Mass releases of *Trichogramma* wasps can reduce damage from codling moth

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Mass releases of commercially produced* Trichogramma *wasps can be used to reduce damage from codling moth by 60% in walnut and pome fruit orchards in California. Results from field trials indicate that release rate and evenness of distribution are important factors influencing the effectiveness of wasp releases, and that damage reduction is more effective in walnuts and pears than in apples. Because the environmental risks of large-scale releases of* Trichogramma *wasps are likely to be small, wasp releases could be integrated with pheromone-based mating disruption for effective management of codling moth.

Codling moth is the key insect pest of pome fruit (apple and pear) and walnut production in California, as well as in most other deciduous-fruit-growing regions (UC IPM 1993, 1999). In California there are typically three generations each year, and the young larvae burrow into the fruit and nuts to complete their development. With approximately 37,000 acres of apple production, 19,300 acres of pear production, 193,000 acres of walnut production and a total annual value of $430,000 million, codling moth is one of the state's most important pests (NASS 2000).

For more than 40 years, codling moth has been effectively managed through intensive use of organophosphate insecticides, primarily azinphosmethyl (Guthion). However, recent regulatory pressure and evidence of cross-resistance to a number of insecticides has highlighted the need to develop sustainable management systems for codling moth that use more diverse control tactics. For example, in August 1999, the U.S. Environmental Protection Agency significantly lowered the allowable residues for azinphosmethyl on apples and pears, under the Food Quality Protection Act (FQPA).

Trichogramma platneri, which is indigenous to the western United States, is a tiny parasitic wasp that attacks, kills and completes its development in the eggs of a wide range of Lepidoptera. In unsprayed orchards, wild populations of *T. platneri* attack codling moth eggs and by midseason 50% parasitism is not uncommon. *T. platneri* recolonizes orchards each season, because it is unable to maintain populations year-round in pome fruit and walnut orchards due to an absence of overwintering host eggs in which it must spend the winter as full-grown larvae. It has a much shorter generation time (approximately 10 to 14 days) than codling moth (approximately 30 to 40 days) so it is not well-synchronized with the successive generations of this host, and produces an average of two adult wasps from each codling moth egg attacked. Codling moth is a very acceptable host for *T. platneri*, suggesting that augmentative releases of commercially produced parasitoids could provide an effective tool in the management of codling moth populations in California.

Early-season inoculative releases of *T. platneri*, relying on reproduction of the parasitoids in orchards throughout the growing season, are not feasible because of lack of synchronization; the discrete nature of codling moth generations early in the season (eggs are not continuously available for *T. platneri* reproduction); and the relatively low abundance of codling moth eggs in orchards. In contrast, we focused on the potential for inundative releases of *T. platneri* to reduce insecticide use in orchards and to complement the increasing adoption of pheromone mating disruption for codling moth management (Gut and Brunner 1998). The key aspects of *Trichogramma* inundation that we have addressed are the effectiveness of different release rates; whether releases are as effective in all commodities; the importance of release distribution; and the risk of unintended environmental impacts.

Effective release rates

One of the most important questions regarding the use of *Trichogramma* parasitoids for inundative release against codling moth is how many to release on each occasion. In a series of field trials in commercial orchards in 1994, we examined the efficacy of different release rates of *T. platneri* in reducing codling moth damage in one walnut orchard ('Ashley' variety, 52 trees per acre, tree height 25 feet) and two pear orchards ('Bartlett' variety, 250 trees per acre, tree height 15 feet). An 8-to-10-acre block in each orchard was sectioned into square 0.5 acre plots to allow three or four replicate plots for each of five release rates, including a no-release control. The two pear orchards were under mating disruption for codling moth control, but no other codling moth management was present in the walnut orchard.

Commercially produced parasitoids (Rincon-Vitova, Ventura, Calif.) were

released in each orchard by stapling individual sections of cards bearing parasitized eggs of stored-product moths to the underside of the leaves in the lower canopy of the trees. A series of four releases were made at weekly intervals (10-day intervals during the first generation) during the oviposition period of each of the three codling moth generations in walnuts, starting around 100 degree days after the biofix for each generation.

We determined the biofix, or date representing the start of a codling moth generation, by pheromone trap catches of moths on two successive nights with sunset temperatures above 62°F. Because there are only two generations of codling moth before harvest of Bartlett pears, we made six weekly releases during the first generation and four weekly releases during the second generation. The release rates are expressed as number of parasitized eggs per acre and represent the rates used for each of the successive releases through the season.

We verified the activity of the *Trichogramma* parasitoids in these orchards by monitoring sentinel codling moth eggs exposed to parasitism on PVC poles running through the canopy of individual trees in each plot. Sentinel eggs were rarely parasitized in the no-release control plots, indicating an absence of wild populations of parasitoids in these orchards, but they were frequently parasitized in the release plots, suggesting that any reduction in fruit damage in the experimental plots was due to the action of the released parasitoids.

Codling moth damage at harvest was estimated by sampling 1,000 fruit from each plot in the pear orchards and 750 nuts from each plot in the walnut orchard. Figure 1 shows the reduction in codling moth damage, as a proportion of the damage observed in the no-release control plots, in relation to release rate for the three orchards. Damage in the control plots of each orchard was 3.9% (±1.2 SE, n = 4) for the walnut orchard, and 7.1% (± 0.2 SE, n = 3) and 5.0% (± 2.2 SE, n=3) for the pear orchards. In all three orchards, the inundative releases of *T. platneri* reduced damage by approximately 60%. The greatest level of reduction occurred over the lower release rates and damage leveled off beyond a release rate of 200,000 parasitized eggs per acre. It is also interesting to note that in the pear orchards, *Trichogramma* releases were complementary to the mating disruption, providing additive damage control.

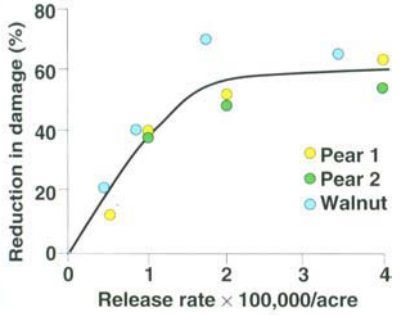

Fig. 1. The influence of release rate on reduction in codling moth damage through *Trichogramma* inundation in one walnut and two pear orchards in California.

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Codling moth larvae burrow into apples, pears and walnuts, *shown*, damaging the crop.

Effective in all commodities?

Codling moth is most damaging in apple orchards, but it is also an important pest in early-harvest pears and walnuts. Are *Trichogramma* releases likely to be as effective in each of the three commodities? This is an important question, because walnut orchards have a much greater canopy volume than apple or pear orchards. It is more difficult to make a direct comparison between commodities, because differing lengths of the growing season (early harvest in pears) and susceptibilities to codling moth have led to different approaches to *Trichogramma* releases in these orchards. For example, releases have focused only on first generation in apples, but have been season-long in walnuts. However, a comparison can be made of the reduction in damage observed at the end of the first generation of codling moth in 1993 and 1994 in a set of 11 orchards.

Each orchard had replicated *Trichogramma* release treatments that included a release rate of 400,000 parasitized eggs per acre. The apple and pear orchards were under mating disruption and received six consecutive releases at weekly intervals, whereas the walnut orchards had no mating disruption (nor other management for codling moth) and received only four releases at 10-day intervals. Damage estimates, from direct observation of 1,000 fruit or 750 nuts from each of the replicate plots, have been combined to give a single mean for each orchard.

The reductions in codling moth damage at the end of the first generation were not quite as effective in apples as in walnuts and pears (fig. 2), although the variation in mean level of damage reduction was not significantly different between commodities ($F = 1.86$, $df = 2,8$, $P > 0.05$). The pressure from codling moth in apples is greater than in pears or walnuts; therefore, even a small reduction in the efficiency of *Trichogramma* releases early in the season is amplified through subsequent codling moth generations, leading to reduced control of damage at harvest. However, because the canopy of a walnut tree is much larger, with a greater surface area to be

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◀ Loose parasitized eggs are dropped by airplane into the canopy of the orchard for even coverage. Adult parasitoids emerge from the parasitized eggs to attack codling moth eggs in the trees.

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Above left, Trichogramma platneri attacks a codling moth egg. *Above right*, a parasitized egg.

searched by the parasitoids, it is perhaps surprising that *Trichogramma* releases were so effective in walnut orchards. In contrast to apple and pear orchards in California, walnut orchards support low populations of aphids that produce a consistent source of honeydew for the released *Trichogramma*.

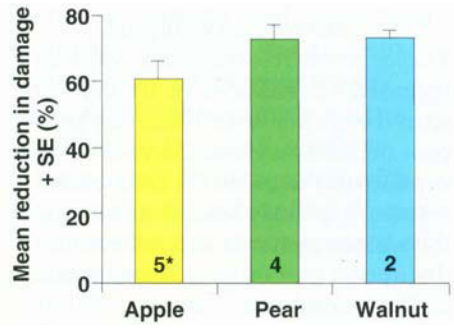

Fig. 2. A comparative analysis of the effectiveness of *Trichogramma* inundation (400,000 parasitized eggs per acre) in reducing damage at the end of the first generation of codling moth in a series of apple, pear and walnut orchards. *The number of orchards of each commodity.

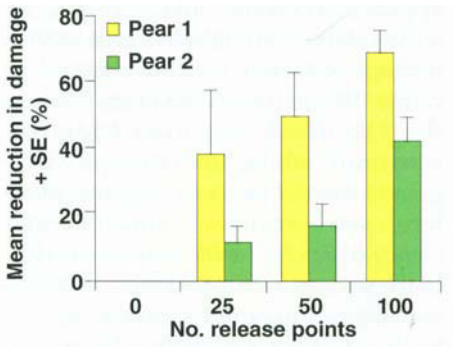

Fig. 3. The influence of the number of release points on damage reduction by codling moth through *Trichogramma* inundation (200,000 parasitized eggs per acre) in pears.

Honeydew is an important food source for adult *Trichogramma*, because it increases their longevity (McDougall and Mills 1997a) and presumably increases their duration of activity and potential to search a larger canopy volume following release. Therefore the presence of aphids may explain the surprising success of *Trichogramma* inundation in walnut orchards.

Release distribution importance

Trichogramma parasitoids are raised on the eggs of stored-product moths and are sold commercially as parasitized host eggs, either on cards, in special dispensers or as loose eggs. The parasitized eggs must then be placed out in the orchard to allow the emerging adult wasps to search the orchard canopy for codling moth eggs. To illustrate the importance of an even distribution of the released parasitized eggs, we set up a replicated field trial in two Bartlett pear orchards in the Sacramento Delta region in 1995. The same release rate of 200,000 parasitized eggs per acre was used in each orchard, and the *Trichogramma* distribution treatments were 0, 25, 50 or 100 release trees in each of four replicate 0.5 acre release plots. We made six *Trichogramma* releases at weekly intervals during the first generation of codling moth and four weekly releases in the second generation. Fruit damage at harvest was again recorded from 1,000 fruit in each plot.

The number of release points in a plot had a significant influence on the reduction in codling moth damage in both orchards ($F = 6.38$, df = 3,24, $P = 0.002$), although the two orchards also differed significantly in the level of damage reduction achieved by the *Trichogramma* releases ($F = 24.70$, df = 1,24, $P < 0.001$). These results demonstrate that the more evenly the *Trichogramma* are released, the better the reduction in codling moth damage, suggesting that a broadcast release of parasitized eggs may be the best approach to releasing *Trichogramma* in orchard canopies.

During the past 2 years, Russ Stocker of ARENA Pest Management has developed a method of aerial application of loose parasitized eggs in walnut orchards, and a similar technique could also be developed for application from the ground. Loose eggs are metered out at a constant rate and coated with a sticker so that they adhere to leaves in the orchard canopy. Emergence of adult parasitoids from parasitized eggs is significantly improved by the metering process, but slightly reduced by the coating of sticker. Perhaps more importantly, however, broadcast application into the canopy of the orchard reduces general predation of parasitized eggs (predation can be extensive on unprotected squares cut from *Trichogramma* cards), and should place emerging adult wasps closer to the source of codling moth eggs in the canopy. Demonstration trials using aerial applications of *Trichogramma* are currently taking place in walnut orchards.

Risk of nontarget impacts

The majority of *Trichogramma* species, including *T. platneri*, are polypha-

gous parasitoids with an ability to successfully develop in a variety of lepidopteran eggs. Although inundative releases of large numbers of *Trichogramma* are needed to reduce damage by codling moth in commercial orchards, do these releases pose a significant risk for other insects that live in the surrounding environment? Whether releases of *Trichogramma* result in parasitism and death of nontarget insect eggs depends on three factors: the longevity of the released wasps, the extent of dispersal from the release point and the range of potential hosts. Using parasitism of sentinel eggs to monitor dispersal of *T. platneri* in apple orchards, parasitism declined from 62% at the release point to less than 10% at a distance of 47 feet (McDougall and Mills 1997b). Similarly, the increased control of fruit damage in pears from a more even coverage of released parasitoids, discussed earlier, again suggests that dispersal is limited in an orchard environment. In fact, parasitism of sentinel eggs by *T. platneri* placed at distances greater than 33 feet from the edge of walnut orchards in 1998 resulted in no detectable parasitism, indicating that the risk of inundative releases to nontarget insects is confined to the immediate proximity of the orchard.

The small size of the wasps makes the direct estimation of longevity under field conditions a significant challenge. However, using dialysis tubing (a porous material that has minimal impact on microclimate) to enclose adult wasps in small transparent sleeves on walnut trees, we have recently obtained good estimates of the longevity of *T. platneri* in an orchard near Winters in Yolo County. Not surprisingly, the longevity of *T. platneri* is inversely related to temperature, and varied from 7.5 days during cooler periods in the presence of food to 0.5 days when temperatures exceeded 100°F in the absence of food. The life span of the *T. platneri* was typically 1 to 4 days, suggesting a distinct temporal as well as spatial limit to the risk of nontarget environmental impacts.

From laboratory observations on the physiologically acceptable host range of *T. platneri*, a broad range of Lepidoptera (from many different families) and the green lacewing *(Chrysoperla carnea)* can be successfully attacked. However, there was significant variation in the extent of reproduction by *T. platneri* exposed to host eggs in no-choice tests, suggesting that acceptable hosts differ in suitability and may be differentially attacked under field conditions. This was tested by exposing sentinel egg cards for each of six diverse acceptable host species *(Chrysoperla carnea* [Chrysopidae], *Cydia pomonella* [Tortricidae], *Ephestia kuehniella* [Pyralidae], *Helicoverpa zea* [Noctuidae], *Manduca sexta* [Sphingidae] and *Sitotroga cerealella* [Gelechiidae]) to parasitism in the canopy of each of six trees in nine replicated release plots in a walnut orchard in Tehama County in 1999. The release plots received weekly releases of 200,000 parasitized eggs per acre, and the sentinel egg cards were exposed for a period of 3 days. There was no difference in the percentage of sentinel egg cards parasitized for the exposed host species (Kruskal-Wallis = 3.92, $P = 0.56$), indicating that variation in physiological suitability under laboratory conditions does not influence vulnerability to attack under field conditions.

Parasitoids another tool

These studies have shown that inundative release of a sufficient number of *T. platneri* can lead to substantial reduction in fruit and nut damage by codling moth, particularly in walnut and pear orchards. These releases are not as effective as conventional insecticide sprays, since they appear not to be able to reduce damage by more than 60%, but they have proved to be consistent in their impact both in the presence and absence of pheromone-based mating disruption. Additional studies have shown that *T. platneri* is much more effective in California orchards than other commercially produced *Trichogramma* species, presumably because of its adaptation to local climatic conditions. Therefore, the choice of *Trichogramma* species and strains may be a particularly important element of inundative biological control.

Because of its relatively high cost, *Trichogramma* inundation has not yet been widely adopted by growers. At $20 per acre (active ingredient only) for each release, *Trichogramma* inundation is more expensive than most conventional insecticides. However, the cost could be significantly reduced in the future through economies of scale. *Trichogramma* releases provide growers with an additional tool that is likely to be most effective either in orchards with low pressure from codling moth or in those using pheromone-based mating disruption. The latter combination is currently being tested in walnuts as a possible solution to the impending loss of organophosphate insecticides resulting from regulatory changes such as FQPA.

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