Evaluation of Unbaited Pyramid Traps for Monitoring and Controlling Plum Curculio Adults (Coleoptera: Curculionidae) in Apple Orchards[1]

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Abstract We investigated unbaited black pyramid traps, placed on the ground, for monitoring overwintered adult plum curculios, *Conotrachelus nenuphar* (Herbst), in eight large commercial apple orchards in Massachusetts. None of the trap positions for any tree size in any orchard showed a significant positive relationship between the temporal occurrence of adult captures from petal fall until 4 to 5 wks afterward and the temporal occurrence of adult-initiated ovipositional injury to developing fruit during the same period. The amount of adults captured by traps was not significantly related to the amount of injury to fruit caused by adults, either across the entire period of overwintered adult activity or within periods of adult activity before, between or following insecticide applications. Similar traps placed next to trunks of groups of four adjacent trees in a small unmanaged orchard or next to trunks of every tree in a small commercial orchard failed to provide detectable or commercially-acceptable control of plum curculio. An alternative to unbaited pyramid traps on the ground is needed to effectively monitor or control plum curculio in apple orchards in Massachusetts.

Key Words *Conotrachelus nenuphar*, traps, insect monitoring, insect control.

The plum curculio, *Conotrachelus nenuphar* (Herbst), is a major pest of stone and pome fruit in eastern and central North America (Racette et al. 1992). Most adults overwinter in woods or hedgerows outside of commercial orchards and immigrate into orchards during spring, shortly before, during or after the blossoming of orchard trees (Lafleur and Hill 1987). Numerous types of traps have been compared for ability to attract and capture plum curculio adults (LeBlanc et al. 1981, Yonce et al. 1995, Eller and Bartelt 1996, Prokopy and Wright 1998). Based upon these studies, the trap showing the most promise for plum curculio is a dark-colored pyramid that is placed on the ground and capped with an inverted wire screen funnel. This is a visual trap and is believed to represent a super-normal mimic of a tree trunk for host-seeking pecan weevils, *Curculio caryae* (Horn), for which the trap was originally developed (Tedders and Wood 1994).

Previous studies in peach and apple orchards have evaluated unbaited pyramid traps for temporal concurrence of peak periods of captures of plum curculio adults and peak periods of adult presence in host tree canopies or adult injury to fruit. For peach orchards in Arkansas, unbaited pyramid traps show considerable promise of being effective in monitoring adult populations and predicting need for insecticide

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treatment to prevent injury (Johnson 1996). However, in a small apple orchard in Vermont and a small apple orchard in Massachusetts, unbaited pyramid traps showed little promise of being an effective monitoring tool (Schmitt and Berkett 1995, Prokopy and Wright 1998). Until now, no study has examined the potential of unbaited pyramid traps for directly controlling plum curculios.

Here, in blocks of small- medium- and large-size apple trees in several Massachusetts commercial apple orchards, we investigated relationships between temporal occurrence and extent of captures of plum curculio adults by unbaited pyramid traps and temporal occurrence and extent of plum curculio ovipositional injury to developing fruit. In addition, in two small orchards, we evaluated whether unbaited pyramid traps were capable of directly controlling plum curculio.

Materials and Methods

Pyramid traps were a modification of those developed by Tedders and Wood (1994) for monitoring pecan weevils and were constructed as described in Prokopy and Wright (1998). They were painted black and unbaited.

In 1997, in each of eight large commercial apple orchards, we placed six traps in each of three blocks of apple trees. All blocks contained 98 trees (14 rows of seven trees each) of fruit-bearing age. 'McIntosh' was the predominant cultivar in each block. Trees of small, medium and large size were on M. 9, M. 26 and M. 7 rootstock, respectively. One trap was placed within 30 cm of the trunk (termed trunk trap) of each of two trees at ends of rows (i.e., at perimeter trees), one mid-way between the canopy of a perimeter tree and the first interior tree (termed inter-tree trap) in each of two rows (not the same rows having trunk traps), and two at the margin of the nearest woods or hedgerow (termed border traps), 10 to 30 m from and opposite to perimeter apple trees. The ground beneath and between the orchard trees was either free of vegetation or vegetation was mowed to prevent obscuring of traps. Traps were deployed during apple blossom and were examined for captured plum curculio adults every 3 to 4 d thereafter for 4 to 5 wks. At each trap examination, beginning at petal fall, 15 fruit per tree on each of the 14 perimeter trees were examined for presence of plum curculio oviposition scars (total of 210 fruit per block per sampling date). Scarred fruit were allowed to remain on the tree. All blocks received either two or three grower-applied sprays of azinphosmethyl, beginning at petal fall and 8 to 11 d (second spray) as well as 16 to 20 d (third spray) thereafter. Growers applied sprays according to their own estimation of need, without access to our data for making application decisions. To protect against insecticide, a plastic bag was used to completely envelop each trap just before spraying and was removed immediately thereafter.

In 1997, in one 50-tree commercial orchard described in Prokopy and Wright (1998), we placed an unbaited black pyramid trap within 30 cm of the trunk of each tree during the pink stage of blossom development. Trees were of medium size (on M. 26 rootstock) and of fruit-bearing age. Cultivars present included 'Liberty' (30 trees), 'Prima' (7 trees), 'Freedom' (6 trees), and other cultivars (7 trees). Traps were positioned adjacent to tree trunks because this position proved more effective than any other for capturing plum curculio adults in a 1996 study in this orchard (Prokopy and Wright 1998). The ground beneath the canopy of each tree was maintained free of vegetation throughout the study. Traps were examined for plum curculio adults every 3 or 4 d for 4 wks beginning at petal fall. At each trap examination, five fruit per tree were sampled for evidence of plum curculio oviposition scars (total of 250 fruit per sampling period). Scarred fruit was not removed during sampling. One application of phosmet was made 4 d after petal fall and another 17 d after that to prevent further increase in plum curculio injury. A plastic bag was placed over each trap just before spraying and removed immediately thereafter.

In 1997, in one 216-tree unmanaged orchard that had not received insecticide since 1995, we placed an unbaited black pyramid trap within 30 cm of the trunk of each of four adjacent trees (two trees in each of two rows) and repeated this pattern across eight sets of four trees each within the orchard. Another eight sets of four trees each were untrapped and served as experimental controls. Trees were of medium size (M. 26 rootstock), of fruit-bearing age, and comprised of 'McIntosh' or 'Red Delicious' cultivars. Trapped and untrapped sets of trees alternated in arrangement and were represented equally between cultivars. The ground beneath the trees was free of vegetation. Traps were deployed at the pink stage of blossom development and were examined for plum curculio adults every 7 d (beginning 4 d after petal fall) for 5 wks. At each trap examination, ten fruit per tree were sampled for evidence of plum curculio oviposition scars (total of 320 fruit for trapped trees and 320 fruit for untrapped trees per sampling period). Scarred fruit were not removed during sampling.

For statistical analysis of data from the eight large commercial orchards, numbers of adults captured by traps at each position in each block type (i.e., tree-size type) were summed across the two traps at the same position in a block and were submitted to two-way analysis of variance (following square-root transformation in which 0.5 was added to each value before transformation) to determine effect of trap position on numbers of adults captured. For each of the 24 blocks, data on numbers of adults captured each sampling data at a given position were related to numbers of sampled fruit showing a plum curculio ovipositional scar on those dates using linear regression. Across all blocks of a given type, we then performed linear regression analysis relating mean numbers (across all sampling dates) of captured adults per trap position per block to mean numbers (across all sampling dates) of fruit injured per block. Similar analyses were performed across all blocks of a given type relating mean captures per trap position to mean fruit injury across those sampling dates before the first, between the first and second, between the second and third, or after the last insecticide application against plum curculio. For the 50-tree commercial orchard, linear regression analysis was used to relate data on numbers of adults captured each sampling date to numbers of sampled fruit showing plum curculio injury on those dates. Finally, for the 216-tree unmanaged orchard, plum curculio injury level to fruit each sampling date was compared between the eight sets of trapped trees and the eight sets of untrapped trees using *t*-tests.

Results

Traps for monitoring. In the eight large commercial orchards, there was no significant effect of trap position on adult captures in blocks of any type (for small-tree blocks, $F = 0.05$, df = 23, $P \leq 0.95$; for medium-size-tree blocks, $F = 0.27$, df = 23, $P \leq 0.77$; for large-tree blocks, $F = 1.92$, df = 23, $P \leq 0.17$). In none of the 24 blocks was there a significant positive relationship between sample-date trap captures and sample-date numbers of fruit injured by plum curculio, irrespective of trap position (Table 1). Indeed, in no case did a r^2 value exceed 0.12, indicating that in no block did

Table 1. Relationship (denoted by r^2 value) between sample-day numbers of overwintered plum curculio adults captured by unbaited pyramid traps at tree trunk, inter-tree, or orchard border positions and sample-day percent fruit showing ovipositional injury by plum curculios in each block of small, medium-size or large apple trees in each of eight commercial orchards in Massachusetts in 1997.

		Mean no. adults captured per sampling date*			Mean % injured fruit per sampling date	r^2 value**		
Tree size	Orchard	Trunk traps	Inter-tree traps	Border traps		Trunk traps	Inter-tree traps	Border traps
Small	TS	0.00	0.00	0.00	0.81	—	—	—
	BK	0.10	0.10	0.00	0.71	0.07	0.07	—
	CR	0.00	0.00	0.10	0.28	—	—	0.06
	SK	0.11	0.22	0.00	0.16	0.03	0.07	—
	CY	0.00	0.00	0.00	0.26	—	—	—
	SH	0.00	0.00	0.25	0.24	—	—	0.12
	SR	0.00	0.00	0.00	0.00	—	—	—
	CK	0.00	0.00	0.00	0.23	—	—	—
	Mean	0.03	0.04	0.04	0.36	0.06	0.00	0.04
Medium	TS	0.00	0.00	0.00	1.00	—	—	—
	BK	0.00	0.00	0.00	0.00	—	—	—
	CR	0.00	0.00	0.00	0.14	—	—	—
	SK	0.11	0.00	0.00	0.58	0.05	—	—
	CY	0.00	0.00	0.11	0.69	—	—	0.02
	SH	0.00	0.00	0.00	0.00	—	—	—
	SR	0.00	0.13	0.00	0.06	—	0.02	—
	CK	0.00	0.00	0.13	0.12	—	—	0.02
	Mean	0.01	0.01	0.04	0.34	0.06	0.08	0.11
Large	TS	0.10	0.00	0.10	1.10	0.10	—	0.10
	BK	0.30	0.00	0.00	0.19	0.08	—	—
	CR	0.00	0.00	0.10	0.19	—	—	0.07
	SK	0.00	0.00	0.00	0.16	—	—	—
	CY	0.00	0.00	0.00	0.00	—	—	—
	SH	0.00	0.00	0.00	2.50	—	—	—
	SR	0.00	0.00	0.00	0.00	—	—	—
	CK	0.13	0.00	0.00	0.65	0.09	—	—
	Mean	0.07	0.00	0.03	0.58	0.01	—	0.01

* Number of sampling dates per orchard were: TS, BK, CR = 10; SK, CY = 9; SH, SR, CK = 8.

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

rises in level of injury coincide in time, to any substantial degree, with rises in trap captures. Nor for any trap position was there a significant positive relationship between mean number of captured adults per block and mean number of sampled fruit injured per block (no r^2 value exceeded 0.11).

When data from these eight orchards were segregated according to sampling dates before, between or after insecticide applications, the data show that no fruit injury was detected prior to the first insecticide application even though some captures by traps in each position had occurred. In no case was there a significant positive relationship between mean number of captured adults per block and mean number of sampled fruit injured per block, either for sampling dates between the first and second insecticide application, between the second and third insecticide application, or following the last insecticide application (no r^2 value exceeded 0.03) (Table 2). In every block type, mean fruit injury increased between the first and second, between the second and third, and after the third insecticide application, whereas in most cases, mean trap captures either successively decreased from levels that were reached prior to any insecticide treatment or were nil throughout.

In the 50-tree commercial orchard that received an unbaited pyramid trap next to the trunk of every tree, there was a significant negative linear relationship between trap captures and numbers of fruit injured by plum curculio ($r^2 = 0.53$, df = 6, $P \leqslant 0.05$) (Fig. 1). As fruit injury levels increased, captures of plum curculios decreased. This negative relationship was particularly evident during the week prior to application of the last insecticide treatment, when captures dropped precipitously but injury increased substantially. Also, this negative relationship was true not only when data were combined across cultivars but also for each of the three principal cultivars individually when data were segregated according to cultivar (data not shown).

Traps for control. In the 216-tree unmanaged orchard where an unbaited pyramid trap was placed next to the trunk of each of four adjacent trees in eight sets of trees, there was no significant difference between sets of trapped trees and sets of untrapped trees in percent sampled fruit injured by plum curculio for any of the five weekly sampling periods (Table 3). Amount of damaged fruit in trees having pyramid traps rose from a mean of 4.8% 4 d after petal fall to a mean of 75.3% at the last sampling period. Damage to fruit by plum curculio exceeding 0.5% is considered unacceptable by most commercial apple growers.

In the 50-tree commercial orchard having an unbaited pyramid trap next to the trunk of every tree, fruit injured by plum curculio rose from 0.0% at petal fall to a mean of 3.6% 4 d later (when the first insecticide application was made) and to a mean of 6.0% 17 d later (when the second and last insecticide application was made) (Fig. 1).

Discussion

Collectively, our findings show that the temporal occurrence of captures of overwintered plum curculio adults by unbaited pyramid traps located next to orchard tree trunks, between orchard tree canopies, or near woods bordering orchards did not coincide with the temporal occurrence of ovipositional injury to fruit by overwintered plum curculios in blocks of either small, medium-size or large apple trees in commercial orchards in Massachusetts studied in 1997. Nor was the amount of adult captures by traps at any of these three positions significantly related to the amount of ovipositional injury to fruit in an orchard block having traps, either across the entire period of overwintered adult activity or within periods of adult activity before, between or

Table 2. Relationship (denoted by r^2 value) between numbers of overwintered plum curculio adults captured by unbaited pyramid traps at tree trunk, inter-tree or orchard border positions and percent fruit showing ovipositional injury by plum curculios across sampling dates before, between or after insecticide spray applications against plum curculio in blocks of small, medium-size or large apple trees and across all eight commercial orchards studied in Massachusetts in 1997.

Tree size	Sampling dates	No. orchard blocks	Mean no. sampling dates per block	Mean no. adults captured per sampling date			Mean % injured fruit per sampling date	r^2 value*		
				Trunk traps	Inter-tree traps	Border traps		Trunk traps	Inter-tree traps	Border traps
Small	Before first spray	8	1.1	0.22	0.22	0.22	0.00	—	—	—
	Between first & second spray	8	2.5	0.00	0.05	0.05	0.35	—	0.03	0.02
	Between second & third spray	3	2.7	0.00	0.00	0.00	0.36	—	—	—
	After final spray	8	4.4	0.00	0.00	0.00	0.45	—	—	—
Medium	Before first spray	8	1.1	0.00	0.11	0.11	0.00	—	—	—
	Between first & second spray	8	2.5	0.05	0.00	0.05	0.33	0.02	—	0.01
	Between second & third spray	3	2.7	0.00	0.00	0.00	0.36	—	—	—
	After final spray	8	4.4	0.00	0.00	0.00	0.42	—	—	—
Large	Before first spray	8	1.1	0.22	0.00	0.11	0.00	—	—	—
	Between first & second spray	8	2.5	0.10	0.00	0.05	0.31	0.03	—	0.03
	Between second & third spray	3	2.7	0.00	0.00	0.00	0.48	—	—	—
	After final spray	8	4.4	0.03	0.00	0.00	0.90	0.02	—	—

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

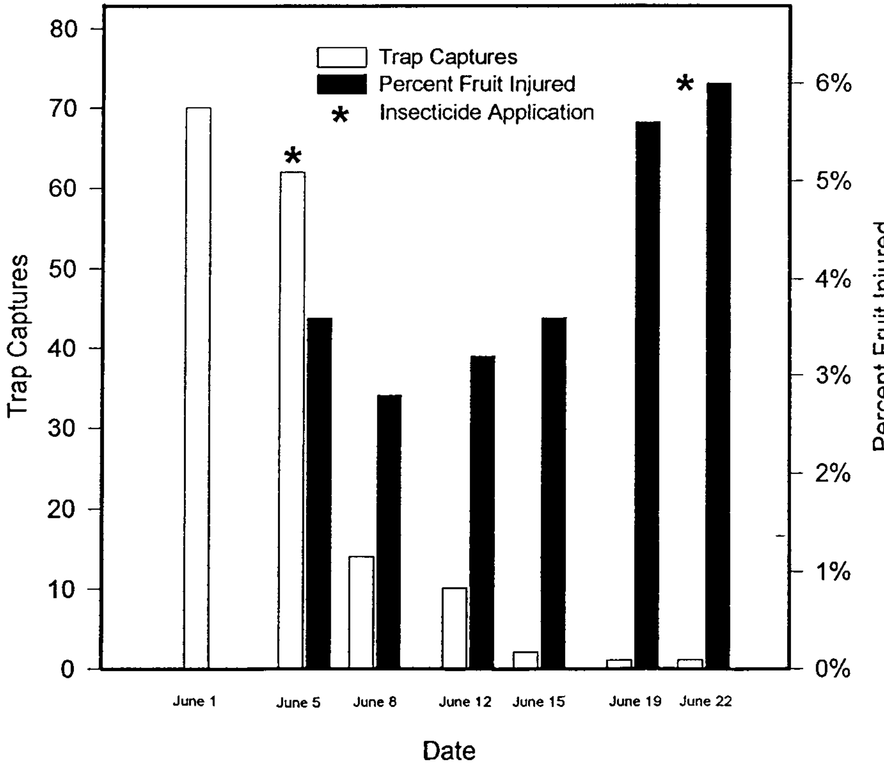

Fig. 1. On each sampling date from June 1 (petal fall) through June 22, percent sampled fruit (n = 250) showing a plum curculio ovipositional scar and numbers of plum curculio adults captured by unbaited pyramid traps (n = 50) adjacent to tree trunks in a small commercial apple orchard. Tree canopies were sprayed with insecticide on June 5 (80% petal fall) and on June 22, Conway, MA, 1997.

following insecticide applications. Finally, unbaited pyramid traps next to apple tree trunks afforded no detectable or economic protection of fruit against plum curculio injury.

Data from a 1996 study in the 50-tree commercial apple orchard (Prokopy and Wright 1998) are consistent with 1997 data obtained here from that same orchard and with 1997 data obtained here from 24 blocks of apple trees in larger commercial orchards. In general, captures of overwintered adults by traps in any of the three aforementioned positions tended to decline substantially soon after the first insecticide application, whereas amount of fruit injured by plum curculios tended to increase. The cause of such a trend toward decline in adult captures by unbaited pyramid traps shortly after petal fall or the first application of insecticide was unrelated to the presence of insecticide on the traps (which were protected from sprays) but possibly related to a general trend toward a rise in temperature during several weeks following

Table 3. Injury to fruit by plum curculios in eight sets of four trees having an unbaited pyramid trap next to the trunk of each tree compared with eight sets of four trees without traps in a 216-tree unmanaged apple orchard. Belchertown, MA, 1997.

No. days after petal fall	Mean no. (±SEM) captured adults per tree set	Mean percent (+SEM) sampled fruit with scars*	
		Tree sets with traps	Tree sets without traps
4	4.3 ± 1.3	4.8 ± 1.4a	3.8 ± 1.1a
11	2.0 ± 0.7	16.3 ± 2.8a	20.6 ± 4.1a
18	6.3 ± 1.6	47.8 ± 2.9a	40.0 ± 3.6a
25	6.3 ± 1.7	65.3 ± 2.9a	62.5 ± 3.1a
32	5.8 ± 2.1	75.3 ± 4.5a	77.5 ± 3.1a

* Means in each row followed by the same letter are not significantly different according to t tests at the 0.05 level.

petal fall. Overwintered plum curculio adults beneath host trees exhibit an increasing propensity to fly and an increasing propensity to cause fruit injury with increasing ambient temperature above ~20°C (Prokopy, Wirth and Dixon, unpub. data). Adults in flight are much less likely to orient towards and be captured by unbaited pyramid traps than are crawling adults (Prokopy and Wright 1998). Instead, adults in flight are prone to fly directly into apple tree canopies. Hence, when temperatures increase above ~20°C, the probability of injury to apple fruit in tree canopies increases as does the probability that adults will bypass tree trunks and pyramid traps when entering apple tree canopies. In addition to temperature, application of insecticide to tree trunks and canopies may play an as yet undetermined role in affecting the relationship between captures by pyramid traps and amount of fruit injury.

Even if pulses in captures of plum curculio adults by unbaited pyramid traps were of no value here in predicting pulses of injury to apple fruit, in concept total captures by unbaited pyramid traps could still be of value in predicting total injury to fruit. The data obtained here relating season-long mean numbers of trap captures to mean percent fruit injury do not, however, support this hypothesis. On the contrary, they argue against it. For example, the greatest fruit injury in any of the 24 blocks in large commercial orchards was in a block of large trees in the SH orchard (a mean of 2.5% fruit injured) (Table 1). Not a single plum curculio adult was captured by any trap in this orchard. Conversely, in the two blocks receiving the greatest trap captures (small trees in the SH orchard and large trees in the BK orchard), there was a mean of only 2.4 and 0.19% injured fruit, respectively. Many blocks received greater injury than this. It might be argued that use of more than one trap per 49 trees (the ratio used here) could lead to improved ability to predict fruit injury based on trap captures. The approximate $10.00-$15.00 cost of constructing or purchasing an unbaited pyramid trap of the type used here would be prohibitive for use of high trap densities for monitoring purposes, however.

With respect to the prospect of directly controlling plum curculio in apple orchards using unbaited pyramid traps at the tree trunk position (the position yielding more or as many captured adults as any other position), data obtained here are not encouraging. In the 216-tree unmanaged orchard, the approach of using one trap per tree for each of four adjacent trees failed to detectably reduce plum curculio injury to fruit. It could be argued, however, that such an approach was an inappropriate one for assessing control potential owing to the substantial pool of adults, on nearby untrapped trees, available for recolonization. An unbaited pyramid trap for every tree in an orchard might be a more appropriate approach, as was shown when using unbaited sticky red sphere traps for controlling apple maggot flies, *Rhagoletis pomonella* (Walsh) (Prokopy and Mason 1996). Even when each tree in the 50-tree commercial orchard did receive an unbaited pyramid trap, plum curculio injury reached a commercially unacceptable level of 3.6% of sampled fruit prior to application of the first insecticide treatment, 4 d after petal fall. Thus, the prospect of using unbaited pyramid traps for achieving appreciable control of plum curculio in commercial apple orchards in Massachusetts appears dim.

What might be a more suitable trap than an unbaited pyramid trap on the ground for effectively monitoring or possibly controlling plum curculios in apple orchards? Potentially, addition of synthetic attractive sex pheromone (Eller and Bartelt 1996) in combination with synthetic attractive host fruit odor (Prokopy et al. 1995, Leskey et al. 1996, Butkewich and Prokopy 1997) to such a pyramid trap could improve effectiveness to the level desired. Alternatively, a baited trap mimicking upright tree-canopy branches or twigs, to which crawling plum curculio adults seeking oviposition sites are attracted (Prokopy et al. 1998), or a 'Circle' trap enveloping the tree trunk (Mulder et al. 1997), might be more appropriate candidates for monitoring and control purposes.

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