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RELATIONSHIP BETWEEN FRUIT YIELD AND DAMAGE BY
CODLING MOTH AND PLUM CURCULIO IN A
BIOLOGICALLY-MANAGED APPLE ORCHARD

M. Sean Clark¹ and Stuart H. Gage²

ABSTRACT

Fruit yield, codling moth (*Cydia pomonella*) damage, and plum curculio (*Conotrachelus nenuphar*) damage were monitored over an 8-year period in a 0.5-ha, biologically-managed apple orchard in southwestern Michigan. The relationship between yield and damage was examined for both of these pests. The orchard showed clear biennial bearing patterns of alternating high and low yields. A significant negative correlation was found for yield and percentage damage by codling moth but not for plum curculio damage. However, the estimated amount of fruit damaged by codling moth remained relatively stable over the period, indicating that changes in percentage damage depended on yield dynamics rather than changes in codling moth abundance. In contrast, the amount of fruit damaged by plum curculio showed biennial fluctuations and a positive correlation with yield, indicating that the population of this pest was capable of responding with increased oviposition in years with greater fruit yield. In addition, a comparison of codling moth fruit injury in years with and without the use of pheromone mating disruption showed no statistically significant reduction in damage as a result of using this method, suggesting that the orchard may be too small or codling moth populations too high for effective use of this management tactic.

Codling moth (*Cydia pomonella* L.) and plum curculio (*Conotrachelus nenuphar* Herbst) are among the most important economic pests of apple (*Malus domestica* Borkh.) in the United States (Prokopy and Croft, 1994). Codling moth is native to Asia but now occurs in apple-producing regions throughout the world. Its damage is caused by larval feeding and is characterized by shallow or deep, frass-lined burrows in the fruit. Plum curculio is native to eastern North America. Its damage is usually characterized by crescent-shaped oviposition scars on the fruit surface, however it also causes damage due to larval and adult feeding and premature drop of internally-damaged fruit (Racette et al., 1992). Actual yield loss due to premature drop is not known because its occurrence coincides with the natural fruit abscission commonly known as "June drop" (Racette et al., 1992). The oviposition scars commonly seen on mature fruit are cosmetic injuries and their presence indicates failed larval survival rather than larvae within the fruit. Nevertheless, due to the strict cosmetic standards for apples, such surface damage is generally not tolerated by wholesalers, retailers, processors, or consumers.

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A fundamental prerequisite for sustainable management of these pests is an understanding of the abiotic and biotic factors that influence their abundance and regulate their populations. Current management for both of these pests rests largely on chemical control, although developments in degree-day models, trapping and monitoring, and biological-based control have reduced the amount of pesticide applied and the number of applications (Vincent & Roy 1992, University of California 1991, Howitt 1993). There is still relatively little information in the literature describing the factors that influence the abundance of these pests and the damage they cause under conditions without pesticide use. This paper reports findings on the relationship between fruit yield and damage by codling moth and plum curculio in a biologically-managed apple orchard.

MATERIALS AND METHODS

The experimental orchard block in this study was a 0.5 ha planting, initially consisting of 210 trees, located at the Kellogg Biological Station in southwestern Michigan. It was 1 of 3 orchard plantings established 1983 in a 2 ha area with disease-resistant varieties 'Redfree', 'Priscilla', and 'Liberty' on M.26 rootstock. The 3 blocks have been managed without the use of pesticides (insecticides, herbicides, and fungicides) since establishment. Practices used for reducing insect pest damage have included removal of dropped fruit from the orchard in some years, use of red sticky spheres for apple maggot (*Rhagoletis pomonella* Walsh), natural enemy conservation with mulching and establishment of flowering plants in the groundcover. In addition, free-range chickens have also been evaluated as predators (Clark & Gage 1996). In 1990, 1991, and 1994 pheromone mating disruption (Isomate-C, 1,000 dispensers ha⁻¹, Great Lakes IPM, Inc., Vestaburg, MI) was used for codling moth management. Groundcover management was accomplished with several mowings between May and October and with experimental rotational grazing of weeder geese (Clark & Gage 1996). The landscape around the orchard blocks consisted of crop fields planted to corn, wheat, soybean, and alfalfa. No other orchards were located within several kilometers of the site, though several unmanaged apples trees were within this range.

All apples on all trees were harvested and weighed each year from 1988 to 1995. Dropped apples on the ground were not included in the yield determinations for several reasons. The presence of free-range chickens and geese presented some risk of fecal contamination to fruit on the ground. In addition, mowing was avoided near harvest time in an effort to prevent knocking fruit from the trees; thus vegetation was generally quite tall at harvest, making fruit collection from the orchard floor difficult and inefficient. At harvest, five fruit were arbitrarily selected from each tree for codling moth and plum curculio damage assessment. Data from each tree were pooled and used to calculate the average yield per tree and the average percentage of fruit damaged by the two pests (percent damage). Over the eight-year period, approximately 15% of the trees died as a result of rodent damage, most during the winter of 1991–1992. Although new trees were planted in 1994 to replace the missing trees, these were not included in the yield determinations.

The relationship between yield and fruit damage was analyzed graphically and statistically. In addition, the weight of damaged fruit each year was estimated based upon the percent damage and the total yield. Pearson correlation coefficients were used to assess the relationship between yield and percent damage and the estimated weight of damaged fruit. The effect of pheromone disruption on codling moth fruit injury was assessed by compar-

ing damage in years with and without this control tactic using a Student's t-test.

RESULTS AND DISCUSSION

Apple yields over the eight-year period clearly showed biennial bearing patterns which are typical of orchards that are not thinned in the heavy-bearing years (Fig. 1). Mean yield per tree ranged from a low of 2 kg of fruit in 1991 to a high of 24 kg of fruit in 1992 and 1994 (standard errors $\leq 5\%$ of the means). Typically, commercial orchardists chemically thin fruit within several weeks of full bloom to prevent these kinds of dramatic fluctuations in yield.

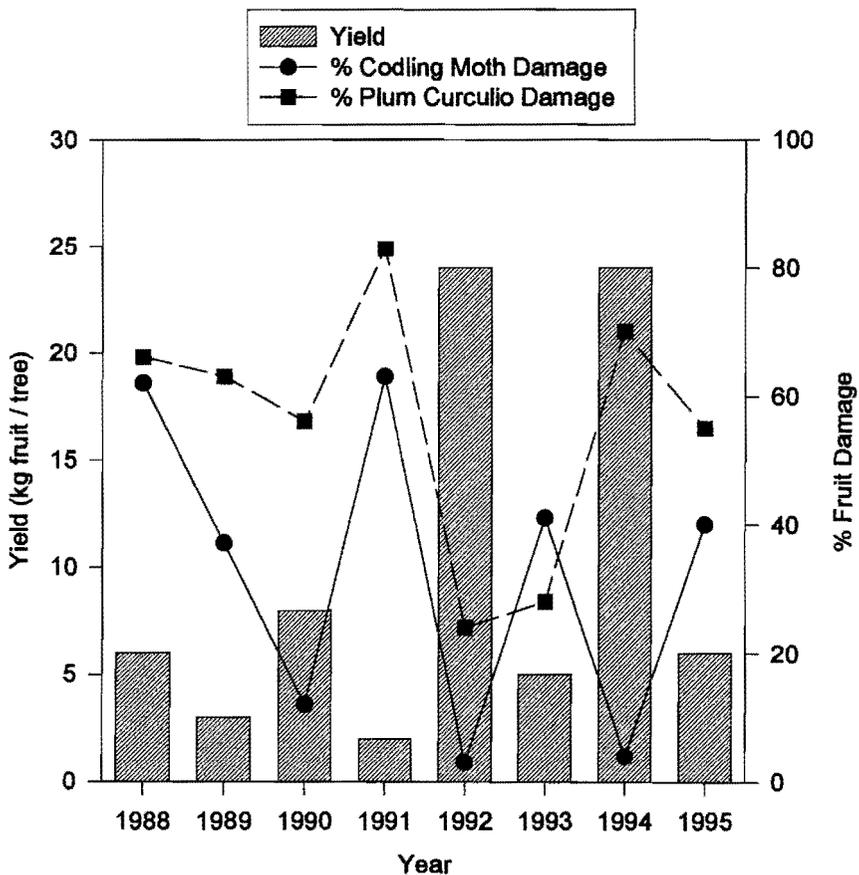


Figure 1. Mean fruit yield (kg fruit/tree) and the percentage of fruit damaged by codling moth and plum curculio from 1988 to 1995. Fruit yield means are based on 200 trees and standard errors are $\leq 5\%$ of the means.

Damage by codling moth and plum curculio was also highly variable over the 8-year period (Fig. 1). Codling moth damage ranged from 3 to 63% and averaged 33% while plum curculio damage, tending to be somewhat higher, ranged from 24 to 83% and averaged 56%. These values are comparable to, though somewhat higher than, other studies of unsprayed apple orchards. Glass & Lienk (1971) reported codling moth damage to range from 7 to 35% and average 18% and plum curculio damage to range from 1%–46% and average 15% in a New York orchard, over a 10-year period following the discontinuance of insecticides. In a 2-year study of an organic orchard in British Columbia, codling moth damage ranged from 5.6 to 16.4% (Madsen & Madsen 1982). And a study by Vincent & Roy (1992) showed plum curculio damage in an unsprayed orchard in Quebec to average 48% with a peak at 86% over a 13-year period. None of these studies, however, reported if a relationship existed between yield and damage.

In this orchard, the percentage of damaged fruit due to codling moth was found to be negatively correlated with fruit yield ($r = -0.82$, $P = 0.01$) (Fig. 2). In years with low yield, percent damage was relatively high, while in high-yielding years, percent damage was relatively low. This pattern was observed between all years except between 1988 and 1989 when both yield and percent damage declined (Fig. 1). No such relationship was found for plum curculio ($r = -0.32$, $P = 0.43$) (Fig. 2). The estimated weight of fruit damaged by codling moth remained relatively stable over the 8-year period, while that of plum curculio showed biennial fluctuations (Fig. 3) and was positively correlated with yield ($r = 0.80$, $P = 0.03$) (Fig. 4).

The negative correlation between percent damage by codling moth and fruit yield and the relatively small degree of year-to-year variability in the estimated amount of damaged fruit (Fig. 3) indicate that changes in percent damage were due largely to yield dynamics rather than to changes in codling moth abundance or activity. By contrast, the amount of fruit damaged by plum curculio increased in years with greater yields (Fig. 3, Fig. 4), indicating that this pest was capable of responding to the increased yields with increased oviposition activity.

Although reports on the oviposition rates of codling moth vary considerably, ranging from 30 to several hundred per female (Davidson & Lyon 1987, Hill 1987, University of California 1991, Howitt 1993), they are generally lower than those of plum curculio, which are reported to be 100–500 eggs per female (Howitt 1993), and considered to be relatively low for an insect pest (Begon et al. 1990, p. 552). This provides a possible explanation for the differing patterns in codling moth and plum curculio damage. Low percent damage by codling moth in high yield years may have been due to a combination of the alternating years of high and low yields and the relative slow growth of codling moth populations. Thus, the biennial yield cycling may have suppressed codling moth abundance in high-yielding years by limiting population growth with low fruit availability in the low-yielding years. The percentage of fruit damaged by plum curculio showed no such relationship to yield. Instead, the absolute amount of damaged fruit increased in high-yielding years apparently because of this pest's inherent ability for more rapid population growth.

Codling moth damage during the 8-year period averaged 26% in years with pheromone disruption and 37% in other years. This difference, however, was not statistically significant ($P = 0.60$). We view this comparison with caution as it was not a replicated experiment but rather a case study. The lack of a significant reduction in codling moth damage may have simply been due to the orchard being too small or because the resident population was too large prior to the use of disruption. Furthermore the population size in one season

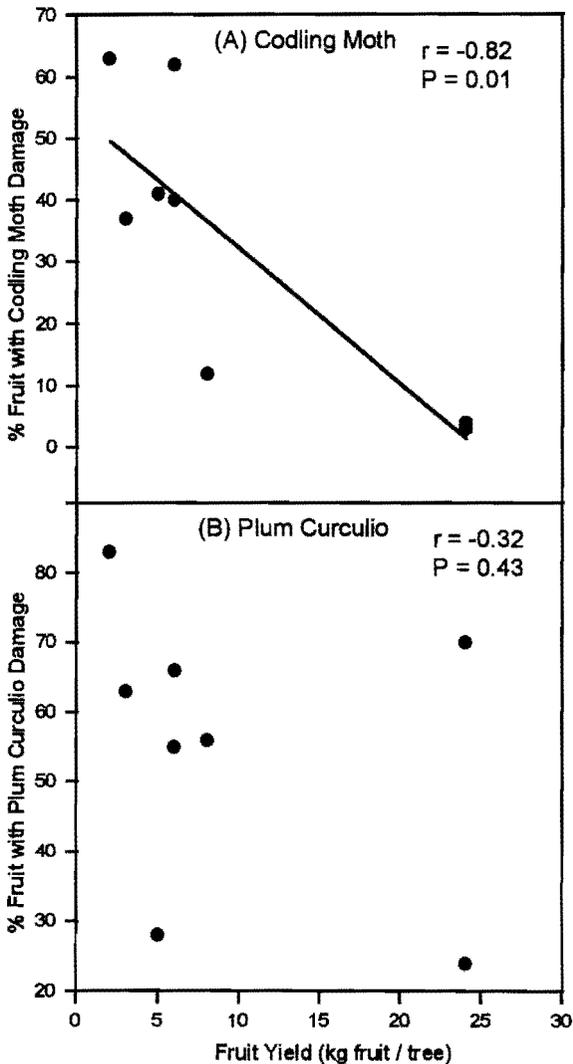


Figure 2. Correlation between fruit yield and percent damage by (A) codling moth and (B) plum curculio over the 8-year period, 1988–1995.

undoubtedly influenced those of following seasons, leading to complex interactions and confounding effects.

Codling moth mating disruption with pheromones has been tested in North America in recent years as an alternative to chemical insecticides and the results have been mixed (Pfeiffer et al. 1993, Bentley et al. 1994, Trimble

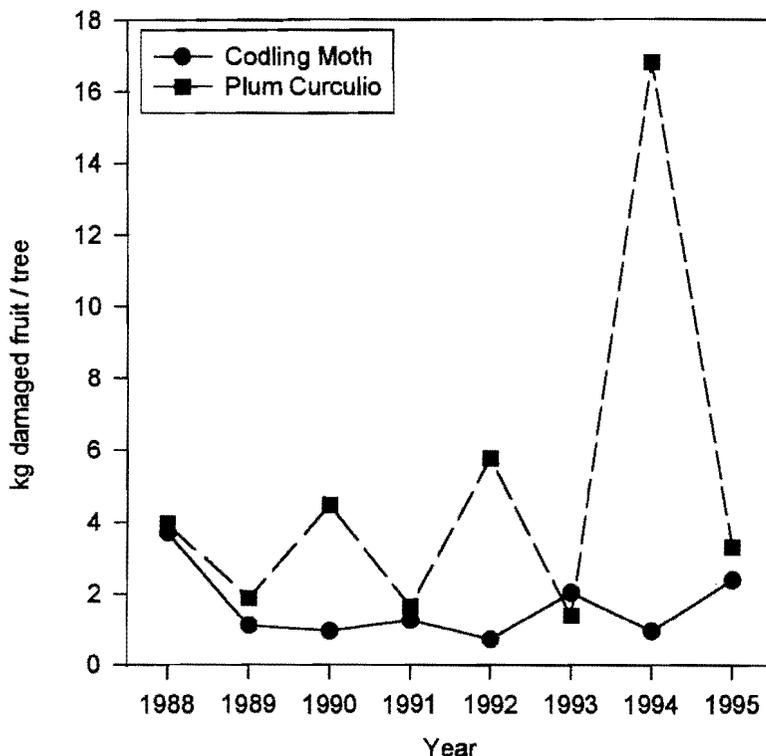


Figure 3. Estimated weight of fruit damaged by codling moth and plum curculio based upon the percent fruit damage and the total yield, 1988–1995.

1995). Pfeiffer et al. reported that pheromone mating disruption in Virginia orchards can reduce codling moth damage; however, under high pest pressure, damage levels can still be unacceptable for many commercial growers. Similarly, Trimble found pheromone disruption to be ineffective at preventing codling moth damage on two organic orchards in Ontario and suggested that there may be a relationship between crop load and infestation levels. Our study is consistent with this suggestion and offers no statistical evidence that pheromone disruption reduces codling moth damage.

In summary, yield and fruit damage patterns over the eight-year period indicate that codling moth and plum curculio populations in this orchard were affected by yield. Codling moth damage levels suggest that the population of this pest remained relatively stable from year to year, a pattern to be expected of a K-selected species (Begon et al. 1990). Although many factors may influence codling moth abundance, including weather and natural enemies (Leius 1967, MacLellan 1977, Subinprasert 1987, Riddick & Mills 1994), damage levels in this orchard suggest a limitation by the availability of fruit in low-yielding years, resulting in relatively little damage in high-yielding years. Percent damage by plum curculio showed no relationship to yield, however, it was es-

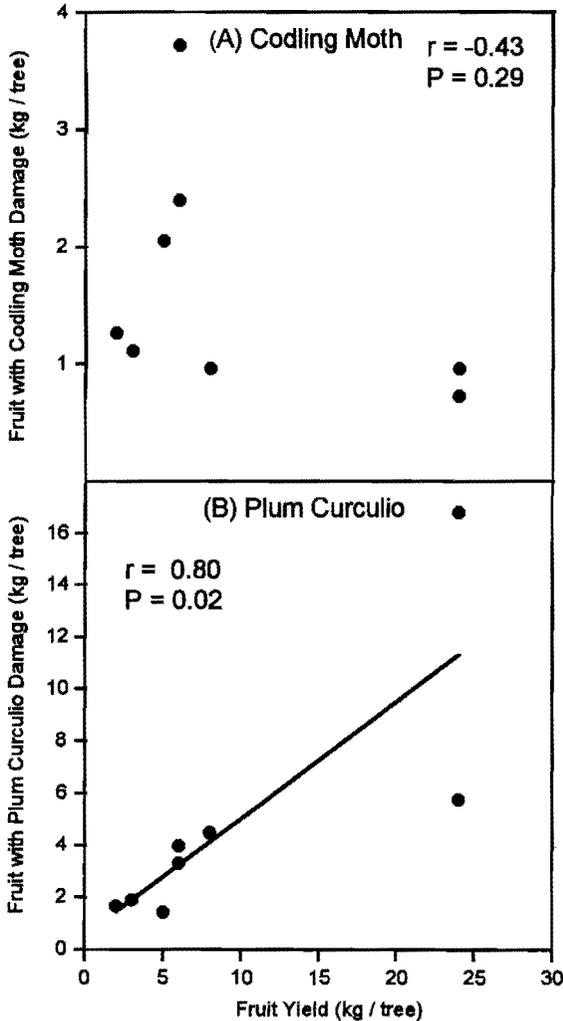


Figure 4. Correlation between fruit yield and damaged fruit (kg of fruit) by (A) codling moth and (B) plum curculio over the 8-year period, 1988–1995.

timated that there was a significantly greater amount of damaged fruit in years with higher yields, indicating that this pest's population is capable of responding to increased fruit abundance in the high-yielding years. Finally, a comparison of codling moth damage in years with and without pheromone disruption indicated that this pest management method did not result in a detectable reduction in fruit damage, possibly because the orchard was too small or codling moth populations were too high.

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