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Ecosystem Approaches to Managing Insect and Mite Populations Effectively in Inland Desert Vineyards Utilizing Sustainable Production Practices — a Review

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Additional index words: beneficial insects, cover crops, flowering plants, biological control

Abstract

Vineyards worldwide have adopted sustainable management practices and integrated pest management (IPM) to reduce dependence on broad spectrum insecticides that may reduce beneficial insect populations. Use of IPM techniques can minimize negative impacts on predator-pest dynamics and reduce certain types of pest outbreaks. While vineyards in inland desert climates face fewer threats to vine and grape quality than those in more humid locations, utilizing conservation biological control methods such as attracting beneficial insects may be a challenge due to low annual precipitation. This review identifies the major vineyard insect and mite pests of the inland Pacific Northwest, their associated beneficial predators, and discusses techniques to enhance beneficial insect populations in these climates.

Sustainable grape production systems that implement best management practices have garnered much attention in the research community and with consumer marketing entities over the past decade. Consumers, concerned about the effects of conventional production systems on grape and wine quality have responded with increased demand for wine produced with sustainable or "green" practices that are implemented at the farm or winery level (Forbes et al., 2009; Zucca et al., 2009). However, while sustainable approaches allow for the use of both naturally and synthetically-derived chemicals, organic production restricts the use of chemicals to those derived from natural sources. Within the winemaking process, an organic designation restricts manipulation of juice (must) contents, such as the addition of nitrogen sources for optimal yeast growth and wine quality. Thus, interest has increased in sustainable grape production as to allow for flexibility to optimize wine quality.

One focus of a sustainable approach has been on pest management and the sensible application of chemicals (synthetic or organic) in conjunction with monitoring pest and beneficial insect populations, and efforts to make vineyards better habitats for natural regulation of pests (James et al., 2012; Simpson et al., 2011). Sustainable management is a whole-system approach that takes into account many elements of ecosystem management or services, including integrated pest management, preservation of natural resources and biodiversity, judicious monitoring of nutrient and water applications to optimize reproductive and vegetative growth, and protection of water quality (Costanza et al., 1997; Fiedler et al., 2008). In desert climates, although pest and disease pressures are relatively lower than in humid environments, there is concern about the impact of other cultural practices on the environment, such as the increase of salinity and heavy metals as a result of repeated

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nutrient and pesticide applications (e.g., Fernández-Calviño et al., 2010; Zalidis et al., 2002).

Organic grape producers apply naturally-derived or organically approved chemicals to their grapevines. Those products defined as "natural" or non-synthetic are derived from mineral, plant, or animal matter that do not go through a synthetic process (USDA, 2010). All fruit and vegetable producers apply some chemicals to their systems, thus, no organically-grown produce label can state that no chemicals were applied. Wine labels may indicate that grapes are organically grown; however, for a wine to be produced organically, no additional sulfites or other synthetically-produced chemicals may be added while being grown, or during the fermentation, stabilization or bottling process. Sulfites added to wine in conventional production systems lengthen the shelf stability of a wine; but are not allowed during the organic winemaking process.

Organic vineyard systems must adhere to state, national, and international guidelines for production of organic produce. In the United States, the National Organic Program is administered by the United States Department of Agriculture (http://www.ams.usda.gov/AMSv1.0/nop); while in Europe, the Research Institute of Organic Agriculture administers Council Regulation (EEC) No 2092/91 on Organic Production (http://www.fibl.org/en.html). To achieve sustainability, organic production must use a whole system approach to pest management. Organic agriculture in general can enhance the biodiversity and quantity of beneficial insects and native pollinators (Kremen et al., 2002); however in some cases, increases in predatory organisms have decreased the diversity of non-predatory insects and pests (Bengtsson et al., 2005; Letourneau and Bothwell, 2007). The impacts of organic chemical use on pest and beneficial insect populations have raised questions about the belief that organic chemicals are more environmentally benign (Bahlai et al., 2010; Gent et al., 2009), while in apple, organic production including organically-approved chemical application resulted in greater fruit quality and greater energy efficiency (Reganold et al., 2001). However, there can be negative impacts of pesticides used in organic systems, specifically heavy metals. Frequent applications of Bordeaux mixtures ($Ca(OH)_2$ + $CuSO_4$) have resulted in toxic concentrations of copper that have negatively impacted the quantity and distribution of microorganisms important for nutrient cycling or limited the exportability of product when residues of copper are regulated in markets such as Canada (Mackie et al., 2012; Mackie et al., 2013).

In sustainable production systems unlike in organic, both synthetic and naturally-derived chemicals can be applied. However, there is considerable monitoring for pests and diseases to ensure that chemicals are applied in an environmentally-conscious manner, rather than on a regimented course dictated by the calendar. Although there are no official government standards for sustainability, there are several groups that promote sustainable production and provide guidelines for vineyards. These organizations have originated in the western United States, where much of the grape production arises (e.g., Low Input Viticulture and Enology [LIVE; http://live.org], California Sustainable Winegrowing Alliance [http://www.sustainablewinegrowing.org/], Salmon Safe [http://salmonsafe.org/]). Several companies provide third-party certification to ensure that sustainable production practices are being followed. Many wine and grape industries have worked with university and extension personnel to author "best management practice" guides, such as VineWise (http://vinewise.org) and VineBalance (http://www.vinebalance.com/). Many of these guides have an online presence, which enhances the potential for their use as a grower-driven assessment system for sustainable production.

Integrated pest management (IPM) is a strategy that combines the use of all available controls including chemical, biological and cultural, usually with the aim of minimizing pesticide inputs (Kogan, 1998; Stern et al., 1959). A pest, from this point forward, is defined as an organism that can harm grapevine growth and ultimately, fruit quality. Regular monitoring of pest and beneficial insect and mite populations is a key component of IPM systems. Information on insect and mite population levels allows growers to make informed decisions regarding the need to apply control measures. Research and development efforts have resulted in the production of chemicals that target specific groups of insects, rather than a broad-spectrum insecticide (BSI) which also kills beneficial and incidental insects and mites (Baum et al., 2007; Epstein et al., 2000; Koss et al., 2005; Pimentel et al., 1991).

Biological controls can minimize the impact on off-target and beneficial insects. The use of pheromones for attraction or mating disruption is an example of a successful biological control. This technique employs a chemical signal (pheromone) that is used in communication of insects among each other to attract (and kill) or to disrupt mating and reproduction. Mating disruption over time can reduce the insect population provided area-wide management of orchard, vineyard, or groves is implemented (Thomson et al., 2001; Welter et al., 2005; Witzgall et al., 2010). Pheromone-based management techniques have been successfully applied in many perennial crops including apple, pear, and citrus (e.g., Carde and Minks, 1995; Howell et al., 1992; Moffitt and Westigard, 1984; Zada et al., 2004). In vineyards, pheromone-based management has successfully controlled grape berry moth (*Lobesia botrana* Denis and Schiff.) (Taschenberg et al., 1974; Trimble et al., 2003), western grape skeletonizer (*Harrisina americana* Barnes and McDunnough) (Soderstrom et al., 1985), and vine mealybug (*Planococcus ficus* Signoret) (Millar et al., 2002; Walton et al., 2004).

The availability of selective pesticides and/or biological controls are important in driving the development of sustainable approaches to vineyard pest management. From an economic point of view however, this works best in a climate with lower pest pressure, such as in the inland Pacific Northwest, which is designated as a shrub-steppe system with low seasonal rainfall and humidity (Fig. 1).

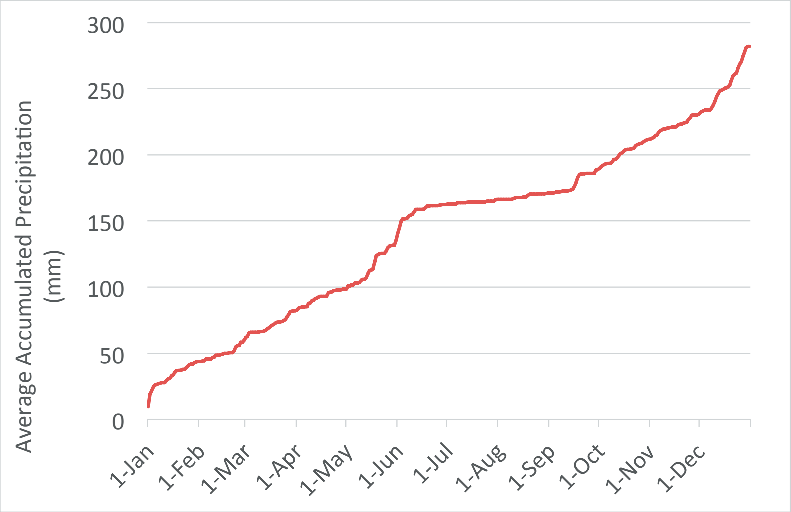

Fig. 1. Five year accumulated annual precipitation (mm) for Prosser, WA from January−December 2005-2011. Two years (2007-2008) were eliminated due to an incomplete data set. (Data provided courtesy of Washington State University AgWeatherNet. Data are copyright of Washington State University.)

The kind of ecosystem approach utilized to manage vineyard pests is dependent on the pest/natural enemy complex occurring in the region. For example, in Washington State, which is classified as having a cool, inland desert climate, vineyards have few serious arthropod pests with no individual pest guaranteed to occur at damaging levels annually in every vineyard. In humid or subtropical environments, the populations and diversity of pests are typically greater and pest-predator interactions more complex. Grape pests in inland desert climates are sporadic and vary greatly in importance from year to year and vineyard to vineyard, emphasizing the importance of regular population monitoring. A small complex (four to six species) of low-to-moderately damaging pests is an ideal target for an ecosystem approach to IPM.

Major Insect and Mite Pests Affecting Grapevine Growth in Inland Desert Climates

Two species of leafhoppers affect grape production in the inland deserts of the US, the western grape leafhopper (*Erythroneura elegantula* Osborn) and the Virginia creeper leafhopper (*Erythroneura ziczac* Walsh). Additionally, vine leafhopper (*Empoasca vitis* Goethe) is found in southern Europe and the variegated leafhopper (*Erythroneura variabilis* Beamer) is found in the Western US. These leafhoppers can cause leaf damage to grapevines, decreasing vine productivity (Böll and Herrmann, 2004; Settle et al., 1986). Recently, they have been suggested as a possible vector in grapevine red blotch disease, caused by a grapevine red blotch-associated virus (GRBaV) (Al Rwahnih et al., 2012; Krenz et al., 2012; Sudarshana and Wolpert, 2012). This disease can reduce sugar contents in the fruit as much as 5°Brix, severely reducing fruit and wine quality.

Leafhoppers are small (1-3 mm) insects that pierce grape leaf cells and remove the contents, resulting in leaves with yellow mottling. Severe infestations may reduce the ability of the leaves to produce and export optimal levels of photosynthates, limiting the sugar content of fruit. Both species found in inland deserts of the US overwinter as adults in plant debris at the base of vines and in vineyard pruning material or litter. Two to three generations occur each season and they pass through an egg and five nymphal stages before becoming adults. Treatment thresholds are relatively high (mean of 15-20 nymphs per leaf) and biological control provided by minute parasitic wasps in the genus *Anagrus* can be effective (Böll and Herrmann, 2004; Murphy et al., 1998; Prischmann et al., 2007; Williams and Martinson, 2000).

The grape mealybug (*Pseudococcus maritimus* Ehrhorn) is an occasional pest but rarely occurs at densities causing direct damage. Its primary significance is as a potential vector of grapevine leafroll disease, an important disease of grapevines in the western US (Golino et al., 2002). Three other mealybug species have long been associated with grapevines in California including the longtailed mealybug (*Pseudococcus longispinus* Targioni Tozzetti), the obscure mealybug (*Pseudococcus viburni* Signoret) and the vine mealybug (Daane et al., 2012). Although recent research in Washington State has shown mealybugs to be poor vectors of leafroll disease, continuing grower concern over the presence of this pest means that even low populations are not tolerated. Grape mealybugs have also been demonstrated to

Fig. 2. Convergent ladybeetles (*Hippodamia convergens*) overwintering. Cover-cropping and habitat refugia in vineyards may provide areas for overwintering of beneficial insects. (Photo: D. James)

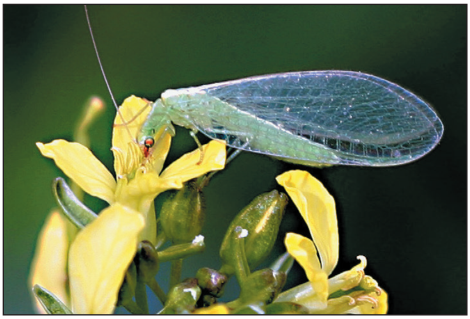

Fig. 3. Green lacewing (Chrysopidae) feeding on yellow mustard (*Brassica* spp.) ground cover. (Photo: D. James)

transmit other viruses, such as Little Cherry Virus 2 which is implicated in Little Cherry Disease (Mekuria et al., 2013). This is of great concern, as in many western US states, grapevines are planted in close proximity to cherries as part of diversified agricultural operations. Natural enemies are important regulators of mealybugs in vineyards (Daane et al., 2008; Grasswitz and Burts, 1995) but chemicals used to suppress mealybug populations reduce populations of these natural enemies. Efforts to phase out dormant applications of chlorpyrifos targeting grape and vine mealybugs in California has improved the outlook for retaining more diverse insect populations that may be natural enemies of both mealybug species, as well as protecting worker safety (Fenske et al., 2002). In addition, targeted chemicals such as neonicotinoids have shown effective control of grape mealybug with limited negative reductions in parasitoid populations (Lo and Walker, 2011).

Cutworms are the larvae of moths in the family Noctuidae. These larvae climb grapevines in early spring and feed nocturnally on opened and developing buds causing serious losses to production (Cone et al., 1990; Wright and Cone, 1980). They are sporadic in occurrence but tend to affect the same blocks annually. Monitoring is important to enable detection of significant infestations before damage is caused. Using synthetic pyrethroid barrier sprays to prevent cutworms from climbing up vines from overwintering sites on the ground is an effective management strategy with minor disruption to the vineyard ecosystem (Ferguson et al., 2007). Vineyard equipment can be modified to apply these barrier sprays which has reduced both the economic and environmental cost of applying chemical sprays (Kang et al., 2011).

Spider mites, primarily two-spotted spider mite, *Tetranychus urticae* Koch, and McDaniel's mite, *Tetranychus mcdanieli* McGregor, occasionally occur in outbreaks as a consequence of the use of BSIs or multiple applications of sulfur (Gent et al., 2009; James and Price, 2002). Reductions in BSI and sulfur use has led to a decrease in spider mite herbivory since 2005 and mites are now generally well controlled by natural enemies, primarily predatory mites (Phytoseiidae; Fig. 4).

Eriophyid mites are new pests of western US grapes and caused significant problems in Oregon and Washington during 2004-2007. Previous use of BSI and multiple applications of sulfur probably controlled eriophyids previously, however, reduced use of these chemicals appears to have led to a surge in their numbers. Two species, grape leaf rust mite (*Calepitrimerus vitis* Nalepa) and bud mite (*Colomerus vitis* Pagenstecher), cause most of the problems, primarily by damaging developing buds and shoots in the early spring (Bernard et al., 2005; Walton et al., 2007). Large populations at this time cause severe stunting and distortion of new growth (short shoot syndrome) resulting in yield reduction. However, rust and bud mites are easily controlled by single, well targeted applications of sulfur near budburst and subsequent biological control provided by predatory mites and other natural enemies during spring through autumn.

Beneficial Insects and Mites

When not exposed to broad-spectrum insecticides, beneficial insects thrive in agroecosystems that have both pollen and nectar sources within the cover crop or flowering plants in refuge islands (Ioriatti et al., 2008; Fig. 3). All vineyard insect pests have an at-

Fig. 4. Predatory mirid nymph (*Deraeocoris brevis*), a predator of mites, leafhoppers and mealybugs. (Photo: D. James)

tendant complex of natural enemies. Most of these beneficial insects or complexes either parasitize or feed on insect pests, helping to decrease the overall population of detrimental pests in the vineyard (Fig. 4).

Parasitic wasps or 'parasitoids' are important biological control agents of leafhoppers, mealybugs and scale insects in Washington grapes. Mymarid wasps in the genus *Anagrus* (Fig. 5) are minute, but play an enormous role in regulating leafhopper populations (English-Loeb et al., 2003; Nicholls et al., 2000; Triapitsyn, 1998; Williams and Martinson, 2000). *Anagrus* parasitize leafhopper eggs, turning them red, enabling a simple assessment of parasitism levels by monitoring leaves and eggs in spring. Parasitism levels of 10 percent or more in early spring indicate that early summer levels of parasitism will be sufficient to keep leafhopper populations under economic damage thresholds (English-Loeb et al., 2003). *Anagrus* overwinter as dormant immatures within the eggs of other leafhopper species like the rose leafhopper *Edwardsiana rosae* L. Encouraging overwintering populations of rose leafhoppers in or near vineyards by cultivating plants in the Rosaceae family like roses, plums and blackberries, provides overwintering hosts for *Anagrus* and facilitates rapid access to vines and grape leafhopper eggs in the spring (Böll et al., 2007; Murphy et al., 1998; Nicholls et al., 2001; Prischmann et al., 2007).

Predatory mites in the family Phytoseiidae are important biological control agents of spider mites and rust mites (eg., James et al., 1995; McMurtry and Croft, 1997; Prischmann et al., 2005; Prischmann et al., 2006) (Fig. 4). In addition, some species of mites in the family Tydeidae are mite predators and can aid in biological control late in the season (Flaherty and Hoy, 1971). Populations and the diversity of phytoseiids in western US vineyards have improved substantially with the decrease in BSI usage, enhancing biological control of grapevine mites (English-Loeb et al., 1986; Tuovinen and Rokx, 1991). Many species of tydeid mites are fungivorous and potentially could spread grape downy mildew (*Uncinula necator* Schwein) in the vineyard (Duso et al., 2005). However, other studies have found that they can control grape powdery mildew (English-Loeb et al., 1999). Further improvements in the maintenance and sustainability of predatory mite populations will ensue with greater use of ground covers and habitat refugia by grape growers (English-Loeb et al., 2003; James et al., 2013).

Ecological Diversity in the Vineyard

Enhancing the vineyard ecosystem by establishing native plant refuge islands, insectaries, and ground covers within vineyard rows is not a new concept in global viticulture. In the US, establishing such beneficial insect refugia is being integrated into guidelines for sustainable grape production (e.g., Low Input Viticulture and Enology, http://www.live.org; Central Coast Vineyard Team, http://www.vineyardteam.org/; VineWise, http://vinewise.org; VineBalance, http://www.vinebalance.com). Several US wineries have established insectaries, which not only attract beneficial insects, but serve an aesthetic purpose as well. Native plant refuge islands and insectaries attract multiple species of beneficial insects (e.g., Landis et al., 2000; Pontin et al., 2006; Thomas et al., 1991), and help to diversify a typical "monoculture" system of grapevines (English-Loeb et al., 2003; Scarratt et al., 2008). Monocultures are generally characterized by pest outbreaks and enhancing the biodiversity within these systems allows predators and pests to come into equilibrium. In many vineyards that have been farmed as monocultures, diversity in the ecosystem can be increased simply by introducing a green or flowering cover crop, preferably one with an abundance of nectar and pollen to attract beneficial insects. Staggering flowering periods will ensure that there is season-long availability of pollen and nectar to maintain a strong beneficial insect population (Altieri et al., 2005; Nicholls et al., 2000). In addition, a successful refuge island, insectary, or flowering cover crop will re-seed each year to contribute to a strong stand of flowers without additional input of new plant material (Landis et al., 2000; Thomas et al., 1991). Furthermore, this effort is enhanced if neighboring vineyards, orchards or other perennial cropping systems adopt this ideal to increase ecodiversity in the overall area (Kogan, 1998; Prokopy, 1994).

Native plant refugia within or near vineyards can serve as more than just reservoirs of biological control agents. They can also serve a broader purpose of helping to restore natural communities/conservation zones of wildlife that existed prior to the establishment of vineyards and other cropping systems (Fiedler et al., 2008; Landis et al., 2000). This concept is already being adopted in the Waipara Valley wine growing region of New Zealand with much success (Tompkins, 2008; http://www.waiparawine.co.nz/index.cfm/Research/GreeningWaipara), and is now being developed in Washington State (James et al., 2013).

Fig. 5. A species of Ichneumonid wasp. Many are parasitoids of cutworms. (Photo: D. James)

One caveat with establishment of refuge islands and insectaries is that the beneficial insect population within these sometimes does not suppress pests across an entire vineyard. Often, the impact of these beneficial insects is reflected only in vineyard rows immediately surrounding the refuge island or insectary. Thus, it is important that refuge islands are distributed appropriately throughout the crop acreage in order to be most effective (Altieri et al., 2005; Nicholls et al., 2001).

Cover cropping in various perennial fruit crops is used to benefit ecosystems in both conventional and organic production systems attracting and retaining insect populations that can benefit and diversify the vineyard ecosystem. Other positive aspects of cover cropping in vineyards include decreasing soil erosion caused by wind or water, improving soil nutrition profiles, altering soil microbial populations and improving soil physical characteristics (e.g., Baumgartner et al., 2009; Bugg et al., 1996; Hartwig and Ammon, 2002; Langdale et al., 1991; Steenwerth and Belina, 2008). Alternatively, from a negative aspect, cover crops can also increase competition for nutrients and water, increase frost damage (depending upon cover crop height), attract additional pests, decrease vine vigor, and may introduce weed species that can "escape" and become invasive (e.g., Bermudagrass [*Cynodon dactylon* L.]) (Perry, 1998; Ripoche et al., 2011; Tesic et al., 2007).

The benefits of ground covers or cover crops in vineyards have been amply demonstrated in research in other parts of the world (e.g., Barnes et al., 2010; Gurr et al., 2003; Landis et al., 2000; Zehnder et al., 2007). Research in Washington is confirming the value of ground covers in increasing and retaining populations of beneficial insects (Grasswitz and James, 2009, James et al., 2013). An additional research focus has been to develop attractants for beneficial insects using synthetic versions of chemicals that plants produce when attacked by pests, i.e., Herbivore-Induced Plant Volatiles-HIPV (James, 2005; James and Price, 2004). One of these chemicals, methyl salicylate, when dispensed in Washington State vineyards in slow release sachets (50-100 per acre or 125-250 per hectare) has consistently produced significant increases in the density of a number of predators and parasitoids including mite eating ladybeetles, minute pirate bugs, lacewings and *Anagrus* (James and Grasswitz, 2005; James and Price, 2004). Research in Australian vineyards has provided similar results (Simpson et al., 2011). Concomitant decreases in pest populations have also been observed in some instances (James and Price, 2004; Simpson et al., 2011; Woods et al., 2011).

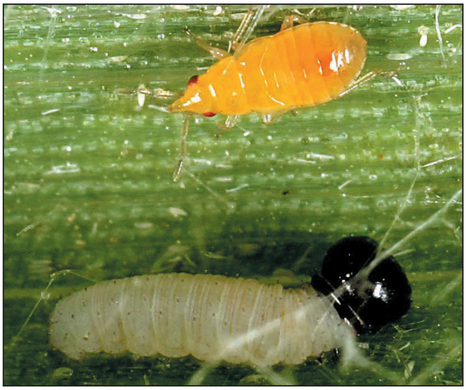

Fig. 6. Minute Pirate Bug (*Orius tristicolor*) nymph preparing to attack a caterpillar. (Photo: D. James)

Washington State Case Study in Attraction of Beneficial Insects

In 2005, a cover crop project was initiated to improve the attraction and retention of beneficial insects in vineyards located in the Columbia Valley of Washington State, USA. While many viticultural areas are capable of sustaining a cover crop between vineyard rows, much of eastern Washington lies in the rain shadow of the Cascade Mountains, resulting in a dry, desert climate. Vineyards in this area receive an average of 250 mm of rain per year, with much of the precipitation falling between November and April. Therefore, the majority of vineyard acreage in eastern Washington is drip-irrigated with no additional water applied between the vineyard rows, in the interest of water conservation and efficiency. Thus, cover crop choices must be made with this desert climate in mind and drought tolerance is of utmost importance.

Successful cover crop establishment in these inland desert areas is often achieved by autumn plantings between vineyard rows with protected seedlings (i.e., drilled into the ground or broadcast seeded and rolled into the ground). A number of cover crop species that had been used in previous research experiments were evaluated (Olmstead et al., 2001); however few of these had flowering sources that contained nectar and/or pollen to attract beneficial insects. Thus the objective of this experiment was to investigate the ability of a flowering cover crop mix to attract and retain beneficial insects for drip-irrigated vineyards in Washington State.

Materials and Methods. This study was conducted in a conventionally managed vineyard site located in Prosser, WA (46°, 119.7°) and in an organically certified vineyard site, located in Paterson, WA (46°, 119.8°) during the 2005-2007 growing seasons. Vine spacing in both vineyards was 1.8 m between vines and 3.1 m between rows and all vines were drip irrigated. Cover crops were seeded between the vine rows in 100 m^2 plots that encompassed three vineyard rows. The experiment was set up with a randomized complete block design (N = 4). Data from vines and cover crop plots were taken from the middle of the three rows to avoid plot borders. No supplemental irrigation was applied to the row middles where cover crop treatments were planted.

The treatments were a control, which consisted of resident vegetation (both native and weed species), an annual cereal rye (*Secale cerale* L.; standard practice in many vineyards, seeded at 67 kg·ha^{-1}), a drought tolerant medic mix (consisting of Barrel Medic [*Medicago truncatula* Gaertn.], Burr Medic [*Medicago polymorpha* L.], and Snail Medic [*Medicago scutellata* L. Miller]; Peaceful Valley Farm and Garden Supply, Grass Valley, CA, USA; seeded at 28 kg·ha^{-1}), and a flower mix containing several flowering species (Silver Falls Seed Company, Silverton, OR). The flowers were seeded at various rates: California poppy (*Eschscholzia californica* Cham.; seeded at 9 kg·ha^{-1}), California bluebell (*Phacelia campanularia* A. Gray; seeded at 3.4 kg·ha^{-1}), Bachelor's button or cornflower ('Dwarf Blue'; *Centaurea cyanus* L.; seeded at 4.5 kg·ha^{-1}), sweet alyssum (*Lobularia maritima* L.; seeded at 2.2 kg·ha^{-1}), and dwarf candytuft (*Iberis umbellata* L.; seeded at 16.8 kg·ha^{-1}). The cereal rye was drilled with a grass drill (Tye grass drill, AGCO, Duluth, GA) during November (autumn) to take advantage of winter precipitation for germination and growth. Seeds were raked in by hand in 2005, while in 2006, seeds were incorporated with a ring roller (Brillion Farm Equipment, Brillion, WI, USA).

Aerial insect populations were monitored with yellow sticky traps placed in three locations in the middle of each treatment plot and collected biweekly (Great Lakes IPM, Vestaburg, MI). Leaf samples were collected biweekly throughout the growing season to monitor key beneficial and pest insects. Sweep samples were collected biweekly throughout the growing season to monitor insects in the cover crop treatments.

All data were analyzed using General Linear Models performed using SAS v.9.2 (SAS Institute, Inc., Cary, NC).

Results and Discussion. Throughout the first two growing seasons (2005 and 2006), autumn-seeded establishment of the flowering mix was poor (less than 50%). In fact, there was such poor establishment of the drought tolerant medic mix, that this treatment was eliminated from the study. In addition, sweet alyssum and dwarf candytuft were eliminated from the flower mix, and flowering buckwheat (*Fagopyrum esculentum* Moench; seeded at 84 kg·ha^{-1}) was added in 2007, which had shown some success in a separate beneficial insect study in south central Washington State (Grasswitz and James, 2009). Despite the poor establishment, beneficial insect populations were higher in the final year of this project (Fig. 7).

Specific insects found in the flowering mix included minute pirate bugs (*Orius* spp.), big-eyed bugs (*Geocoris pallens* Stäl), and parasitic wasps, all of which can have an impact on pest populations in eastern Washington vineyards (data not shown). Thus, despite the low germination rate, the presence of these flowering mixes attracted significant populations of beneficial insects. For growers interested in attracting beneficial insect populations to their vineyard, planting a drought-tolerant reseeding annual flower or perennial flower can provide nectar sources that attract and help in keeping these beneficials in their vineyard.

One caveat to this experiment was that these beneficial insects tended to stay in the ground cover provided, and the next step in the research is to encourage them to feed on insect pests within the vine canopy. This has been a challenge with similar research (Berndt et al., 2006; Costello and Daane, 1998). One solution might be to mow alternative rows of cover crop to force beneficial insects into the vine canopy. Growers that mow every row of the cover crop face dwindling beneficial insect populations, as this action can be fatal for many of these insects. Another solution is to plant a greater diversity of flowering cover crops including more native plants that thrive with low water applications. Although one cover crop flowered throughout the season, a greater diversity of flowers that bloom for periods throughout the growing period will help to sustain beneficial

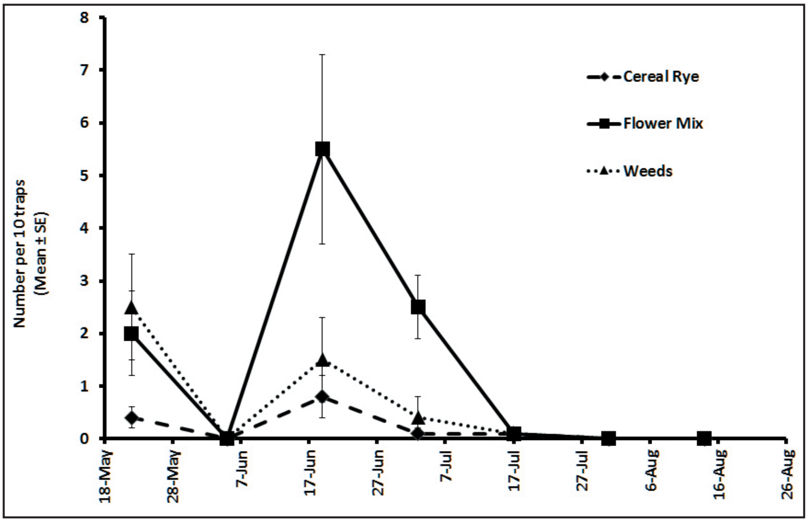

Fig. 7. Beneficial insects (predominantly *Orius* spp.) found in an organic vineyard in Washington State designed to enhance attraction and retention of these populations using flower mixes between vineyard rows in 2007. Rye (*Cereale secale* L.), a flower mix containing California poppy, California bluebell, Bachelor's button, sweet alyssum and dwarf candy tuft were planted between vineyard rows. A control containing resident vegetation (weeds) was also included for comparison. Error bars are reported as the SE of the mean.

insect populations.

Conclusions

Understanding the variability in abundance and distribution of pest species and their associated predators is a key component to successful implementation of techniques to reduce BSI usage in agricultural systems. In inland desert systems with lower insect pest pressure, manipulating the ecosystem can be successful to increase beneficial insect populations. However, further research is needed on how to increase beneficial insect populations sufficiently before pests increase, as well as to identify groups of plant species that will sustain these beneficial insects throughout the season.

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