MONITORING AND MANAGEMENT OF MEALY PLUM AND LEAF-CURL PLUM APHIDS USING SEX PHEROMONES

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OBJECTIVES

1. Investigate whether aphid sex pheromones may be used to develop monitoring protocol for mealy plum and leaf-curl plum aphids in dried plum orchards.
2. Explore the use of aphid sex pheromones for mating disruption of mealy plum and leaf-curl plum aphids in dried plum orchards.

This project addresses two primary pests that affect the production of California's dried plum crop, mealy plum aphids, *Hyalopterus pruni*, and leaf-curl plum aphids, *Brachycaudus helichrysi*. Spring populations of mealy plum aphids and leaf-curl plum aphids inflict significant damage to the crop as a result of both feeding activity and the production of honeydew. Improving monitoring practices and providing reduced-risk alternatives to dormant insecticide treatment may reduce the number of insecticide applications, thereby reducing grower costs and impacts on the environment.

In the major dried plum ('prune') producing regions of California, mealy plum aphids (MPA) and leaf-curl plum aphids (LCPA) exhibit holocyclic heteroecious life cycles involving alternating generations. In late winter/early spring, viviparous females emerge from overwintering eggs laid on prune trees (the primary host) during the previous fall. A series of parthenogenetic (asexual) generations then occurs on prune trees prior to migration of the aphids to their secondary hosts. These spring populations of MPA and LCPA on prune trees are responsible for inflicting injury resulting in damage to the prune crop. Migration of MPA and LCPA to their secondary hosts from the prune crop occurs during late spring to early summer. The aphids remain on the secondary hosts throughout summer, reproducing asexually. The sexual stage of the life cycle begins in fall when winged gynoparae produced on the secondary host migrate back to the primary host (prune) and produce a generation of egg-laying wingless oviparae. Within a few weeks of migration of gynoparae to the primary host, winged males, also produced on the secondary host, migrate to the primary host where they locate and mate with adult oviparae. Overwintering eggs are then laid near the bases of buds and will give rise to damaging spring populations. Given the nature of the aphid life cycle, the current research is focused on management tactics that target the sexual phase of the life cycle, which occurs in prune orchards during fall. Disrupting the life cycle at this point may reduce the abundance of fertile overwintering eggs, leading to a decrease in damaging spring populations.

During the sexual generation, males locate oviparae for mating utilizing a sex pheromone released by oviparous adult females. To date, all aphid species investigated produce and release sex pheromones in which the active components are the cyclopentanoid compounds nepetalactone and nepetalactol (Hardie et al. 1999). Air entrainment bioassays of adult oviparae of a number of aphid species indicate that the ratio of the two pheromone components is

relatively species-specific (Sewart-Jones et al. 2007, and references therein). In the cases of MPA and LCPA, air entrainment of adult oviparae indicated that the sex pheromones of the two species also are blends of the (4aS, 7S, 7aR)-nepetalactone isomer and the (1R, 4aS, 7S, 7aR)-nepetalactol isomer (Symmes et al., submitted). These have been shown to be the isomers released by the majority of aphid species examined thus far (Sewart-Jones et al. 2007, and references therein). Volatile analyses of laboratory aphid strains indicated that the sex pheromone ratio emitted by United Kingdom (UK) strains of MPA and LCPA contained 2.5:1 and 2.6:1 ratios of nepetalactone:nepetalactol, respectively. Samples collected from a California strain of MPA contained a 3.4:1 nepetalactone:nepetalactol ratio (Symmes et al., submitted).

Nepetalactone is a naturally occurring compound found in catnip, *Nepeta cataria* (Lamiaceae). Nepetalactone can be obtained in high yield from fresh plant material via a steam distillation process, after which nepetalactol can be acquired via a chemical reduction of nepetalactone (Birkett and Pickett 2003). Experimental pheromone lure products of the common isomers (those utilized by MPA and LCPA) of each compound have been formulated using polymer extrusion technology. This formulation prevents UV degradation and oxidation of the compounds and provides a slow and consistent release rate. The product is produced in the form of flexible polyvinyl chloride (PVC) polymer strips (‘ropes’) formulated as 5% extrusions of each compound separately. The rope can then be cut to various lengths to achieve the desired ratio and release rates of the two sex pheromone components. Standard lure lengths provide a minimum release of 200 micrograms/day, stable for up to one month (Birkett and Pickett 2003).

Current monitoring practices for MPA and LCPA in prune orchards, as outlined in the University of California’s Pest Management Guidelines (Pickel et al. 2009), include dormant season spur samples aimed at detecting overwintering aphid eggs. The UC guidelines recommend treatment if one aphid egg is found in 100 spur samples. However, the guidelines also state that the absence of aphid eggs in spur samples is not conclusive evidence that aphids will not be a problem, and that orchard history should be used as an additional guideline. Another obstacle concerning dormant sampling for aphid eggs is that it can be difficult and time-consuming, even for well-trained individuals, to detect the eggs. These factors impact the reliability and practicality of the current monitoring protocol and often result in the majority of orchards being treated during the dormant season, often without quantification of the actual overwintering population. Development of a reliable method to assess the population density of return migrants that give rise to the overwintering and subsequent spring populations could be a valuable tool in the management of MPA and LCPA in prune orchards.

Presently, the most common practice for managing aphids in prune orchards involves the application of a dormant insecticide treatment, usually a pyrethroid or organophosphate with or without oil. As occurs with the application of any management tactic, there are concerns with insecticide treatment during the dormant season, namely runoff and water quality issues. Changing the dormant spray timing to mid-fall could help mitigate runoff issues, but monitoring of MPA and LCPA in the fall becomes even more critical. The use of aphid sex pheromones for monitoring and/or mating disruption has yet to be widely researched, likely because many of the most severe aphid pests affect the secondary host plant, where reproduction is strictly asexual. The fact that MPA and LCPA are pests of the primary host plant provides an ideal system in

which to investigate the potential for exploiting the sexual stage of their life cycle to improve management practices.

The overall objectives of this research focus on utilizing the sex pheromones of MPA and LCPA to improve upon current monitoring recommendations and to investigate whether sex pheromones can be used to effectively disrupt mating and thereby reduce damaging spring populations.

Our initial studies examining the impacts of pheromone lures of various ratios on trap captures of aphids in the prune cropping system demonstrated that the greatest numbers of male MPA were caught in traps releasing a 1:1 ratio of the (4a*S*, 7*S*, 7a*R*)-nepetalactone and (1*R*, 4a*S*, 7*S*, 7a*R*)-nepetalactol pheromone components and catches of male LPCA were greatest in traps releasing any of the two-component pheromone ratios tested. There was no evidence that any of the pheromone treatments affected trap catches of gynoparae of either species. Results of these trials were detailed in a prior year's research report (Symmes and Zalom 2010).

PROCEDURES

Monitoring Trials

The overall objective of this study was to examine relationships among the numbers of aphids trapped during fall monitoring and overwintering egg densities, spring aphid populations and aphid-related fruit damage. In this experiment, we also assessed different trap designs for their utility in pheromone-based aphid monitoring. Seven experimental replicates were established in four commercial prune orchards in Sutter County, CA. Each replicate consisted of eight 25-tree plots (5x5 trees per plot) with a monitoring trap located in the center tree of each plot, and fall aphid monitoring occurred from 23-Sept-2010 through 6-Dec-2010. Eight trap design-pheromone treatment combinations were included in each replicate; four different trap designs were assessed and each trap design was represented twice per replicate, once baited with a pheromone lure and once without. Based on our earlier studies in this system, pheromone lures were comprised of a 1:1 ratio of the aphid sex pheromone components (4a*S*, 7*S*, 7a*R*)-nepetalactone and (1*R*, 4a*S*, 7*S*, 7a*R*)-nepetalactol at the standardized release rate of approximately 200 microgram/day; lures in pheromone-baited traps were replaced every fourth week. The following trap designs were evaluated: white delta traps (Pherocon® IIB, Trécé, Inc.), white sticky traps, deployed as two-sided sticky cards (Pherocon® V Tent Trap, Trécé, Inc.), water traps (made from clear 16-oz. polyethylene terephthalate (PET) containers, No. DM16-0090, Solo Cup Co., Urbana, IL), and two-sided yellow sticky cards (Pherocon® AM/NB, Trécé, Inc.). The monitoring traps were processed weekly and aphid numbers quantified. In February 2011, a minimum of 100 spur samples (spurs = the short shoots containing the flower buds), each containing at least two flower buds (on the bases of which aphids deposit overwintering eggs), were collected from all four compass quadrants of each of the 25 trees per monitoring plot, and overwintering aphid egg numbers were quantified in the laboratory using a dissecting microscope. The experiment was designed to compare a number of parameters among treatments: (1) efficiency (numbers of aphids trapped); (2) selectivity (numbers of aphids relative to non-target arthropods trapped); (3) predictive value (relationships between fall aphid trap catches and subsequent overwintering aphid egg densities, spring aphid populations, and fruit damage ratings); (4) convenience of use (preparation time in the laboratory and handling time in

the field); (5) ease of processing (time required to process traps, i.e., quantify aphids, in the laboratory); and (6) cost (price per trap design-pheromone treatment combination).

Measures associated with aphid abundance were generated based upon total numbers of aphids of all genders and species trapped, rather than total numbers of the primary pest species in prune orchards (MPA and LCPA). This was due, in part, to the difficulty in proper species identification, particularly of male aphids when definitive host plant associations are unavailable; aphids captured in pheromone traps during the fall migratory period are not necessarily colonizers of the crop in which they are trapped. Additionally, precise species identification of aphids trapped in glue-based traps (in this study the delta traps, and white and yellow sticky cards) can be problematic if aphids are damaged prior to or during removal from the traps. Moreover, the objective of our study focused on evaluating trapping criteria for practical application, which typically involves family-level taxonomic identification of trapped aphids by end-users. Therefore, our analyses sought to evaluate trapping criteria based on total numbers of aphids trapped, rather than totals of particular species trapped. To analyze the efficiency parameter, numbers of aphids captured in each trap design-pheromone treatment combination were summed over the fall trapping period and $\log_{10}(x+1.5)$ transformed. For the selectivity parameter, all arthropods trapped in each treatment were summed over the fall trapping period and the percent of aphids relative to non-target arthropods trapped was calculated and $\log_{10}(x+0.5)$ transformed. Data for each measure were analyzed using analysis of variance (ANOVA) followed by Tukey's honestly significant difference (HSD) means separation test.

Evaluation of the predictability parameter involved linear regression analyses of the total numbers of aphids captured during the fall trapping period for each trap design-pheromone treatment combination in relation to the overwintering egg densities in the associated monitoring plots. The experiment was originally designed to assess spring aphid populations and to obtain fruit damage ratings in 2011 from the same monitoring plots. However, due to an unexpected and abrupt change in property ownership in February 2011, and subsequent conventional insecticide applications to experimental blocks, samples of aphid populations and aphid-related fruit damage planned for spring and summer 2011 were not possible to obtain and therefore were unavailable for correlation analyses with numbers of aphids trapped during the fall monitoring season.

Convenience of use and ease of processing were assessed using a rating scale where each trap design-pheromone treatment combination was assigned a numeric rank based on the time required for preparation and handling (convenience of use) and aphid quantification (ease of processing), with a value of one representing the least time required and a value of eight representing the most time required. Costs associated with each trap type were compared by calculating the price ($USD) per trap design-pheromone treatment combination.

Mating Disruption Trials

Experiments to investigate the potential for mating disruption of MPA and LCPA were established in fall 2010 in commercial prune orchards in Sutter County, CA. Five experimental replicates, in separate orchards, were initiated on 19-Oct-2010, each consisting of two 9-tree plots (3x3 trees per plot). Because of the nature of the aphid life cycle and biology (i.e., the fact that mated females are wingless), we were able to use much smaller mating disruption plots than

are feasible with other insect pests (e.g., Lepidoptera) because there is no possibility of mated females from outside the treatment area migrating into mating disruption treatment plots and laying eggs. For each replicate, one plot was treated with pheromone (mating disruption) and one plot was left untreated (control). Mating disruption plots were treated with 27 individual pheromone lures (3 lures/tree), a rate equivalent to the approximately 400 hand dispensers per acre recommended for hand-dispensed pheromone lures used in mating disruption for a number of insect pest species. A pheromone-baited trap, located in the center tree of each three-by-three tree mating disruption and control block, was used to evaluate the impact of mating disruption treatments throughout the fall (27-Sept-2010 through 7-Dec-2010); these traps were processed weekly and aphid numbers quantified. Based on our earlier studies in this system, pheromone lures in mating disruption blocks and in pheromone-baited traps were comprised of a 1:1 ratio of the aphid sex pheromone components (4a*S*, 7*S*, 7a*R*)-nepetalactone and (1*R*, 4a*S*, 7*S*, 7a*R*)-nepetalactol at the standardized release rate of approximately 200 microgram/day; disruption and trap lures were replaced at week four of the experiment. There was a minimum of 150 meters between mating disruption and control plots to minimize the likelihood of pheromone drift between the plots. To examine the impacts of mating disruption treatments on overwintering egg densities, egg samples were obtained in February 2011. A minimum of 108 spur samples, each containing at least two flower buds, were collected from all nine trees in each mating disruption and control plot, taking at least three spur samples from all four compass quadrants of each tree. Overwintering aphid egg numbers were quantified in the laboratory using a dissecting microscope.

The following comparisons between mating disruption and control plots were planned for this experiment: numbers of male MPA and LCPA in pheromone-baited traps during the fall, overwintering egg densities, spring MPA and LCPA populations, and aphid-related fruit damage. However, as reported above for the monitoring trials, samples of aphid populations and aphid-related fruit damage planned for spring and summer 2011 were not possible to obtain and therefore were unavailable for comparison between mating disruption and control plots.

Due to the formulation of the pheromone lures being used in these experiments (i.e., the pheromone is ‘contained’ in hand-dispensers rather than sprayed on and dispensers can be easily removed from the environment following the experiments) and the timing of application (pheromone application occurs post-harvest and pheromones are never in the environment at the same time as the harvestable product), clearance for mating disruption experiments was obtained from the California Department of Pesticide Regulation under the University’s research exemption without the need for additional research authorization or other precautions often required for mating disruption experiments.

Natural enemy responses to sex pheromone lures

During the experiments conducted in fall 2008 (1-Oct-2008 through 10-Dec-2008) examining the responses of MPA and LCPA to lures comprised of various ratios of the aphid sex pheromone components, there also was evidence that pheromone baiting impacted trap catches of natural enemies, namely adult green lacewings (Neuroptera: Chrysopidae) and adult female Aphidiinae parasitoids (Hymenoptera: Braconidae). In this study, eighteen replicates of a randomized complete block design were established across four prune orchards in Yolo and Sutter Counties, CA. Pheromone-baited water traps were deployed in the tree canopy utilizing

the hand-applied pheromone PVC rope product with the following (4a*S*, 7*S*, 7a*R*)-nepetalactone:(1*R*, 4a*S*, 7*S*, 7a*R*)-nepetalactol ratios tested in the experiment: 1:0, 0:1, 1:1, 2.6:1, 3.4:1, 5:1, 7:1, and 0:0 (no-pheromone control), each at the standardized total release rate of approximately 200 micrograms/day. Traps were changed, processed, and re-randomized within replicates weekly, and pheromone lures were changed at weeks four and eight of the experiment. The numbers of adult green lacewings (Neuroptera: Chrysopidae) and female Aphidiinae (Hymenoptera: Braconidae) parasitoids were quantified for each pheromone ratio treatment tested. Trap counts were summed over the trial, square root (x+0.5) transformed, and analyzed by (ANOVA) followed by Tukey's HSD means separation test.

RESULTS AND CONCLUSIONS

Monitoring Trials

The total numbers of aphids and non-target arthropods trapped during the fall 2010 monitoring period by trap design-pheromone treatment combination are shown in Table 1 and weekly totals of aphids trapped by treatment are shown in Figure 1. The overall trends in the numbers of aphids trapped each week throughout the monitoring period were similar in pheromone-baited traps of all four designs, with peak trap catches occurring during the third week of October for delta, white sticky, and water traps, and one week later for yellow sticky traps. Yellow sticky traps exhibited a greater sustained high level of trap catches throughout November than did the other pheromone-baited trap designs, which tended to exhibit single distinct peaks in trap captures, followed by reduced numbers trapped for the remainder of the monitoring period. Weekly aphid catches among non-baited trap designs exhibited less correspondence than the pheromone-baited traps, and most of the aphids in non-baited trap designs were caught during the first through third weeks of November.

Efficiencies of the trap design-pheromone treatment combinations, represented as the mean number of aphids (± SE) trapped during the fall 2010 monitoring season are shown in Figure 2. These data confirm that the addition of pheromone lures to each trap design increased aphid trapping efficiency as each trap design deployed with a pheromone lure caught significantly more aphids than did the non-baited counterparts of the same design. Among the pheromone-baited treatments, yellow sticky cards were the most efficient, trapping the highest percentage of aphids, and there were no significant differences among the efficiencies of the remaining three pheromone-baited trap designs, nor were there differences among baited delta traps, white sticky cards, and water traps when compared to non-baited yellow sticky cards (ANOVA, followed by Tukey's HSD test, $F = 26.09$, df = 7, 42, $P < 0.0001$).

Selectivity of the trap design-pheromone treatment combinations, represented as the mean percent of aphids relative to non-target arthropods (± SE) trapped during fall 2010 are shown in Figure 3. The results indicate that the selectivity of each trap type was increased by the addition of the pheromone lure, as each pheromone-baited trap caught a significantly greater percent of aphids relative to non-target arthropods when compared to non-baited traps of the same design. For the pheromone-baited treatments, delta and water traps were more selective than yellow sticky cards and there was no difference in the selectivity of white sticky cards when compared to delta traps, water traps or yellow sticky cards. There were no differences in the selectivity measure among any of the non-baited trap designs, nor were there statistical differences among

non-baited delta traps, white sticky cards, and water traps compared to pheromone-baited yellow sticky cards (ANOVA, followed by Tukey's HSD test, $F = 22.29$, df = 7, 42, $P < 0.0001$).

Predictive values of the trap design-pheromone treatment combinations, expressed by linear regression statistics for numbers of aphids trapped during fall 2010 in relation to overwintering egg densities in associated monitoring plots is shown in Table 2. As described in the procedures section, analyses of the relationships between numbers of aphids trapped during the fall monitoring period and spring aphid populations and aphid-related fruit damage were not possible. Only pheromone-baited yellow sticky cards showed a statistically significant relationship between numbers of aphids trapped and overwintering egg densities ($P = 0.0488$) and pheromone-baited white sticky cards exhibited a strong trend between numbers of aphids trapped and overwintering egg densities ($P = 0.0701$). The remaining treatments indicated no associations between numbers of aphids trapped during fall and overwintering aphid egg densities.

A summary of the monitoring parameters examined in this study is presented in Table 3, including the convenience of use and ease of processing criteria, generated from on our experiences servicing the traps throughout the course of the experiment, and economic measures associated with the various treatments. In descending order from most convenient (i.e., least preparation and handling time required) to least convenient (i.e., most preparation and handling time required) were delta traps, white sticky cards, yellow sticky cards, and water traps. In all cases the addition of pheromone lures increased preparation and handling time slightly for each trap type. Differences in processing time for traps in the various treatments were the result of differing amounts of time required to quantify aphids on traps due to the numbers of non-target arthropods and debris also trapped as well as the trapping medium (i.e., water versus trap glue). Ease of processing, in order from least time to most time, were non-baited then baited delta traps, baited then non-baited white sticky cards, non-baited then baited water traps, and finally non-baited then baited yellow sticky cards. Based on price per trap ($USD), from least to most expensive, were water traps, white sticky cards, yellow sticky cards, and delta traps. Water traps, in addition to having the lowest price per trap, can be reused for multiple monitoring seasons, assuming appropriate cleaning and storage. The pheromone lures used in this study are not yet commercially available; therefore their pricing cannot be determined. However, because equivalent lures were compared among trap types and replaced at the same intervals, the additional costs associated with placing lures in the traps would increase the price per trap equally.

In summary, the assessment of different trap designs for pheromone-based fall aphid monitoring revealed that pheromone-baited yellow sticky traps were highly efficient but exhibited reduced selectivity in trapping aphids. This was not unexpected, as aphids and many other phytophagous insect taxa are attracted to yellow surfaces. The lack of selectivity in trapping aphids can substantially increase the time required to quantify trapped aphids, as was the case in the current study, and may lead to confusion in distinguishing aphids when similar small arthropods are present in the trap. These factors render the yellow sticky cards less ideal than the other trap designs examined for pheromone-based aphid monitoring, despite their higher efficiency in trapping aphids. There were no statistical differences in efficiency or selectivity among the three remaining pheromone-baited trap designs, and similarities in the patterns of weekly trap catches

among the pheromone-baited delta traps, white sticky cards, and water traps indicated uniformity in their ability to accurately detect and track aphid populations throughout the fall monitoring period. However, the utility parameters (convenience of use, ease of processing) for delta traps and white sticky cards were superior to water traps, indicating that these may be the preferred trap designs for pheromone-based fall aphid monitoring. Cost associated with white sticky cards was less than half that required for delta traps. Overall economic input can be regarded as a combination of labor costs (indicated by the convenience of use and ease of processing measures) and material costs (price per trap); based on this economic approach, white sticky cards are overall the most cost-effective of the trap designs examined in the current study.

Unfortunately, due to our inability to obtain spring aphid population and fruit damage data in the current study, the applicability of the traps to forecast damaging pest population levels and/or economic crop damage remains somewhat unresolved. In the present study, the assessment of predictive value of the trap design-pheromone treatment combinations, represented by the correlation between numbers of aphids trapped during the fall and overwintering egg densities, indicated a significant relationship between fall aphid trap catches and overwintering egg numbers only in the pheromone-baited yellow sticky trap treatment. However, egg densities detected in our research blocks during the experimental season were low overall; in all cases egg densities were below current treatment guidelines of 1 egg per 100 spurs (Pickel et al. 2009). Additional research is therefore necessary to examine the predictive value of pheromone-baited trapping when densities of overwintering eggs are more substantial and to determine if pheromone trapping has an impact on the overwintering egg densities in the vicinity of the pheromone traps. Furthermore, experiments including assessment of subsequent spring aphid populations and crop damage are needed to determine if they can be predicted by numbers of aphids trapped during fall monitoring. Another season of monitoring experiments aimed at addressing these outstanding issues is currently underway for the 2011-2012 experimental period.

Mating Disruption Trials

A total of only four leaf-curl plum aphid males and no mealy plum aphids males were trapped throughout the entire fall monitoring season in this experiment. No aphid eggs were detected from the spur samples, and spring aphid and fruit damage samples were not possible (see procedures section); therefore, statistical analyses were not possible on data from the 2010-2011 mating disruption experiment. Mating disruption experiments are being repeated in the 2011-2012 experimental period.

Natural enemy responses to sex pheromone lures

Seasonal trap catches of adult green lacewings and adult female Aphidiinae (all pheromone ratio treatments and control traps combined) are shown in relation to trap catches of MPA and LCPA (Figure 4) and in relation to the total numbers of aphids of all species trapped throughout the fall monitoring period (Figure 5). The numbers of green lacewings trapped were greatest early in the monitoring period and generally declined throughout the fall, likely reflecting the natural seasonality and activity period of adult lacewings as they enter the overwintering phase of the life cycle. Peak trap catches of female Aphidiinae were synchronized with peak catches of MPA and overall aphids numbers; trap catches of LCPA were also relatively high during the week in which to majority of female Aphidiinae were trapped. In temperate regions, Aphidiinae

overwinter as larvae inside parasitized aphids (‘mummies’); the sexual aphid forms represent the last opportunity for parasitoids to secure hosts necessary for successful overwintering. As generalist predators, green lacewings have a large number of potential prey taxa and therefore likely rely less on aphid abundance in prune orchards compared to the aphid-specialized parasitoids, which is evidenced by the greater synchrony among trap catches of parasitoids and aphids in this study.

Table 4 shows the total numbers of the natural enemies trapped by pheromone ratio treatment over the fall 2008 trapping period, and Figures 6 and 7 show the mean numbers of adult green lacewings and adult female Aphidiinae trapped by pheromone ratio treatment, respectively. Green lacewings were trapped in greatest numbers in all of the pheromone ratios containing the nepetalactol component (Figure 6), while the results indicate that female Aphidiinae parasitoids were most affected by the ratios containing the nepetalactone component (Figure 7). Our findings are similar to a number of published reports indicating that nepetalactol is the key attractant for lacewings of a number of species (e.g., Boo et al. 1998, 2003, Zhu et al. 1999, 2005). Multiple studies also have reported on the behavioral activity (attraction, flight orientation, increased trap catches, increased parasitization) of aphid sex pheromones for a number of individual Aphidiinae species. Many reports have indicated that although responses tend to be registered to both individual pheromone components alone when compared to control, nepetalactone is the critical behaviorally-active component for the majority of the Aphidiinae species studied (Powell and Pickett 2003, and references therein). Most studies to date have examined the effects of each component individually or of equal ratios of the two components, very few testing the responses of specific Aphidiinae species to a range of ratios of the two components. It is possible that individual parasitoid species may selectively respond to distinct ratios of the aphid sex pheromone components based on their level of host selectivity and the ratios emitted by their particular aphid host species. In our study, the Aphidiinae as a subfamily level group appeared to exhibit the greatest response to the nepetalactone component. However, we detected at least ten different parasitoid species in our traps throughout the season (species identities not yet confirmed), therefore the impacts of pheromone lures of different ratios on the two key Aphidiinae parasitoids in the prune system, *Aphidius colemani* (LCPA parasitoid) and *Aphidius transcaspicus* (MPA parasitoid) require further investigation. In many agronomic environments, natural enemies often arrive too late after the onset of aphid infestation to provide economically significant reductions of pest populations. Application of pheromone technologies to impact natural enemies of aphid pests has been suggested to increase the level of synchronicity of aphid and natural enemy populations by attracting or arresting predators and parasitoids in the environment earlier in the stages of aphid infestation, thereby enhancing their abilities to more effectively reduce the pest populations (Powell and Pickett 2003). Our experiments showed attraction of natural enemies to pheromone-baited traps during the fall in prune orchards, however the likely practical application of pheromones to affect lacewing or parasitoid populations having the greatest impact would be aimed at enhancing management of the damaging spring aphid populations. Studies of the impacts of aphid sex pheromones on spring populations of natural enemies are necessary to determine the potential utility of this tactic in prune aphid management.

REFERENCES

Birkett, M. A., and J. A. Pickett. 2003. *Aphid sex pheromones: from discovery to commercial production.* Phytochemistry 62: 651-656

Boo, K. S., I. B. Chung, K. S. Han, J. A. Pickett, and L. J. Wadhams. 1998. *Response of the lacewing Chrysopa cognata to pheromones of its aphid prey*. J. Chem. Ecol. 24: 631-643.

Boo, K. S., S. S. Kang, J. H. Park, J. A. Pickett, and L. J. Wadhams. 2003. *Field trapping of Chrysopa cognata (Neuroptera: Chrysopidae) with aphid sex pheromone components in Korea*. J. Asia-Pac. Entomol. 6: 29-36.

Hardie, J., J. A. Pickett, E. M. Pow, and D. W. M. Smiley. 1999. *Aphids*, pp. 227-250. In J. Hardie and A. K. Minks (eds.), *Pheromones of Non-Lepidopteran Insects Associated with Agricultural Plants*. CAB International, Wallingford, UK.

Pickel, C., F. J. A. Niederholzer, W. H. Olson, F. G. Zalom, R. P. Buchner, and W. H. Krueger. 2009. *Insects and mites*. UC IPM Pest Management Guidelines: Prune, UC ANR Publication 3464. University of California Statewide IPM Program, Davis, CA.

Powell, W., and J. A. Pickett. 2003. *Manipulation of parasitoids for aphid pest management: progress and prospects*. Pest Manag. Sci. 59: 149-155.

Stewart-Jones, A., S. Y. Dewhirst, L. Durrant, J. D. Fitzgerald, J. Hardie, A. M. Hooper, J. A. Pickett, and G. M. Poppy. 2007. *Structure, ratios and patterns of release in the sex pheromone of an aphid, Dysaphis plantaginea*. J. Exp. Biol. 210: 4335-4344.

Symmes, E. J. and F. G. Zalom. 2010. *Monitoring and management of mealy plum and leaf-curl plum aphids using sex pheromones*. California Dried Plum Board Annual Research Reports. http://ucce.ucdavis.edu/files/repositoryfiles/2010-54-85732.pdf

Symmes, E. J., S. Y. Dewhirst, M .A. Birkett, C. A. M. Campbell, K. Chamberlain, J. A. Pickett, and F. G. Zalom. *The sex pheromones of mealy plum (Hyalopterus pruni) and leaf-curl plum aphids (Brachycaudus helichrysi): identification and field trapping of male and gynoparous aphids in prune orchards*. J. Chem. Ecol., submitted.

Zhu, J., A. A. Cossé, J. J. Obrycki, K. S. Boo, and T. C. Baker. 1999. *Olfactory reactions of the twelve-spotted lady beetle, Coleomegilla maculata, and the green lacewing, Chrysoperla carnea, to semiochemicals released from their prey and host plant: electroantennogram and behavioral responses*. J. Chem. Ecol. 25: 1163-1177.

Zhu, J., J. J. Obrycki, S. A. Ochieng, T. C. Baker, J. A. Pickett, and D. Smiley. 2005. *Attraction of two lacewing species to volatiles produced by host plants and aphid prey*. Naturwissenschaften 92: 277-281.

BUDGET SUMMARY

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Table 1. Total numbers of aphids and non-target arthropods trapped during fall 2010 in Sutter County, CA prune orchards by trap design-pheromone treatment combination.

Trap Design-Pheromone Treatment	Aphids	Total Non-Target Arthropods
Delta trap – lure	16	933
Delta trap + lure	229	986
White sticky card – lure	60	2831
White sticky card + lure	248	2055
Water trap – lure	19	1078
Water trap + lure	132	873
Yellow sticky card – lure	105	8909
Yellow sticky card + lure	553	13488

Table 2. Predictive value of the trap design-pheromone treatment combinations, expressed by linear regression statistics for numbers of aphids trapped during fall 2010 in relation to overwintering egg densities in associated monitoring plots.

Trap Design-Pheromone Treatment	Mean number (± SE) aphids trapped	Mean (± SE) overwintering egg density[a]	Slope	y-intercept	R^2	*F*	df	*P*
Delta trap – lure	2.29 ± 0.47	0.61 ± 0.31	-0.1490	0.9468	0.0524	0.2764	1, 5	0.6215
Delta trap + lure	32.71 ± 12.68	0.60 ± 0.60	0.0207	-0.0776	0.1915	1.1844	1, 5	0.3261
White sticky card – lure	8.57 ± 3.37	0.37 ± 0.26	0.0457	-0.0204	0.3568	2.7732	1, 5	0.1567
White sticky card + lure	35.43 ± 10.14	0.23 ± 0.23	0.0163	-0.3465	0.5132	5.2714	1, 5	0.0701
Water trap – lure	2.71 ± 0.57	0.64 ± 0.42	0.0067	0.6207	$8.275e^{-5}$	0.0004	1, 5	0.9846
Water trap + lure	18.86 ± 2.30	0.00 ± 0.00	0	0	0	0	1, 5	1.0000
Yellow sticky card – lure	15.00 ± 4.17	0.85 ± 0.72	0.0093	0.7146	0.0029	0.0146	1, 5	0.9085
Yellow sticky card + lure	79.00 ± 15.28	0.80 ± 0.55	0.0273	-1.3623	0.5730	6.7095	1, 5	0.0488

[a] Eggs/spur X 100.

Table 3. Summary of results assessing monitoring parameters of the trap design-pheromone treatment combinations for use in aphid management in prune orchards.

Trap Design-Pheromone Treatment	Efficiency[a]	Selectivity[b]	Predictive Value[c]	Convenience of Use[d]	Ease of Processing[e]	Cost[f]
Delta trap – lure	2.29 ± 0.47D	1.66 ± 0.25cd	0.6215	1	1	$1.99
Delta trap + lure	32.71 ± 12.68B	16.65 ± 5.62a	0.3261	2	2	$1.99 + lure
White sticky card – lure	8.57 ± 3.37CD	2.49 ± 0.85cd	0.1567	3	4	$0.92
White sticky card + lure	35.43 ± 10.14B	10.24 ± 2.80ab	0.0701	4	3	$0.92 + lure
Water trap – lure	2.71 ± 0.57D	1.80 ± 0.33cd	0.9846	7	5	$0.56
Water trap + lure	18.86 ± 2.30B	13.48 ± 1.87a	1.0000	8	6	$0.56 + lure
Yellow sticky card – lure	15.00 ± 4.17BC	1.10 ± 0.25d	0.9085	5	7	$1.36
Yellow sticky card + lure	79.00 ± 15.28A	4.61 ± 1.08bc	0.0488	6	8	$1.36 + lure

[a] Mean number (± SE) of aphids trapped. Treatments followed by the same letter are not significantly different (ANOVA, followed by Tukey's HSD test, $F = 26.09$, df = 7, 42, $P < 0.0001$). Data also represented in Figure 2.
[b] Mean percent (± SE) of aphids relative to non-target arthropods trapped. Treatments followed by the same letter are not significantly different (ANOVA, followed by Tukey's HSD test, $F = 22.29$, df = 7, 42, $P < 0.0001$). Data also represented in Figure 3.
[c] Significance (*P*-values) of regression analyses of numbers of aphids trapped during fall in relation to percent overwintering egg densities.
[d] Rank based on preparation time in the lab and handling time in the field (1 = least time required, 8 = most time required)
[e] Rank based on time required to process traps (count aphids) in the lab (1 = least time required, 8 = most time required)
[f] Price ($USD) per trap. Cost of lures not yet determined (experimentally available only). Water traps reusable. All other trap types single-use.

Table 4. Total numbers of natural enemies caught in water traps baited with different ratios of the aphid sex pheromone components nepetalactone and nepetalactol in prune orchards during fall 2008 pheromone ratio trials.

Pheromone ratio (lactone: lactol)	Total number of natural enemies	
	Adult Green Lacewings	Female Aphidiinae
0:0	75	4
1:0	100	29
0:1	300	6
1:1	222	18
2.6:1	243	20
3.4:1	193	19
5:1	218	17
7:1	202	19

Figure 1. Weekly totals of aphids trapped during fall 2010, by trap design-pheromone treatment combination. Non-baited delta traps (DLT-), baited delta traps (DLT+), non-baited white sticky cards (WSC-), baited white sticky cards (WSC+), non-baited water traps (WT-), baited water traps (WT+), non-baited yellow sticky cards (YSC-), baited yellow sticky cards (YSC+).

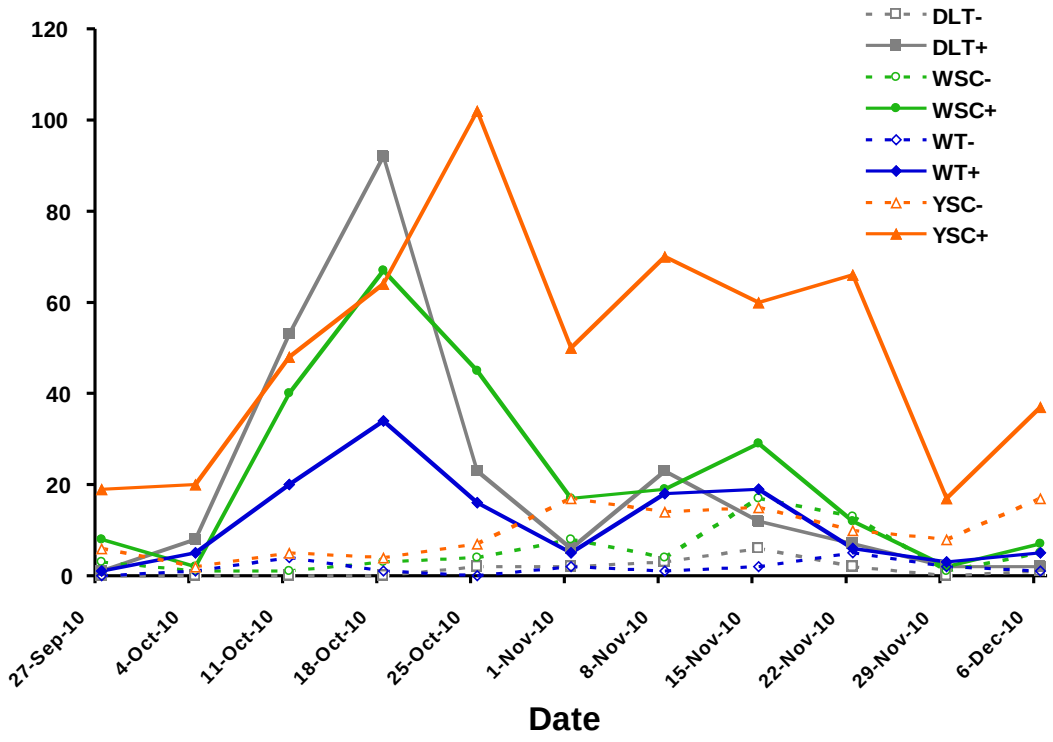

Figure 2. Efficiencies of the trap design-pheromone treatment combinations, represented as the mean number (± SE) of aphids trapped during the fall 2010 monitoring period. Trap counts summed over the fall monitoring period and data $\log_{10}(x+1.5)$ transformed for analysis. Non-transformed means ± SE presented. Treatments with the same letters are not significantly different (ANOVA, followed by Tukey's HSD test, $F = 26.09$, df = 7, 42, $P < 0.0001$).

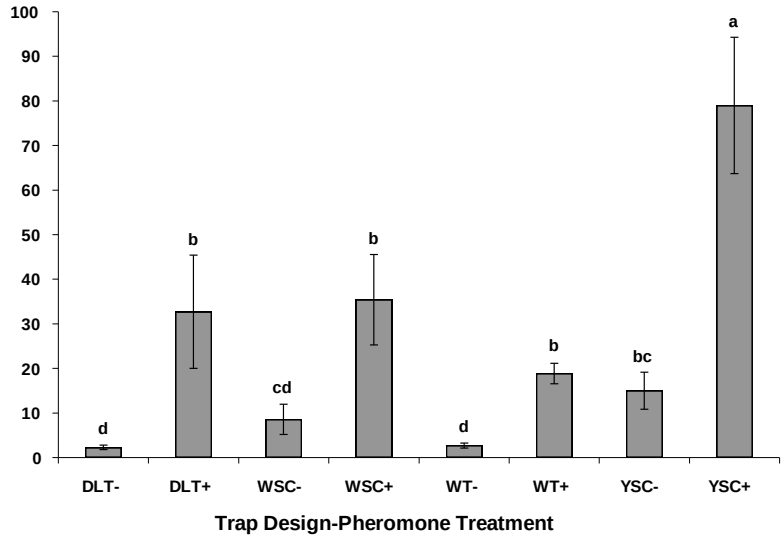

Figure 3. Selectivity of the trap design-pheromone treatment combinations, represented as the mean percent (± SE) of aphids relative to non-target arthropods trapped during the fall 2010 monitoring period. Trap counts summed over the fall monitoring period and data $\log_{10}(x+0.5)$ transformed for analysis. Non-transformed means ± SE presented. Treatments with the same letters are not significantly different (ANOVA, followed by Tukey's HSD test, $F = 22.29$, df = 7, 42, $P < 0.0001$).

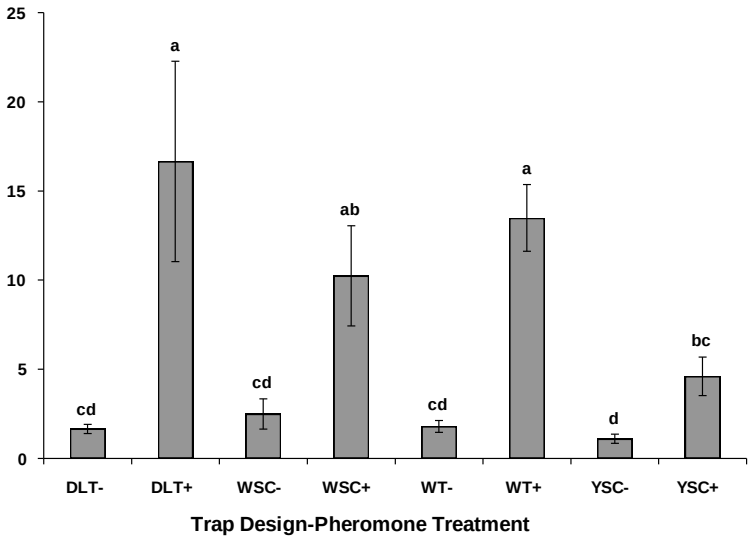

Figure 4. Weekly totals of LCPA, MPA, adult green lacewings, and adult female Aphidiinae caught in water traps during fall 2008 pheromone ratio trials.

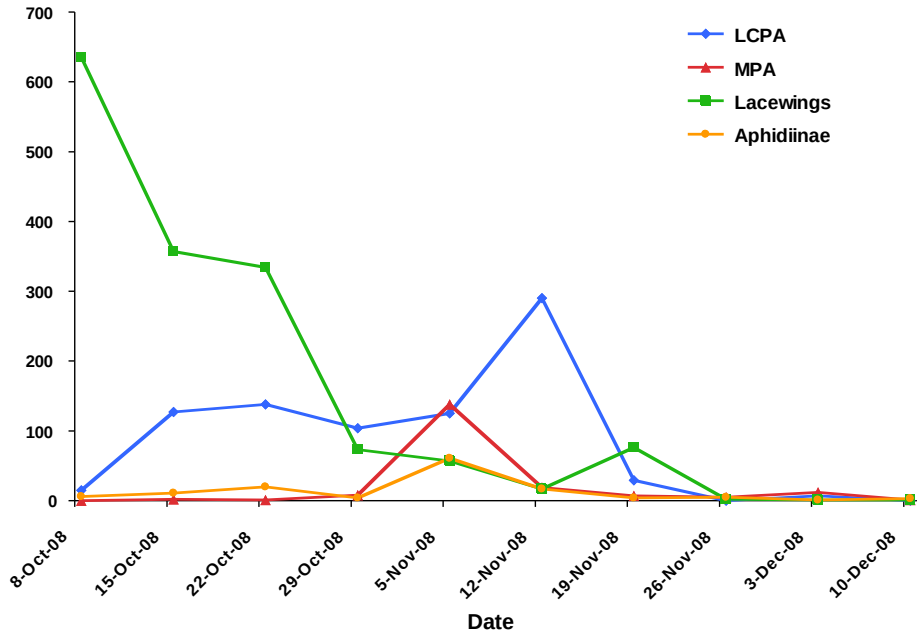

Figure 5. Weekly totals of aphids of all species, adult green lacewings, and adult female Aphidiinae caught in water traps during fall 2008 pheromone ratio trials.

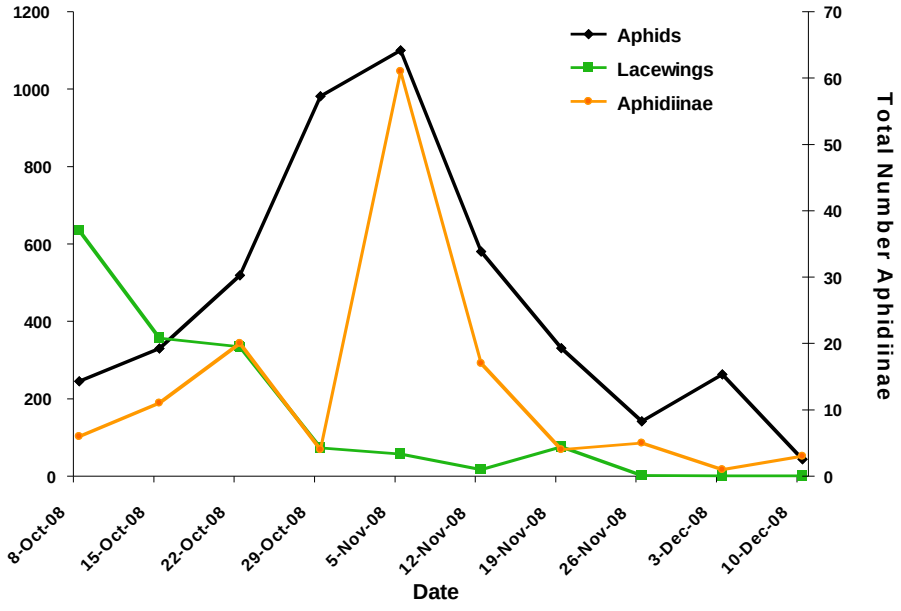

Figure 6. Mean (± SE) numbers of adult green lacewings caught in water traps baited with different ratios of aphid sex pheromone components in prune orchards during fall 2008 pheromone ratio trials. Trap counts summed over the fall trapping period and data square root (x+0.5) transformed for analysis. Non-transformed means ± SE presented. Treatments with the same letters are not significantly different (ANOVA, followed by Tukey's HSD test, $F = 12.09$, df = 7, 119, $P < 0.0001$).

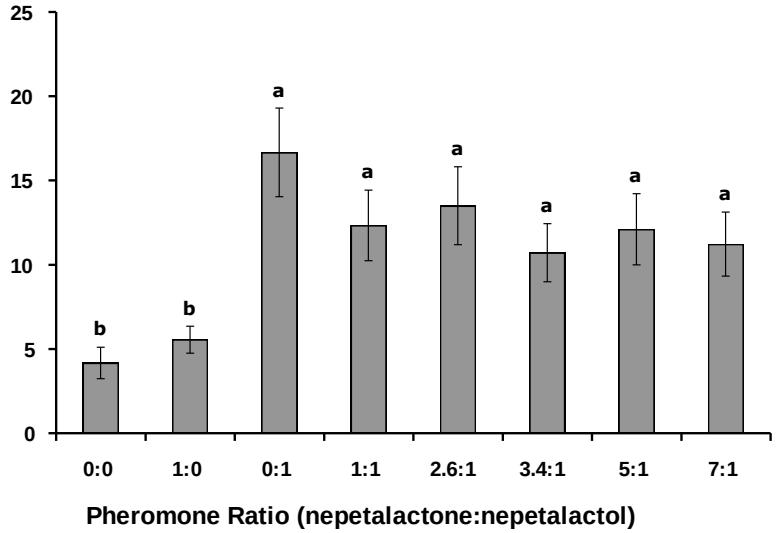

Figure 7. Mean (± SE) numbers of adult female Aphidiinae caught in water traps baited with different ratios of aphid sex pheromone components in prune orchards during fall 2008 pheromone ratio trials. Trap counts summed over the fall trapping period and data square root (x+0.5) transformed for analysis. Non-transformed means ± SE presented. Treatments with the same letters are not significantly different (ANOVA, followed by Tukey's HSD test, $F = 3.42$, df = 7, 119, $P = 0.0023$).