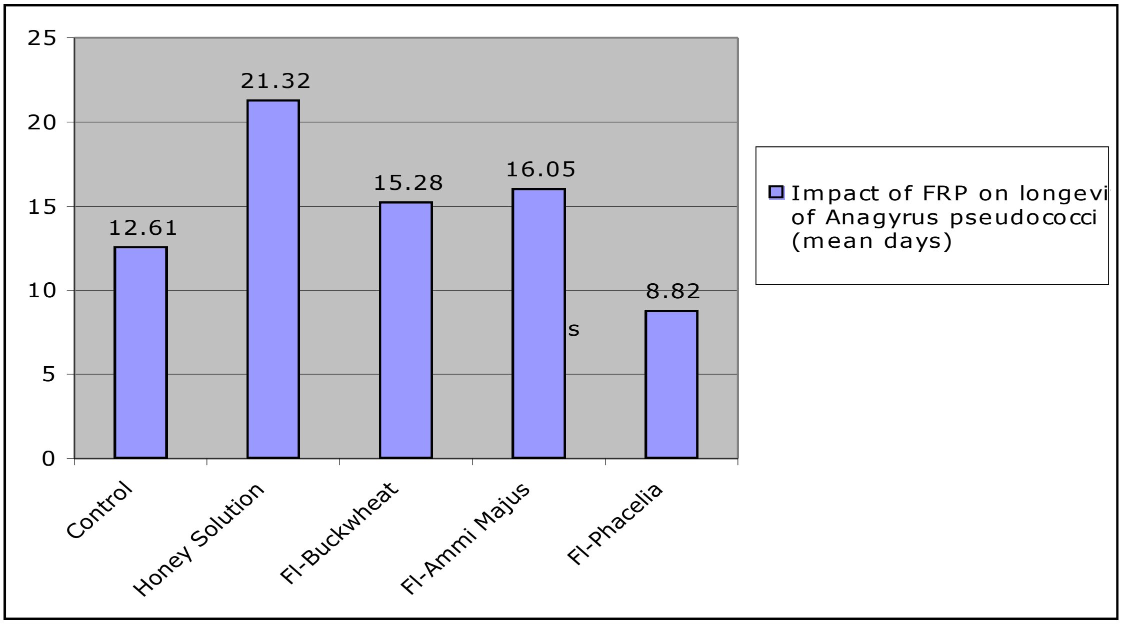
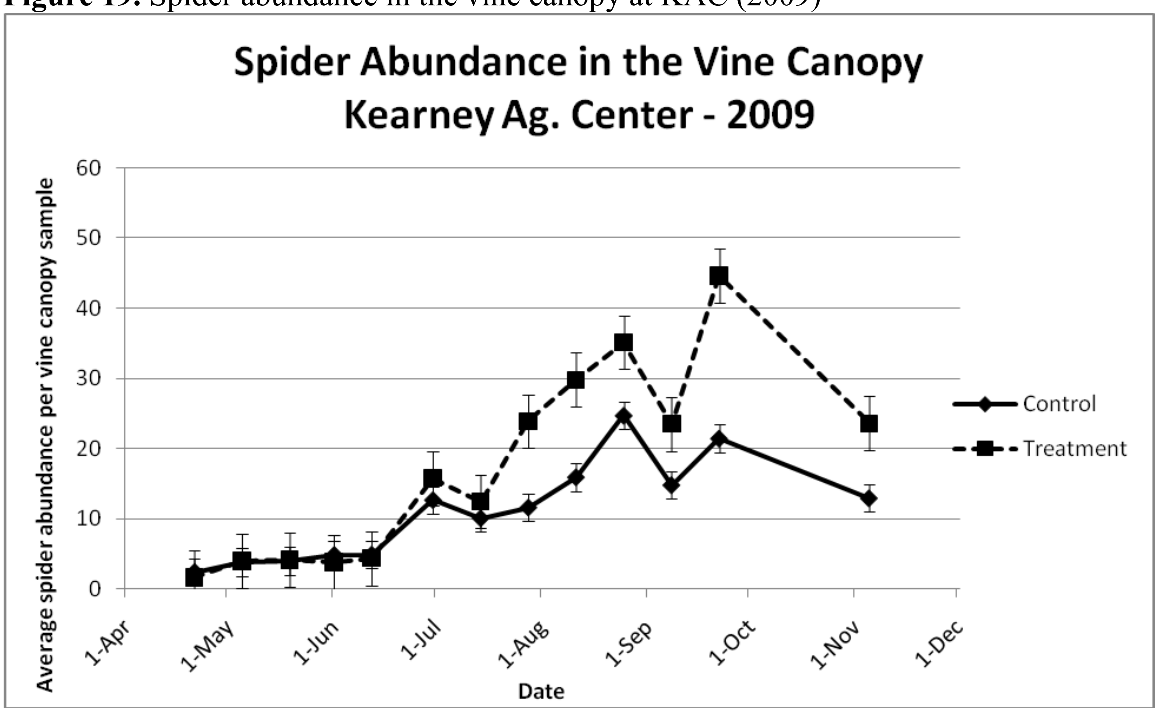
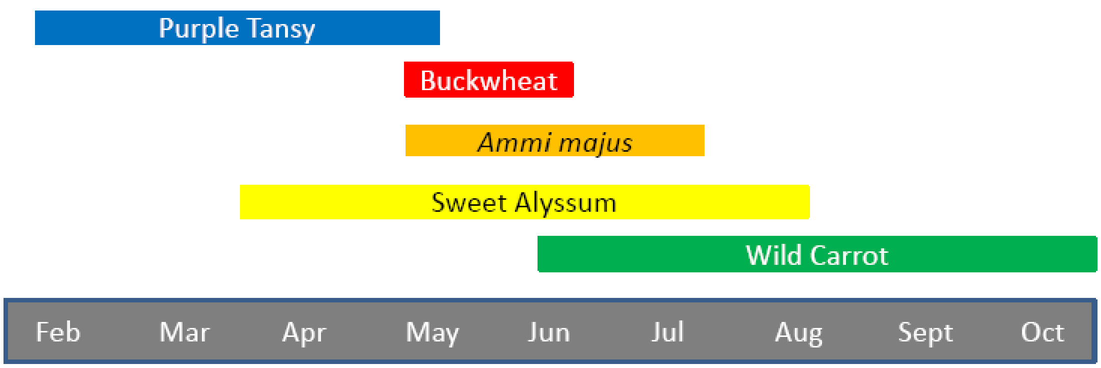


Figure 19. Spider abundance in the vine canopy at KAC (2009)



Appendix 1. Treatment Establishment Guidelines

Full Season Bloom Sequence

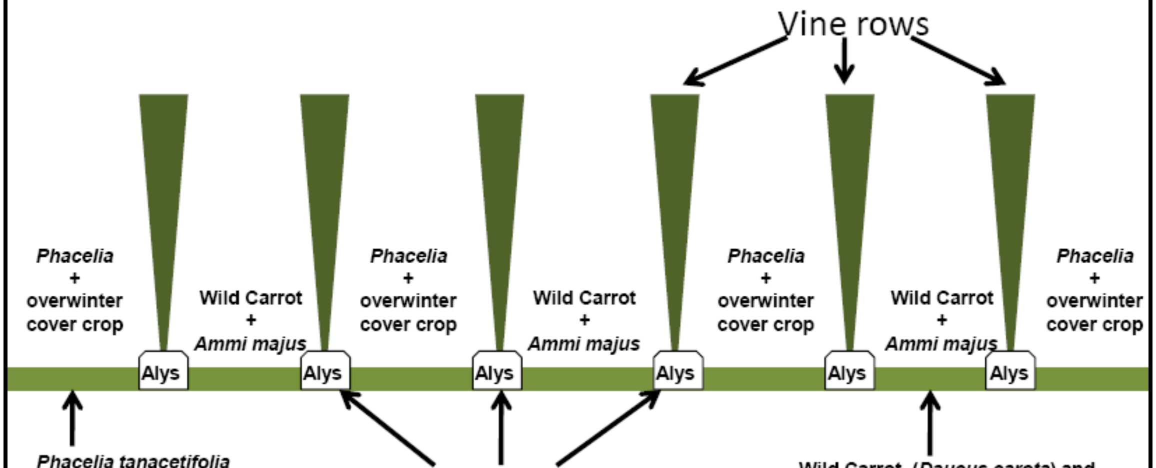


Sowing Rates, Depth, and Timing
more detailed instructions on following page

Species	Location	Rate	Depth	Sown
Purple Tansy *Phacelia tanacetifolia*	(1) Sow *Phacelia* by itself to alternate alleys OR (2) Sow *Phacelia* with LOW DENSITY overwinter legume/grass cover crops, sown to alternate alleys. In spring every other alternate alley is mowed after flowering (April/May) and then sown to annual Buckwheat. Take caution not to sow *Phacelia* too deep. Lightly cover all seed with roller or brushes.	2 lbs/ac.	1/8 - 1/4"	Oct 15
Sweet Alyssum *Lobularia maritima*	Prepare seed bed with under vine cultivator (see notes on following pages). Seed must be sown on either side of vine row to cover entire berm.	4 lbs/ac.	1/8 – 1/4"	Oct 15
Wild Carrot *Daucus carota*	Strip-tilled in center of permanent cover/ no-till alternate alleys. Seed can be mixed with rice hulls to facilitate sowing. Take caution not to sow *Daucus* too deep.	0.5 lbs/ac.	1/8 –1/4"	Oct 15
Ammi majus	If used, mix with Wild Carrot and sown both species simultaneously.	8 lbs/ac.	1/8-1/4"	Oct 15
Buckwheat *Fagopyrum esculentum*	Sown into every other alternate alley of *Phacelia*/cover-crop following spring mow and incorporation (i.e., sow to every 4th alley).	100 lbs/ac.	1/4-1/2"	May 1

Appendix 1 (continued). Treatment Establishment Guide (see following pages)

October



Phacelia tanacetifolia
Is sown with LOW DENSITY alternate row overwinter cover crop

**Caution not to sow this seed too deep and if mixed with cover crop then sow cover at a LOW DENSITY

Phacelia tanacetifolia
Rate: 2 lbs/ac.
Depth: 1/8 – 1/4"

Sweet Alyssum (*Lobularia maritima*)
is sown at a high density underneath every vine row. Prepare seed bed with under the vine cultivator. Sow Alyssum on both sides of the vine row in order to seed the entire berm.

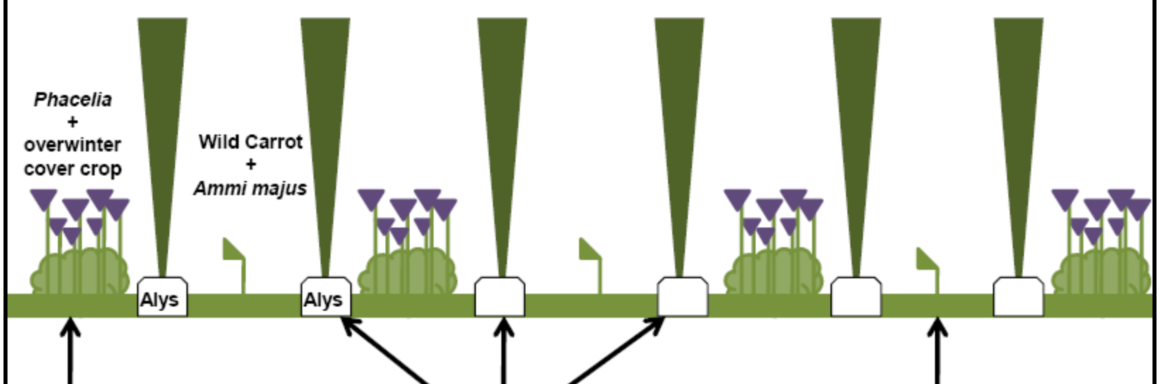
Sweet Alyssum
Rate: 4 lbs/ac.
Depth: 1/8"

Wild Carrot (*Daucus carota*) and *Ammi majus* are strip-tilled in center of permanent cover/ no-till alternate rows

Wild Carrot
Rate: 0.5 lbs/ac. (~1 seed/inch)
Depth: 1/8-1/4"

Ammi majus
Rate: 8 lbs/ac.
Depth: 1/8-1/4"

March/April



Phacelia tanacetifolia
begins to bloom ~March 15

**If necessary, 50% may be mown for frost protection (i.e., mow *every other alternate row*).

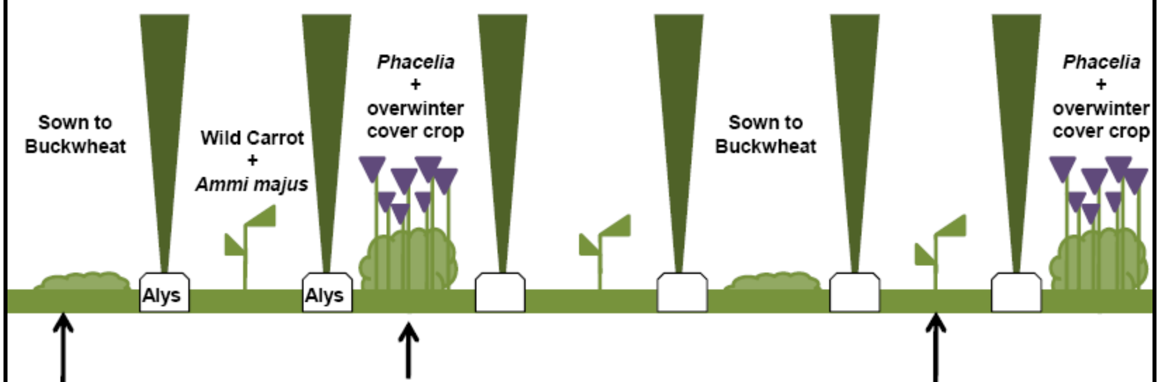
**Do not mow lower than 6"

Sweet Alyssum (*Lobularia maritima*)
begins to bloom ~March 15 and will continue to bloom pending soil moisture and irrigation levels.

Wild Carrot (*Daucus carota*) and *Ammi majus*
establishing, vegetative growth

**May be mown, but no lower than 6"
**DO NOT MOW AFTER MAY 15

May



Every other alternate row of
Phacelia tanacetifolia + cover crop
mown, incorporated,
sown to **Buckwheat ~May 1**

Buckwheat (*Fagopyrum esculentum*)
Rate: 100 lbs/ac.
Depth: 1-2"

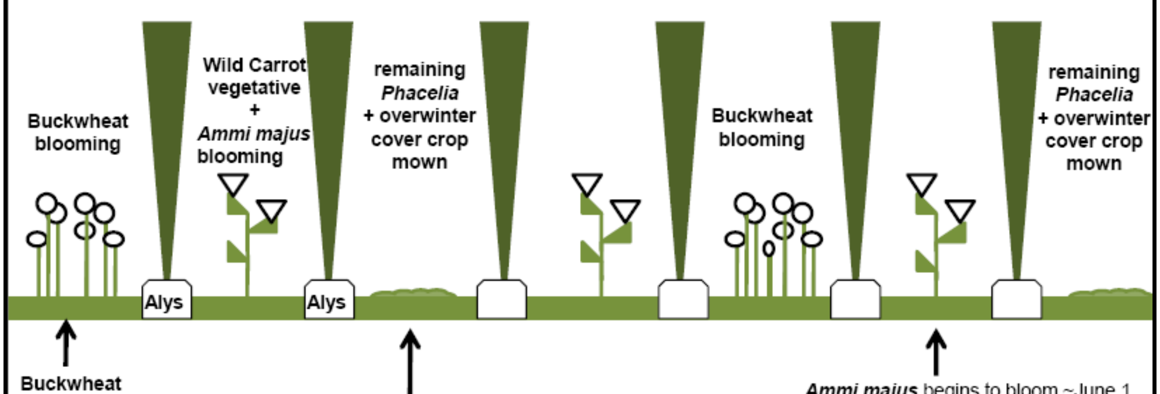
Remaining rows of
Phacelia tanacetifolia + cover crop
left in place to finish bloom

**Mow these remaining rows ~June 1

Wild Carrot (*Daucus carota*) and
Ammi majus
vegetative growth continues

**May be mown, but no lower than 6"
**DO NOT MOW AFTER MAY 15

June



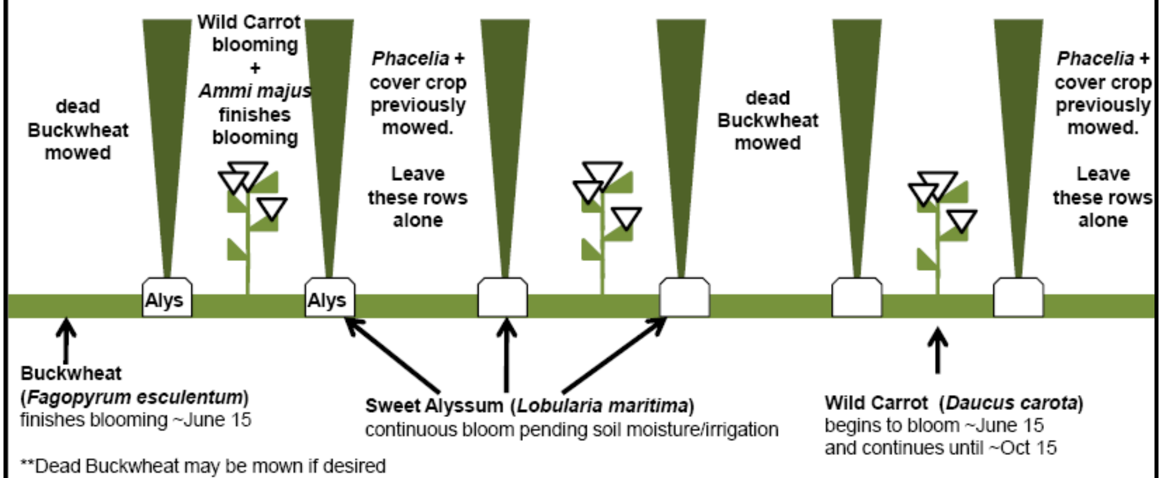
Buckwheat
begins to bloom ~May 15

Remaining rows of
Phacelia tanacetifolia + cover crop
mown ~June 1

Ammi majus begins to bloom ~June 1
Wild Carrot (*Daucus carota*)
vegetative growth continues

**DO NOT MOW AFTER MAY 15

June – September



Alternate Treatment Options

Growers unable to implement the full experimental treatment
as outlined may trial one of the following alternate options.

Option #	Fall (Oct. 15)	Spring (May 1)
1	*Phacelia* sown to alternate rows (with or without cover crop depending on your practices) *Ammi* + *Daucus* (sown to alternate rows)	No additional spring management. Mow cover crops as usual.
2	*Phacelia* sown to alternate rows (with or without cover crop)	Mow every other row of cover crop in April. Sow Buckwheat to these rows. (i.e., Buckwheat sown every 4th row-middle)
3	Alyssum sown at high density (4lbs/ac.) underneath vine row.	Mow cover crops as usual. Sow Buckwheat to alternate rows.
4	Alyssum underneath vine row.	Mow cover crops as usual
5	*Phacelia* + cover crop (alt. rows) Alyssum underneath vine row.	Mow every other row of cover crop in April. Sow Buckwheat to these rows (i.e., Buckwheat sown every 4th row-middle)
6	*Phacelia* + cover crop (alt. rows) *Ammi majus* (alt. rows)	No additional spring management
7	*Phacelia* + cover crop (alt. rows) *Ammi majus* (alt. rows)	Mow cover crops as usual. Sow Buckwheat to alternate rows.
8	*Phacelia* + cover crop (alt. rows) Alyssum underneath vine row *Ammi* (alt. rows)	Mow cover crops as usual. Sow Buckwheat to alternate rows.
9	*Phacelia* + cover crop (alt. rows) Alyssum underneath vine row *Ammi* + *Daucus* (alt. rows)	Mow cover crops as usual. Sow Buckwheat to alternate rows.

Options #3,4,5 have choice of sowing Alyssum underneath vine row in the early spring rather than fall.