Comparisons between different monitoring techniques for plum curculio, *Conotrachelus nenuphar* (Herbst) in apple orchards

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Abstract

Different monitoring techniques were compared in three apple orchards in Quebec, Canada, to evaluate their reliability as tools for estimation of plum curculio activity on damage to fruits, during three consecutive years. Adult plum curculio activity was monitored for four weeks starting at bloom, and damage to fruits was assessed by examination of apple fruitlets during that same period. Adult captures obtained by means of classical limb tapping or visual examination techniques were compared to pyramidal traps adapted from a trap developed for the pecan weevil, *Curculio caryae* (Horn) (Coleoptera: Curculionidae). No single monitoring technique was found to be superior under all conditions. In most cases (eight out of nine), the first signs of activity were detected at the same time or earlier by the trapping device then by visual examination of fruitlets. Examination of fruitlets appeared superior in terms of effectiveness (number of activity signs detected) but trapping appeared equivalent to visual examination of fruitlets in terms of efficiency (number of activity signs detected per unit of time spent monitoring). In a second experiment, the effectiveness of the standard pyramidal trap was compared to traps of alternative size, shape, and quality. In this experiment, flexible (fabric) traps were more powerful than rigid ones prior to bloom, and 30 cm high traps were more powerful than standard 120 cm high traps following bloom. In light of these results, monitoring using flexible semi-conical traps is recommended early in the season to detect and locate first signs of activity, and visual examinations are recommended following bloom, to further detect signs and determine the need for control measures.

Keywords: pheromones, visual cues, traps, apple orchards

INTRODUCTION

The plum curculio, *Conotrachelus nenuphar* (Herbst) (Coleoptera: Curculionidae) remains the only key pest of apples for which there is currently no effective and reliable monitoring technique (Leskey et al., 2013). Adult plum curculios can cause up to 88% damage to unprotected apple crops (Vincent and Roy, 1992; Chouinard et al., 2001). In northeastern America, preventive spraying of organophosphate, neonicotinoid, or other wide-spectrum insecticides is usually done to control against this pest. Spraying is timed at petal fall and repeated when necessary, and up to three times during the next four weeks of egg-laying activity (Vincent et al., 1999; Leskey et al., 2009). The need for those subsequent sprays is usually determined by limb tapping (also referred to as *jarring*) and/or visual examination of apple fruitlets for presence of characteristic crescent-shaped egg-laying damage. Unfortunately, limb tapping often causes tree damage and its effectiveness is highly dependent on the scout's experience, the prevalent weather, and the time of day (Racette et al., 1990). Fruit examination is also time-consuming and detects the damage when it is already done, which is too risky for most growers.

As a result, many attempts were made for many decades to develop a more effective monitoring device, among which Le Blanc et al. (1981, 1984), Racette (1988), Yonce et al. (1995), Leskey and Wright (2004), Piñero et al. (2011), and many others reviewed by Vincent et al. (1999) and Leskey et al. (2009). The availability of a pyramidal trap for monitoring the pecan weevil, *Curculio caryae* (Horn) (Tedders and Wood, 1994), and its adaptation for monitoring plum curculio adults in apple orchards (Prokopy and Wright, 1998) is generally considered as the most promising tool for the development of a better way of estimating the need of specific interventions against this insect.

The present study was undertaken to measure and compare the general characteristics of the two classical monitoring techniques (limb tapping and fruitlet examination) with the characteristics of the pyramidal trapping technique now available for apple orchards in northeastern America. As a first step, comparisons were made for the following characteristics: detection of first signs of activity, and measurement of activity levels. In a second step, we investigated possible improvements to the trapping technique, building on the latest studies by Lafleur et al. (2007) and Lamothe et al. (2008).

MATERIALS AND METHODS

Classical versus trapping techniques

The study took place in three commercial orchards located in southern Quebec (Canada). Representatives of the three different situations in which it is necessary to monitor plum curculio activity were present: a certified organic orchard with very high population pressure, a conventionally managed orchard with high population pressure, and a conventionally managed orchard with moderate population pressure (Table 1). Each orchard was divided into five blocks according to estimated pest pressure, four peripheral blocks of ca. 20 m wide (north, south, east, west) and a central block (Chouinard et al., 1992; Vincent et al., 1997).

Table 1. Characteristics of the three apple orchards in Canada used for the comparison between three monitoring techniques; limb tapping, fruitlet examination, and the pyramidal trapping technique used for pest control against the *Conotrachelus nenuphar*.

Characteristic	Orchard 1	Orchard 2	Orchard 3
Orchard size	1.2 ha	3 ha	1.7 ha
Tree density	High density	Standard-sized	Mixed
Adjacent plot (northeast)	Annual crops	Woodlots	Woodlots
Adjacent plot (southwest)	Organic orchards	Apple tree nursery	Neglected orchard
Pest management	Organic	Conventional	Conventional
Pest pressure[1]	Very high (127; 54)	High (31; 11)	Moderate (16; 0)

[1]Classification based on (*x; y*) where *x* is the average number of *C. nenuphar* egg-laying scars per 100 fruits observed the previous years between full bloom and petal fall, prior the post-bloom insecticide application, and *y* is the average number of *C. nenuphar* adults observed by jarring trees during the same period, using methods described.

Three monitoring techniques were compared concurrently in each block. Monitoring took place from bloom to four weeks after fruit set (cultivar 'McIntosh') for three consecutive years. Fruit examinations were performed yearly on ten randomly selected trees in each block, by examining 20 randomly chosen fruitlets (on the facing side only) and counting the number of fruits bearing characteristic *C. nenuphar* damage. Limb tapping was done on 20 other randomly selected trees in each block, by hitting three randomly selected main branches three times each with a rubber-coated stick, and counting the fallen *C. nenuphar* adults on a 1 m^2 beating sheet below, then immediately releasing the beetles on major branch crotches of the sampled tree (Chouinard et al., 1992). Trapping was done by installing one standard (wooden, 120 cm-high, black) pyramidal trap (Prokopy and Wright, 1998; Johnson et al., 2002) under one randomly chosen tree in the outermost row of each peripheral block and one randomly chosen tree in the central block. Traps were unbaited in the first two years but in the third year, they were used in conjunction with 5 mg of grandisoic acid (Eller and Bartelt, 1996), an identified component of the aggregation pheromone of the plum curculio, impregnated in rubber septa (ChemTica, San Jose, Costa

Rica) and located at the base of the trap. Traps were located at a 50-100 cm distance from the trunk axis. The number of adults caught in the trapping unit at the top was recorded on each visit and trapped insects were removed from the orchard.

Traps were set approximately at the pink stage and visited twice a week, at the same time as fruit examinations and limb tapping. However, because they are lengthier (Table 2) and not usually done by scouts on a biweekly basis, fruit examinations and limb tapping were performed only once a week.

Trap improvement

This experiment took place in an organic orchard in Mont-St-Hilaire, Canada, in which we compared two trap heights (120 vs. 30 cm pyramidal black traps), two trap shapes (semi-conical vs. pyramidal black traps), and two trap qualities (firm vs. flexible brown fabric traps) in a paired design (Figure 1). Other characteristics of the standard pyramidal trap (height, surface, top collection device, attachment) were maintained to allow comparisons. At the “half-inch green” stage (cultivar ‘McIntosh’), 15 pairs of unbaited traps were placed under a tree with a minimum distance of 20 m between the traps. Trees were chosen randomly from a set of trees that were similar in size. Captured insects were collected twice a week until the beginning of July. Trap positions were exchanged at each visit within each pair of treatments. The trapping season was divided into three periods: I, before bloom (17 days); II, during bloom (7 days); III, after bloom (35 days).

Figure 1. Plum curculio traps in an apple (cultivar ‘McIntosh’) orchard in Mont-St-Hilaire, Canada. Traps compared in this study: top left, 120 vs. 30 cm pyramidal black traps; top right, semi-conical vs. pyramidal black traps; bottom, firm vs. flexible brown fabric traps.

Data analysis

In the first experiment, the following parameters were compared for the three monitoring techniques: time needed for installation and execution, ability to detect early signs of *C. nenuphar* activity, and relative effectiveness defined here as the traps ability to detect more activity signs than the other techniques. Relative effectiveness was estimated each year in every orchard by comparing the total number of activity signs (adults or fruit punctures) recorded during the experiment with a given technique to the total number of activity signs recorded with the most effective technique.

In the second experiment, the mean number of insects captured by each type of trap was compared using a Wilcoxon matched-pairs signed-ranks test for each period of capture (Daniel, 1990). To support activity monitoring data, climatic conditions (air temperature 1 m above ground and daily precipitations) were recorded throughout the experiments with Campbell CR10 automated weather stations located within the orchards.

RESULTS AND DISCUSSION

Classical versus trapping techniques

Limb tapping was the most time-consuming of the three techniques (Table 2) and trapping the quickest, even when installation time was included. In eight of the nine situations (orchard-year combinations) encountered, the trapping technique recorded signs of activity before (five situations) or at the same time (four situations) as other techniques (Table 3). The effectiveness of the different techniques, in terms of their ability to detect more or fewer activity signs, is presented in Table 4. Fruit examination found more activity signs than the other techniques, in eight out of nine situations. However, effectiveness, as calculated here, did not take into account the time needed to detect those activity signs, which varied greatly between techniques. Efficiency, which we define here as a measure of effectiveness per unit of time, gave a different picture of the situation: trapping (in 4 out of 9 situations) and fruit examination (in 5 out of 9 situations) were found to be the most efficient techniques for monitoring plum curculio. In the organically managed, high-density, and high-pressure orchard, fruit examination was the most effective and the most efficient method in all three years.

Table 2. Average time (min±SE) needed for three monitoring techniques in Quebec apple orchards. Time includes on-site maintenance and cleaning. Standard error based on data collected during three seasons in three orchards (n=60 except for trap installation where n=15).

Monitoring technique	Unit	Installation time block^{-1}	Execution time block^{-1}
Fruit examination	200 fruitlets	0±0	8.42±1.01
Limb tapping	60 branches	0±0	22.7±3.24
Trapping	1 trap	4.87±1.41	1.25±0.54

Table 3. Observation date (Julian) of first *Conotrachelus nenuphar* activity signs (adults or fruit punctures) recorded by three monitoring techniques in Quebec apple orchards.

Monitoring technique	Orchard 1	Orchard 2	Orchard 3
Year 1			
Fruit examination	149	153	171
Limb tapping	146[1]	157	164[1]
Trapping	152	143[1]	164[1]
Year 2			
Fruit examination	152	159	159
Limb tapping	152	172	165
Trapping	149[1]	152[1]	152[1]
Year 3			
Fruit examination	157[1]	157[1]	177
Limb tapping	157[1]	157[1]	184
Trapping	157[1]	157[1]	157[1]

[1]Day of first recorded sign of activity for each orchard-year combination.

Table 4. Relative effectiveness (efficiency)[1] of three monitoring techniques for *Conotrachelus nenuphar* in apple orchards in Quebec, Canada.

Monitoring technique	Orchard 1	Orchard 2	Orchard 3
Year 1			
Fruit exam	100 (100)	100 (45)	100 (30)
Limb tapping	10 (4)	15 (3)	17 (2)
Trapping	2 (13)	33 (100)	50 (100)
Year 2			
Fruit exam	100 (100)	100 (100)	100 (100)
Limb tapping	1 (1)	8 (3)	2 (1)
Trapping	3 (20)	4 (27)	11 (74)
Year 3			
Fruit exam	100 (100)	100 (17)	43 (6)
Limb tapping	12 (4)	35 (2)	14 (1)
Trapping	6 (40)	87 (100)	100 (100)

[1]Relative effectiveness = 100 × the total number of activity signs (trap catches or fruit punctures) recorded by a given technique/ total number of activity signs recorded with the most effective technique for each orchard-year combination. Efficiency = relative effectiveness per unit of time.

These results suggest that no one simple monitoring method can be recommended for all uses. For detection of the first signs of activity, trapping ranked first. For effectiveness and efficiency, limb tapping clearly appeared as the least appealing of the three methods compared, while fruit examination and trapping ranked best in an approximately similar number of situations. An improved trapping technique could change the picture of this comparison. Although the addition of grandisoic acid bait in the trap in year 3, while increasing trap captures by a ca. two-fold factor in comparison to the two previous years, did not change the ranking with respect to first detections, effectiveness, and efficiency (Tables 3 and 4). It should be noted that year 3 was notably cooler than the previous two years, and that first signs of activity were observed, on average, 6 days later in year 3 than in the previous years.

Trap improvement

There was no significant difference in captures between trap shapes (semi-conical vs. pyramidal traps) during any period (pre-bloom: T_{13}=30, P=0.1527; bloom: T_{15}=46.5, P=0.2271; post-bloom: T_{15}=53.5, P=0.3599) (Figure 2a). Regarding trap qualities, the flexible trap captured significantly more *C. nenuphar* than the rigid one during the pre-bloom period (T_{15}=25; P=0.024) (Figure 2b), but there were no significant differences during the other periods (respectively II, T_{15}=32.5, P=0.1083, and III, T_{15}=39.5, P=0.1262). Regarding trap sizes, the standard 120-cm trap captured more adults than the small 30-cm trap during the blooming period (T_{13}=16.5; P=0.0199) (Figure 2c), but the small trap captured more adult than the standard-sized trap during the post-bloom period (T_{11}=10, P=0.021). There was no significant difference in captures between trap heights during the pre-bloom period (T_{13}=29, P=0.1367).

Thus, significant differences among trap sizes and qualities were observed during all periods, but those differences were not constant between periods. This makes it complicated to recommend one single trap size or design, unless for a specific time or purpose.

In light of the results of both experiments, visual examination of fruitlets and trapping techniques appear to be suited for different uses, and different trap designs appear to be suited for monitoring at different periods. Because it can detect first signs of activity earlier than other methods, trapping with pyramidal traps seems most suited for this, using the trap design that is most suited for the period (while keeping in mind that first signs of activity need to observed prior to or during bloom). Following bloom, since the correlation between trap captures and crop damage is not generally recognized as strong for plum curculio adult trapping (Prokopy and Wright, 1998; Johnson et al., 2002), visual examination of fruitlets should be the preferred method for determining the need for treatments. Action thresholds can be developed for growers using this type of monitoring (e.g., Chouinard et al., 2001), and activity forecasts based on bioclimatic models (Chouinard et al., 2002) can be used to determine the timing of the treatments.

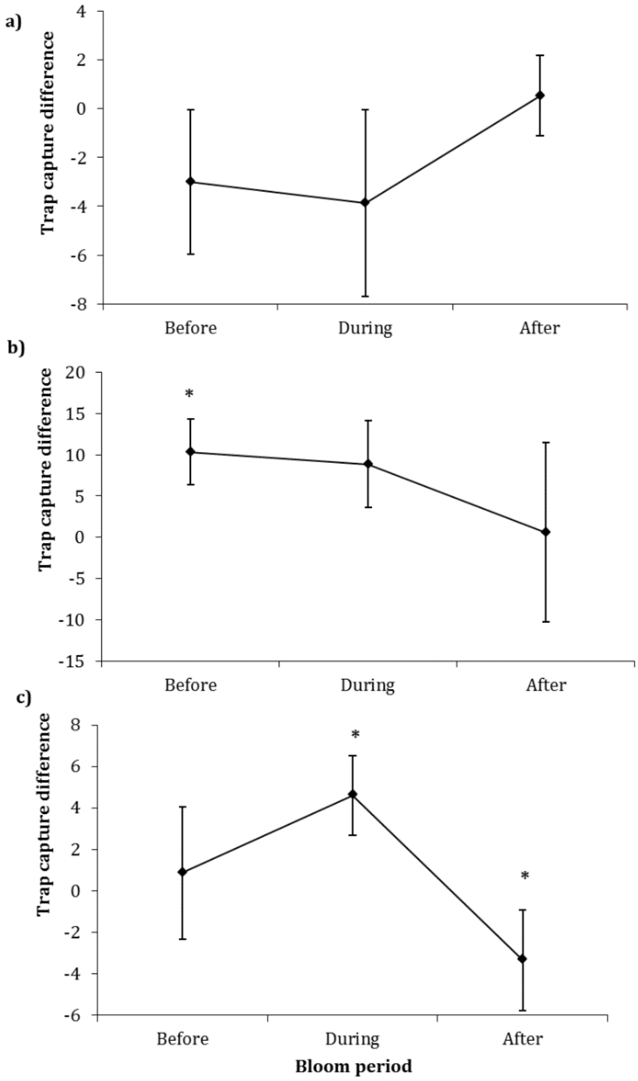

Figure 2. Differential effectiveness (mean ± standard error) in trap shape, quality, and size for monitoring *C. nenuphar* adults in apple orchards. a) Captures in semi-conical trap – captures in pyramidal trap; b) captures in a flexible fabric trap – captures in firm fabric trap; c) captures in 120-cm trap – captures in 30-cm trap. The asterisks indicate a significant difference (Wilcoxon matched-pairs signed-ranks test, α=0.05).

CONCLUSIONS

For first detection purposes, traps currently used for monitoring plum curculio adults were as powerful as fruit examination and limb tapping. In terms of the number of adults caught, flexible (fabric) traps were more powerful than rigid ones prior to bloom, and 30-cm high traps were more powerful than the standard 120-cm traps following bloom. However, taking into account that correlations between trap captures and crop damage is very weak, it is suggested that 120-cm flexible traps be used to detect and locate first signs of activity early in the season, and that visual examination of fruitlets can be used after bloom for the same purpose and for determining the need for control measures. The timing of such applications should be determined by using bioclimatic activity models.

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