Comparison of Traps for Monitoring Plum Curculio Adults (Coleoptera: Curculionidae) in Apple Orchards[1]

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Abstract Effectiveness of four types of odor-baited or unbaited traps for monitoring overwintered adult plum curculios, *Conotrachelus nenuphar* (Herbst), on perimeter apple trees in Massachusetts orchards was compared. Black wooden pyramid traps placed on the ground next to apple tree trunks captured more adults than black plastic cylinder traps placed vertically on limbs within apple tree canopies, squares of clear Plexiglas placed vertically next to apple tree canopies to intercept incoming adults on the sticky-coated outward-facing surface, or "Circle" traps comprised of aluminum screen and fastened to limbs within apple tree canopies (which captured no adults). In no comparison did any of these traps baited with a combination of synthetic aggregation pheromone (grandisoic acid) and synthetic host volatiles (limonene and ethyl isovalerate) capture more adults than unbaited traps. None of the three types of baited or unbaited traps evaluated in commercial orchards (pyramid, cylinder or Circle) yielded captures of adults whose amounts or phenologies reflected amounts or phenologies of ovipositional injuries to fruit caused by plum curculio, although in unmanaged orchards amounts of capture by baited and unbaited pyramid and clear Plexiglas traps did reflect amounts of fruit injury. The only situation where odor bait enhanced trap effectiveness involved clear Plexiglas traps placed next to woods nearby an unmanaged orchard, where baited traps facing woods caught about 10× more immigrating overwintered adults than did unbaited traps. We conclude that odor-baited clear Plexiglas traps placed near woods can be useful for monitoring the beginning, peak and ending of overwintering adult immigration, but a more attractive blend of odor components is needed for effective monitoring by traps of any type placed near, beneath or within canopies of apple trees.

Key Words *Conotrachelus nenuphar* plum curculio, insect traps, attractive odor, monitoring insects

The plum curculio, *Conotrachelus nenuphar* (Herbst), is a key pest of pome and stone fruit in eastern and central North America (Racette et al. 1992, Vincent et al. 1999). In autumn, most adults seek refuge in hedgerows or woods, overwinter there, and in spring immigrate into orchards shortly before, during or after blossoming of orchard trees (LaFleur and Hill 1987). Several types of traps have been examined for ability to attract or capture plum curculio adults (LeBlanc et al. 1981, Yonce et al. 1995, Eller and Bartelt 1996, Mulder et al. 1997, Prokopy and Wright 1998, Prokopy et al. 1998a, b, 1999, Dixon et al. 1999). From these studies, four sorts of traps that either are attractive to plum curculio adults or are otherwise effective in intercepting adults appear to hold the most promise. These include: (1) a square of clear Plexiglas coated on one side with Tangletrap, fastened vertically to a post and positioned to

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intercept adults flying toward an orchard or the canopy of an orchard tree (Prokopy et al. 1998b, Dixon et al. 1999); (2) a dark-colored pyramid (mimicking a tree trunk) capped with an inverted screen funnel and placed on the ground near the trunk of an orchard tree to attract adults moving toward tree trunks (Tedders and Wood 1994, Mulder et al. 1997, Prokopy and Wright 1998); (3) a dark-colored cylinder (mimicking a tree branch), capped with an inverted screen funnel, and positioned vertically on the limb of an orchard tree to attract adults moving within the tree canopy (Prokopy et al. 1998 a,b); and (4) a "Circle trap", consisting of a wire screen cage, capped with an inverted screen funnel, and attached to the limb of an orchard tree to intercept adults walking on tree limbs (Mulder et al. 1997).

Here, in plots of small-, medium-, and large-size apple trees in eight Massachusetts commercial apple orchards, we compared the effectiveness of odor-baited and unbaited pyramid, cylinder and Circle-type traps in capturing plum curculio adults, and we investigated relationships between the extent and temporal occurrence of trap captures and the extent and temporal occurrence of plum curculio ovipositional injury to developing fruit. In addition, in plots of apple trees in three small unmanaged orchards, we conducted studies similar to those in commercial orchards that involved evaluation of clear Plexiglas, pyramid and cylinder traps. Odor bait consisted of a combination of formulated plum curculio pheromone (Eller and Bartelt 1996) and synthetic host fruit volatiles (Leskey et al. 1998).

Materials and Methods

Pyramid traps were a modification of those developed by Tedders and Wood (1994) for monitoring pecan weevils, *Curculio caryae* (Horn), and are sometimes referred to as "Tedders" traps. They were constructed as depicted in Mulder et al. (1997) and described in Prokopy and Wright (1998). They were painted black (Tru-Test Weatherall Flat Acrylic Latex, Tru-Test, Cary, IL) and placed on the ground within 25 cm of orchard tree trunks.

Cylinder traps (Fig. 1) were 8 cm diam by 30 cm tall, constructed of hollow polyvinylchloride pipe, and painted black (above paint) inside and out. Preliminary tests in host trees (Leskey and Prokopy, unpubl. data) revealed that all observed plum curculio adults that arrived on cylinder traps did so by walking from a tree limb onto the base of a cylinder. Thereafter, a proportion walked to the top rim. If the inverted screen funnel (marketed as a cotton boll weevil trap top—Gempler's, Mt. Horeb, WI) capping a cylinder was placed directly upon the cylinder, then few plum curculios proceeded from the cylinder onto the funnel caps. To address this shortcoming, each cylinder was fitted with a wooden, black-painted pyramidal insert (i.e., a miniature version of a pyramid trap) between the cylinder and funnel cap that facilitated movement of adults onto the cap and held the detachable cap firmly in place. Each cylinder was attached in upright position to a horizontal tree limb using a locking plastic cable tie that was threaded through holes at the base of the cylinder and drawn tight to the limb. Positioning was midway between the base and top of a tree canopy and, wherever possible, within 50 cm of the tree trunk.

Circle traps, developed by Kansas pecan grower Edmund Circle and depicted in Mulder et al. (1997), were purchased from Great Lakes IPM, Vestaburg, MI. They consisted of aluminum screen formed in such a way that it could be wrapped tightly around a tree limb, intercept plum curculio adults walking on the limb, and guide them toward an attached inverted screen funnel (cotton boll weevil trap top), where they

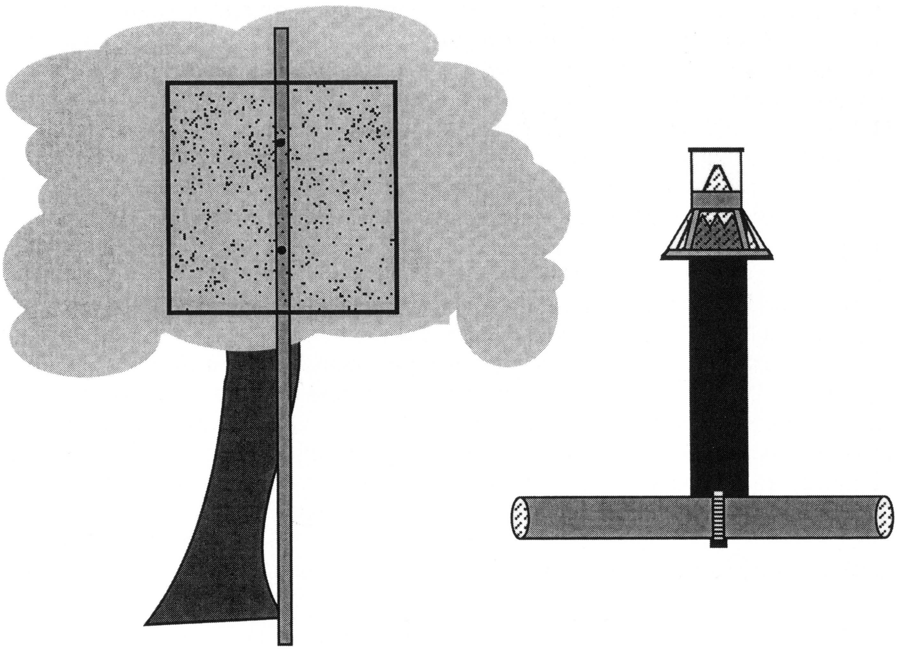

Fig. 1. Schematic version of a black cylinder trap on a tree limb (right) and a sticky clear Plexiglas trap (left) adjacent to a tree canopy.

would be captured. Preliminary observations (Leskey and Prokopy, unpubl. data) revealed that walking adults were equally likely to traverse the skyward and groundward halves of limbs, but we chose to orient each circle trap so that it was the groundward portion that was open to advancing adults. Positioning was on an ascending limb (10-30 degree angle from horizontal) midway between the base and top of a tree and, wherever possible, within 50 cm of the tree trunk.

Clear Plexiglas traps (Fig. 1) consisted of 60 × 60 cm squares of Plexiglas (3 mm thick and manufactured by Cyro Industries, Rockaway, NJ), each of which was fastened vertically at 160 cm height (top edge) to a 6-cm-diam vertical wooden pole seated in the ground. One side of each trap was coated with Tangletrap (Gemplers, Mt. Horeb, WI) to capture alighting plum curculios. Traps were positioned with sticky side facing woods either 2 m outside of perimeter foliage of woods or 30 cm outside of perimeter foliage of apple trees.

Each baited trap received 5 mg of male-produced aggregation pheromone (grandisoic acid) dispensed via a rubber septum (formulated in 1999 by and purchased from IPM Technologies, Portland, OR) and 4 g each of limonene and ethyl isovalerate (Aldrich Chemical Co., Milwaukee, WI), attractive volatiles from plum fruit (Leskey et al. 1998) dispensed via polyethlene vials (Israel Andler and Sons, Everett, MA). Vials containing limonene were unaltered. Each vial containing ethyl isovalerate received two equidistant 1.5-mm diam holes drilled between the base of the cap and the rim of the vial. Release rates of each chemical were set arbitrarily at about 90 mg per day and designed so that the contents of each vial would last through the 6 wks of testing. Odor lures were fastened by clips or wire to the exterior of traps at positions midway between bases and tops of traps. In the absence of information on effect of odor positioning on captures of plum curculios by traps, we judged the midway position to be effective for odor dissemination and attraction and unlikely to cause repulsion of adults approaching inverted screen funnels in which adults were captured.

In 1999, in each of eight large commercial apple orchards, we placed one odor-baited and one unbaited pyramid, cylinder and Circle trap in each of six plots of perimeter apple trees that bore fruit. Six of the seven trees that comprised a plot received a trap, with 'McIntosh' as the principal cultivar. Trees of small, medium and large size were on M.9, M.26 and M.7 rootstock, respectively. Traps were randomized in position within a plot, deployed during apple blossom, and examined for captured plum curculios every 3 to 4 d thereafter for 6 wks. At each trap examination beginning at petal fall, 15 fruit per tree on each of the seven trees per plot were examined for presence of plum curculio oviposition scars (total of 105 fruit per plot per sampling date). All plots received two grower-applied sprays of azinphosmethyl, the first at petal fall and the second 8 to 12 d thereafter. Growers applied sprays according to their own estimation of need, without access to our data for making application decisions.

In 1999, in each of three small unmanaged orchards consisting of 200 or fewer fruiting apple trees of mixed cultivar types on M.26 rootstock, we placed one odor-baited and one unbaited pyramid, cylinder and clear Plexiglas trap in each of four plots of perimeter apple trees. Each of the six trees comprising a plot received a randomly assigned trap, introduced during apple blossom. Traps were examined for plum curculio adults every 3 or 4 d for 6 wks beginning at petal fall. At each trap examination, ten fruit per tree were sampled for evidence of plum curculio oviposition scars (total of 60 fruit per plot per sampling period.) In addition, in one of the three orchards, we placed eight odor-baited and eight unbaited clear Plexiglas traps next to woods that surrounded the orchard. Traps were 10 m apart and alternated in presence vs. absence of odor bait. Also, in part of another of the three orchards, we compared effectiveness of clear Plexiglas traps placed next to canopies of perimeter apple trees with that of same-size and similarly-positioned plywood traps painted white (Gloss White, Sherwin Williams Co., Cleveland, OH), yellow (Sherwin Williams, Lemon Yellow) or green (1 part Sherwin Williams Lemon Yellow: 2 parts Sherwin Williams Bright Blue) [see Prokopy and Owens (1978) for reflectance spectra of these colors]. There were four plots of eight trees each. Each plot contained one randomly-assigned odor-baited and unbaited trap of each color type.

For statistical analysis, data comparing total captures per plot for odor-baited and unbaited pyramid, cylinder and Circle traps in commercial orchards and for pyramid, cylinder and clear Plexiglas traps in unmanaged orchards were submitted to analysis of variance and least significant difference tests (0.05 level) for comparing treatment means. Across all plots of a given type, we performed linear regression analysis relating mean numbers (across all sampling dates) of captured adults per trap type per plot to mean numbers (across all sampling dates) of injured sampled fruit per plot to determine if overall levels of capture for a given trap type reflected overall level of fruit injury. Similarly, for each plot in each orchard, we performed a separate linear regression analysis relating numbers of adults captured on each sampling date by each trap type to numbers of injured sampled fruit on those dates to determine if time of trap captures reflected time of injury.

Results

Commercial orchards. In the eight commercial orchards (Table 1), both baited and unbaited pyramid traps captured significantly more plum curculio adults than baited or unbaited Circle traps, which captured none. This was true in plots of each tree size. Cylinder traps caught significantly fewer adults than pyramid traps in plots of small trees and numerically (but not significantly) fewer adults than pyramid traps in plots of medium and large trees. For no trap type in any plot type did baited traps capture significantly more or fewer adults than unbaited traps.

Mean percent injured fruit per sampling date per plot ranged from 0.0 to 2.1%. For none of the baited or unbaited trap types in plots of any of the three sizes of trees was there a significant positive relationship between mean number of captured adults per plot and mean number of sampled fruit injured per plot (Table 1), indicating that for none of the tree sizes was the amount of adults captured by any trap type significantly related to the amount of injury caused. There was, however, a trend toward increasingly higher r^2 values with decreasing tree size for relationships between numbers of adults captured by baited and unbaited pyramid traps and amount of injured fruit (Table 1). In none of the 48 plots was there a significant positive relationship, for any trap type, between sample-date trap captures and sample-date numbers of injured fruit (data not shown). Indeed, for none of the 48 plots did a r^2 value exceed 0.06, indicating that in no plot did rises in level of fruit injury coincide in time, to any substantial degree, with rises in trap captures.

Unmanaged orchards. In the three unmanaged orchards (Table 2), both baited

Table 1. Captures of overwintered plum curculio adults by odor-baited and unbaited pyramid, cylinder and Circle traps placed beneath or within canopies of perimeter apple trees, and relationships (denoted by r^2 values) between amounts of trap capture and amounts of ovipositional injury to fruit caused by plum curculio in plots of small, medium-size or large apple trees in eight commercial orchards in Massachusetts in 1999

		Mean no. adults captured per trap (±SE) for each tree size*			r^2 value for each tree size**		
Traps	Odor	Small	Medium	Large	Small	Medium	Large
Pyramid	Yes	.83(.27)a	.38(.22)a	.44(.18)a	.23	.17	.03
	No	1.05(.41)a	.38(.15)a	.38(.15)a	.21	.14	.00
Cylinder	Yes	.25(.14)b	.13(.09)ab	.25(.14)ab	.03	.0	.01
	No	.19(.10)b	.13(.12)ab	.06(.02)ab	.03	.01	.01
Circle	Yes	0b	0b	0b	—	—	—
	No	0b	0b	0b	—	—	—

* Values in the same column followed by the same letter are not significantly different according to least significant difference tests at the $P \leq 0.05$ level.

** In no case was the relationship between trap captures and injury level significant at the 0.05 level or less.

and unbaited pyramid traps captured significantly more adult plum curculios than baited or unbaited cylinder or clear Plexiglas traps, among which there were no significant differences. For none of these trap types did baited traps capture significantly more adults than unbaited traps. However, in one unmanaged orchard where clear Plexiglas traps were placed adjacent to woods, baited traps (mean = 1.38) did capture significantly more adults over a 6-wk test period than did unbaited traps (mean = 0.13) (t = 3.16, df = 14, P = 0.001). In another unmanaged orchard where clear Plexiglas traps placed next to apple tree canopies were compared with same-size and similarly-positioned colored traps, there were no significant differences among baited or unbaited clear Plexiglas, white, yellow or green traps in numbers of plum curculio adults captured (Table 3).

Mean percent injured fruit per sampling date per plot ranged from 0.6 to 66.2%. There was a significant positive relationship between mean number of captured adults per plot and mean number of sampled fruit injured per plot for baited as well as unbaited pyramid and clear Plexiglas traps but not for baited or unbaited cylinder traps (Table 2). In none of the 12 plots was there a significant positive relationship, for any trap type, between sample-date trap captures and sample-date numbers of injured fruit (data not shown). In fact, in no case did a r^2 value exceed 0.05.

Discussion

Irrespective of type of orchard (commercial or unmanaged), pyramid traps placed next to trunks of apple trees captured numerically more (and usually significantly more) plum curculio adults than any other type of trap tested. Sticky clear Plexiglas traps placed next to apple tree canopies and cylinder traps placed within apple tree

Table 2. Captures of overwintered plum curculio adults by odor-baited and unbaited pyramid, cylinder and clear Plexiglas traps placed beneath, within or next to canopies of perimeter apple trees, and relationships (denoted by r^2 values) between amounts of trap capture and amounts of ovipositional injury to fruit caused by plum curculio in plots of apple trees in three unmanaged orchards in Massachusetts in 1999

Traps	Odor	Mean no. adults captured per trap (±SE)*	r^2 value
Pyramid	Yes	13.8(3.4)a	.80**
	No	11.2(2.5)a	.56**
Cylinder	Yes	1.4(0.4)b	.28
	No	1.5(0.4)b	.10
Plexiglas	Yes	2.8(0.8)b	.79**
	No	1.8(0.6)b	.67**

* Values in the same column followed by the same letter are not significantly different according to least significant difference tests at the $P \leq 0.05$ level.

** The relationship between trap capture and injury level was significant at the 0.05 level or less.

Table 3. Captures of overwintered plum curculio adults by odor-baited and unbaited clear Plexiglas traps and colored traps of similar type placed next to canopies of perimeter apple trees in an unmanaged orchard in Massachusetts in 1999

Traps	Odor	Mean no. adults captured per trap (±SE)*
Clear	Yes	2.1(0.6)a
	No	1.4(0.4)a
White	Yes	1.8(0.6)a
	No	1.7(0.6)a
Yellow	Yes	1.8(0.6)a
	No	2.0(0.5)a
Green	Yes	1.4(0.3)a
	No	0.8(0.4)a

* Values in the same column followed by the same letter are not significantly different according to least significant difference tests at the $P \leq 0.05$ level.

canopies caught fewer adults, whereas Circle traps placed within apple tree canopies caught none.

On the one hand, it could be argued that pyramid traps caught more adults simply because the surface area of a pyramid trap was much greater than that of any other trap tested. Thus, clear Plexiglas traps may have equaled pyramid traps in captures had they been larger in size. On the other hand, larger size of trap does not necessarily translate into a greater number of insects captured. For example, in the case of cylinder traps within apple tree canopies, there appears to be an optimum diameter (8 cm) beyond which captures of plum curculios do not increase and may decrease (Leskey and Prokopy, unpubl. data). Our observations suggest that the failure of the cylinder traps used here to capture more plum curculios was due less to suboptimal size of trap used (8 × 30 cm) than to inefficiency of our current version of cylinder traps in capturing a high proportion of arriving adults. In this regard, the gradually tapering surface of a pyramid trap may serve to guide arriving adults toward the trap top and into the inverted funnel more effectively than does the vertical surface of a cylinder trap. Even so, mini-pyramids positioned on limbs in apple tree canopies have proven no more effective than cylinders in trapping plum curculios (Prokopy and Wright 1998). In the case of Circle traps, our observations indicated that plum curculio adults arriving at the interface of a tree limb and a Circle trap were highly disinclined to walk more than a few centimeters while on the screen of the trap and proceed toward the trap interior where they could be captured. Perhaps use of a highly attractive odor blend would partially or fully overcome shortcomings of current cylinder and Circle traps. Ultimately, more in-depth direct observation of plum curculio response to natural visual stimuli (eg., tree trunks, tree limbs, canopy foliage) and to traps intended to mimic such stimuli is needed to foster advances in trap design.

Clear square Plexiglas traps, whose sticky-coated surface faced outward to capture adults approaching apple tree canopies, captured numerically though not significantly more plum curculios than traps of similar type and position painted green but captured essentially equal numbers of adults as yellow or white-painted traps. This suggests that flying plum curculios approaching canopies of host trees may not be as specific in their response to particular properties of foliage color or foliage-mimicking colors (e.g., green or yellow) as are many other herbivorous insects (Prokopy and Owens 1983). This suggestion is supported by results of Butkewich and Prokopy (1997), who found no significant difference in captures of released plum curculios by unbaited sticky-coated green versus clear vertical Plexiglas rectangles (60 cm wide × 130 cm tall) placed in a open field. Using clear Plexiglas squares to intercept incoming plum curculios did have one distinct advantage over using squares of other colors tested: substantially fewer other kinds of insects were captured, facilitating more rapid detection of captured plum curculios. Also, clear Plexiglas squares are easy to assemble and disassemble, can be used for many years, and can be coated rapidly with Tangletrap and cleaned rapidly of Tangletrap and insects using a large putty knife.

The only trap type whose captures were significantly enhanced by addition of odor was clear Plexiglas traps facing woods, where captures on baited traps were about tenfold greater than on unbaited traps. There are several possible reasons why odor bait did not enhance captures by any of the other trap types (or trap positions) evaluated here. First, odor from baited traps may have been too weak to compete with attractive natural odor from apple trees themselves and/or plum curculio adults beneath or within apple trees. Indeed, in complementary laboratory and field tests not reported here, we found that dispensers of grandisoic acid used here were attractive to plum curculios for only 3 to 6 days, losing detectable attractiveness thereafter (Leskey and Prokopy, unpubl. data). Second, certain components of the artificial fruit odor may have been repellent at close range at the release rates used here. Again, in subsequent tests not reported here, we found that although limonene was in fact attractive at approximately the release rate used here, ethyl isovalerate was probably repellent, being attractive only at a lower release rate (Prokopy, Phelan, and Leskey, unpubl. data). Had we known this before our baited traps were introduced, we could have made an appropriate adjustment in release rate of ethyl isovalerate. Third, the position at which we deployed odor lures, midway between trap tops and bottoms and exterior to trap surfaces, may not have been optimal for eliciting maximum captures of adults. Finally, information is lacking on the behavior of plum curculio adults when responding to a source of attractive odor, either from a distance or when in close proximity to the source. Until such information becomes available, one can only speculate as to why one approach to odor deployment enhanced captures of adults by traps in this study whereas other approaches did not.

For purposes of monitoring plum curculio, it is not the total number of adults captured by a particular trap type that is important. Of greater importance is the ability of a trap to capture adults in a pattern that reflects both the amount and phenology of plum curculio injury to fruit in the block of host trees where the trap is placed. For these purposes, none of the baited or unbaited trap types evaluated in commercial orchards (pyramid, cylinder or Circle traps) was truly effective. For unbaited pyramid traps, results in 1999 tests reported here are consistent with results of similar tests using unbaited pyramid traps in Massachusetts commercial orchards in 1997 and 1998 (Wright et al. 1998, Prokopy et al. 1999). In unmanaged orchards, captures by baited and unbaited pyramid traps placed next to tree trunks and clear Plexiglas traps placed adjacent to apple tree canopies did in fact reflect amounts of plum curculio injury to fruit among respective plots in which traps were placed, although as in commercial orchards, the pattern of captures by pyramid traps did not reflect the phenological pattern of injury to fruit. Causes underlying the difference between unmanaged and commercial orchards in ability of captures by pyramid traps to accurately reflect amount of plum curculio injury to fruit remain to be determined.

In conclusion, findings reported here suggest that black pyramid traps placed next to apple tree trunks, black cylinder traps placed within apple tree canopies, and possibly also sticky clear Plexiglas traps placed near apple tree canopies all may have future potential for accurately monitoring populations of plum curculio adults in commercial orchards provided that highly attractive odor lures (more attractive than those used here) are employed in conjunction with such traps. Perhaps of more immediate usefulness is placement of odor-baited sticky clear Plexiglas traps in positions facing woods nearby unmanaged or commercial-orchard sites known to have had substantial or detectable plum curculio injury in the past. Captures of immigrating adults by such traps could prove very useful in reflecting the beginning, peak and ending of adult immigration, information that would be valuable in deciding if and when to apply insecticides against this pest.

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