Predicting Apple Injury Caused by *Platynota idaeusalis* (Lepidoptera: Tortricidae) from Summer Brood Sampling

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ABSTRACT Linear and multiple regression analysis was used to evaluate four methods that sampled summer brood tufted apple bud moth (TABM), *Platynota idaeusalis* (Walker), egg masses, larvae, or fruit injury, to predict apple injury caused by fall brood larvae. Summer brood egg masses were low in number and generally were not a significant factor in the regression models. Only high percentages of summer brood fruit injury or high numbers of larvae were significant. Summer brood larvae was consistently the best predictor of fall brood fruit injury. The best sampling method to predict fall brood fruit injury was 5-min timed counts taken during late July–early August. These counts explained comparatively larger percentages of variation (generally r^2 values >0.60) with comparatively less sampling effort.

THE TUFTED APPLE bud moth (TABM), *Platynota idaeusalis* (Walker), is a tortricid pest of apple in fruit orchards in the eastern United States. This insect is bivoltine in south-central Pennsylvania, feeding on leaves and fruit from June until late July, and late August until harvest (Bode 1975). Hull et al. (1983), in a survey of Pennsylvania orchards during 1978 and 1979, found that the most frequent injuries to fruit were caused by this pest. Apple injury caused by larvae is usually not severe enough to reduce the grade of processing apples, but can lower the fruit value by changing the destination of the crop from the fresh to the processing market. Most fruit injury at harvest results from the feeding of fall brood larvae (Hull et al. 1981), although during some seasons summer brood larvae can cause more apple injury (Hull et al. 1982).

Prediction studies relating population parameters with crop loss or damage are minimal in deciduous tree fruit research for tortricids. Wong et al. (1971) correlated codling moth, *Cydia pomonella* (L.), pheromone trap catch with larval entries and stings. Riedl & Croft (1974), in a more intensive study, related early season codling moth cumulative trap catch to fruit damage at harvest under conditions of no chemical control. Dutch researchers have routinely sampled the larvae of the summerfruit tortrix, *Adoxophyes orana* (Fischer von Roslerstamm), in May and July to predict insecticide application dates for June and August, respectively (DeJong 1980). DeJong & Minks (1981) predicted fruit damage at harvest from whole tree counts of summerfruit tortrix larvae in July. They infested insecticide-treated trees with eggs and sampled the resulting larval population.

This study was done to establish a sampling plan whereby apple injury caused by fall brood feeding can be predicted from summer brood TABM egg masses, larvae, or fruit injury. Our objective was to sample early enough in the season to allow growers or consultants an opportunity to make management decisions concerning control of fall brood TABM. Four sampling methods were investigated, and success of a particular method was based on the percent variability explained by the resulting regression models.

Materials and Methods

This study was done in a 0.7-ha apple orchard in Arendtsville, Pa., containing 27-year-old trees arranged in four-tree plots. Each plot consisted of one tree each of 'Delicious', 'Golden Delicious', 'Stayman', and 'Rome Beauty'. Tree size was maintained by pruning to a height of ca. 3.4 m, and a width of ca. 3.5 m.

Four sampling methods were used to predict apple injury caused by fall brood feeding from summer brood egg masses, larvae, and fruit injury. The first method included the egg mass and larval numbers per tree data collected from a complete sampling of 'Golden Delicious' and 'Stayman' trees in 1982 (R.L.M., unpublished data). Ten trees from each of the two cultivars were sampled during the period from 21 July to 3 August by examining every leaf on the tree for TABM egg masses and larvae. Insecticides were not applied to these trees before sampling, but after sampling the trees were sprayed with a combination of azinphosmethyl plus methomyl at recommended rates (Anonymous 1982) for the remainder of the season. Fruit injury caused by summer and fall brood TABM larvae was estimated at harvest by examining all dropped fruit and a random sample of 100 apples from

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each tree. Fruit injury caused by summer brood larvae appeared as surface-feeding marks surrounded by varying amounts of decay; the fall brood injury appeared more recent and its margins were more defined.

The second and third sampling methods included the egg mass and larval shelter data collected from a spur sampling study in 1983 (R.L.M., unpublished data). Larval shelters consisted of one or more leaves rolled or webbed together, leaves attached to fruit, or in some cases a cluster of apples. Trees were divided into eight strata by tying ribbons diagonally to form an X. The ribbon height was ca. 1.8 m, vertically separating upper levels from lower levels, and directionally separating between-row areas from within-row areas. The 'Golden Delicious' and 'Stayman' trees were sampled weekly by randomly examining 25 spurs per stratum (200 per tree). Ten randomly selected trees of each cultivar were sprayed with a combination of azinphosmethyl plus methomyl at recommended rates during the season (Anonymous 1983). Egg masses and larval shelters collected until 3 August (weeks 1–10) were considered to be from the summer brood (Bode 1975). Apple injury caused by feeding of summer brood larvae was estimated by sampling 25 apples per stratum (200 apples per tree) on 10 August. Apples were sampled in situ for summer brood injury. Apple injury caused by fall brood feeding was measured by sampling 50 apples per stratum (400 apples per tree) in late September through early October. The third sampling method used the egg mass, larval shelter, and summer brood fruit injury data only from the four lower strata as independent variables. Fall brood apple injury was the dependent variable.

In the fourth method, conducted in the same orchard, different sprayed and unsprayed 'Golden Delicious' and 'Stayman' trees were sampled. Sampling was done by walking around the periphery of a tree for 5 min and recording the number of egg masses and larval shelters observed. Sampling was done weekly from 1 June until 15 September. Data are presented as means of 3- and 6-week samples. The 3-week samples included the dates 26 July, 2 August, and 9 August; the 6-week samples included the dates from 12 July, inclusive to 16 August. Means were calculated from larval shelter numbers obtained for each tree, and these were regressed against estimated fall brood apple injury. Apple injury due to summer brood feeding was estimated by a 5-min timed count taken 24 August. Fall brood apple injury was estimated by sampling 100 apples from the upper and lower areas of each tree (200 apples per tree).

The stepwise multiple regression procedure of the Statistical Analysis System (SAS) (SAS Institute 1982) was used to regress the independent variables summer brood egg masses, larvae or larval shelters, and fruit injury against observed fall brood fruit injury. Each independent variable was separately regressed using the linear regression procedure of SAS (observed fall brood fruit injury = $\alpha + \beta$ [summer brood variable]) (SAS Institute 1982). An independent variable was significant as determined by the *F*-test in the analysis of variance of the regression model. In all analyses, including comparisons between cultivars, the *P* level was <0.05. To propose a sampling plan, sample size estimates were made using the egg mass and larval shelter data from the timed counts of 1983. Sample sizes were determined using the formula: $n = (s/Em)^2$ where s = the standard deviation, m = the mean, and E = the predetermined standard error as a decimal of the mean (Southwood 1978). The standard deviation was calculated from an analysis of variance that removed the spray component variation.

Results

Complete Sampling, 1982. Multiple regression analysis of the data from the 'Golden Delicious' trees showed that the independent variables summer brood egg masses, larvae, and fruit injury combined, fitted observed fall brood fruit injury with an r^2 value of 0.98. Linear regression analysis from the 'Golden Delicious' and 'Stayman' trees separately showed that the only variable that was significant was summer brood fruit injury. The model for the 'Golden Delicious' trees was $y = 8.4 + 1.8x$, SE = 0.37, $r^2 = 0.77$; the model for the 'Stayman' trees was $y = 1.9 + 1.4x$, SE = 0.41, $r^2 = 0.60$. Summer brood fruit injury was comparatively high in 1982, averaging 7.4% in 'Golden Delicious' and 11.3% in 'Stayman' trees. The regression equation for summer brood fruit injury in 'Stayman' trees had a comparatively low intercept. Therefore, estimating 1% summer brood fruit injury in July would have predicted fall brood fruit injury of 3.3%. The equation calculated from the 'Golden Delicious' trees predicted 10.2% fall brood fruit injury from 1% summer brood fruit injury. The discrepancy between regression equations accentuates the differences between cultivars recognized in a previous spatial pattern study (Meagher 1985). The high estimates of summer brood fruit injury provided a better estimate of fall brood fruit injury because it was a more direct sampling variable.

DeJong & Minks (1981) predicted harvest injury by sampling for summerfruit tortrix larvae in July; however, they did not report any resulting coefficients of determination. In our study, summer brood larvae did not significantly contribute to the explained variation in fall brood fruit injury. Possibly, larvae and injury were located in different parts of the tree. The spatial pattern study (Meagher 1985) indicated that larvae were generally located in the lower levels, while crop load and fruit injury were greater in the upper levels. Also, the earlier study disclosed that larvae were 6-fold more likely to be associated with leaves only, than with leaves and fruit or fruit alone. In general, egg masses contributed little as an independent variable. Summer brood egg mass counts were always low in number and they did not account for early larval mortality as a factor in the model.

Spur Sampling, 1983. The number of summer brood larval shelters was a significant variable in the model to predict observed fall brood fruit injury for all 'Golden Delicious' trees ($y = 9.7 + 1.0x$, SE = 0.16, $r^2 = 0.67$). For all 'Stayman' trees, both fruit injury ($y = 19.6 + 5.1x$, SE = 1.26, $r^2 = 0.48$) and larval shelters ($y = 18.0 + 0.5x$, SE = 0.13, $r^2 = 0.42$) were separately significant and produced similar r^2 values. More summer brood shelters were found on the 'Stayman' than on the 'Golden Delicious' trees (24.5 compared with 11.3), and this difference was reflected in the regression equations. The lower slope of the equation for the 'Stayman' trees indicated that little weight in terms of predictive value was placed on individual larval shelters. Riedl & Croft (1974) found this same characteristic when regressing codling moth catch with fruit damage. The higher intercept reflects the higher fall brood fruit injury levels in the 'Stayman' versus the 'Golden Delicious' trees (30.5 compared with 23%), and also indicated that we were not proficient in sampling the larvae that were causing injury. The spatial pattern study suggested that <15% of the larvae sampled were causing fruit injury (Meagher 1985). Summer brood fruit injury from these samples was lower in 1983 than 1982, averaging 2.8% in 'Golden Delicious' and 1.0% in 'Stayman' trees.

The data from the unsprayed trees of both cultivars showed that summer brood larval shelters ($y = 23.7 + 0.3x$, SE = 0.14, $r^2 = 0.24$) or fruit injury ($y = 26.0 + 2.9x$, SE = 1.19, $r^2 = 0.25$) were significant but produced low coefficients of determination. With the sprayed trees of both cultivars, only summer brood larval shelters were significant in the model ($y = 9.3 + 1.1x$, SE = 0.33, $r^2 = 0.36$). Summer brood fruit injury was not a significant variable in these trees. Unsprayed trees, which contained more summer brood larval shelters, had a regression equation with a higher intercept, but a lower slope than the equation from the sprayed trees. Unsprayed and sprayed cultivars were also analyzed separately. Only sprayed 'Golden Delicious' trees had a significant independent variable (summer brood larval shelters, $y = 7.2 + 2.0x$, SE = 0.60, $r^2 = 0.59$). No independent variables were significant in the regression models for unsprayed 'Golden Delicious', and sprayed and unsprayed 'Stayman' trees. There were no significant multiple regression equations in any of the spur sampling results.

Spur or shoot counts have been successful as a method to sample other leafrollers, e.g., the eyespotted budmoth and fruittree leafroller in Quebec (LeRoux & Reimer 1959, Paradis & LeRoux 1962) and the summerfruit tortrix in Europe (DeJong & Minks 1981). The spur counts were somewhat restrictive (i.e., they limited the sampling to a specified unit). Some of the sampler's time was used in counting spurs and not in searching for larvae. Also, larvae that were associated with shoots were ignored, although it was likely that these larvae did not contribute to apple injury.

Lower Strata Spur Sampling, 1983. In this sampling method spur samples of summer brood egg masses, larval shelters, and fruit injury in the lower strata were regressed against fall brood fruit injury observed in the entire tree. In all 'Golden Delicious' trees, larval shelters ($y = 12.0 + 1.0x$, SE = 0.23, $r^2 = 0.53$) and injury ($y = 16.5 + 4.1x$, SE = 1.88, $r^2 = 0.21$) were significant as separate variables, but produced relatively low coefficients of determination. In all 'Stayman' trees, multiple regression analysis showed that larval shelters and summer brood fruit injury accounted for 61% of the variation. Separately, these two variables were also significant. The model for larval shelters was $y = 15.7 + 0.8x$, SE = 0.2, $r^2 = 0.50$; the model for fruit injury was $y = 19.3 + 5.4x$, SE = 1.35, $r^2 = 0.47$. In all unsprayed trees, larval shelters ($y = 21.7 + 0.6x$, SE = 0.23, $r^2 = 0.25$) or injury ($y = 24.5 + 4.1x$, SE = 1.34, $r^2 = 0.34$) was a significant variable. Larval shelters was the only significant variable in the sprayed trees ($y = 9.9 + 1.4x$, SE = 0.42, $r^2 = 0.38$). When the unsprayed and sprayed cultivars were examined separately, summer brood larval shelters was a significant variable in sprayed 'Golden Delicious' trees ($y = 7.2 + 2.0x$, SE = 0.60, $r^2 = 0.59$), and summer brood fruit injury was a significant variable in unsprayed 'Stayman' trees ($y = 27.2 + 4.5x$, SE = 1.49, $r^2 = 0.53$).

The lower strata spur samples were less labor-intensive and more efficient to take than the spur samples from the entire tree. These lower samples produced regression equations similar to those of the spur samples from the entire tree, and explained similar percentages of the variation in observed fall brood fruit injury. Sampling only the lower areas of the tree would be a more efficient use of the sampler's time without any loss in precision.

Timed Counts, 1983. Weekly samples of larval shelters were initially analyzed individually. However, strong correlations between summer brood larval shelters and fall brood fruit injury occurred only in certain weeks. Thus, it became apparent that more reliable predictions would result if larval shelter means were taken over a span of a specified number of weeks. Mean summer brood larval shelters for 3 weeks and mean larval shelters for 6 weeks were separately significant variables in regressing observed fall brood fruit injury in all 'Golden Delicious' trees (Table 1). Summer brood fruit injury was also a significant variable, producing a low coefficient of determination. Both samples of shelters were significant in all 'Stayman' trees, producing coefficients of determination of 0.79 and 0.81, respectively. Summer brood fruit injury was also a significant separate variable; to-

Table 1. Regression statistics of observed fall brood TABM fruit injury by summer brood larval shelters/3 week sample, summer brood larval shelters/6 week sample, and summer brood fruit injury for the 5-min timed count samples from 'Golden Delicious' (GD), 'Stayman' (S), unsprayed (UN), and sprayed (SPR) trees, Arendtsville, Pa., 1983[a]

Cultivar or spray	Summer brood variable	Regression equation	SE	r^2
GD	Larvae: 3 wk	$y = 8.2 + 1.6x$	0.42	0.51
	Larvae: 6 wk	$y = 7.4 + 2.0x$	0.48	0.57
	Fruit injury	$y = 11.1 + 3.4x$	1.51	0.27
S	Larvae: 3 wk	$y = 10.2 + 1.8x$	0.24	0.79
	Larvae: 6 wk	$y = 9.0 + 2.4x$	0.32	0.81
	Fruit injury	$y = 18.8 + 1.6x$	0.35	0.61
S—UN	Larvae: 3 wk	$y = 5.2 + 2.0x$	0.58	0.68
	Larvae: 6 wk	$y = -1.5 + 3.3x$	0.83	0.72
	Fruit injury	$y = 25.8 + 1.3x$	0.30	0.76
S—SPR	Larvae: 6 wk	$y = 5.1 + 4.3x$	1.24	0.67
UN	Larvae: 3 wk	$y = 7.2 + 1.9x$	0.34	0.69
	Larvae: 6 wk	$y = 2.1 + 2.9x$	0.48	0.73
	Fruit injury	$y = 21.2 + 1.6x$	0.28	0.70
SPR	Larvae: 3 wk	$y = 7.1 + 2.4x$	0.88	0.35
	Larvae: 6 wk	$y = 4.4 + 4.1x$	1.05	0.53

[a] All regressions were significant ($P < 0.05$).

gether with the mean larvae per 6-week sample, these variables explained 87% of the variation in observed fall brood fruit injury.

The same three independent variables were separately significant in unsprayed trees, and the combination of mean shelters per 6 weeks and summer brood fruit injury produced an r^2 value of 0.82. Both samples of larval shelters were significant in sprayed trees, although they produced low coefficients of determination. In unsprayed 'Stayman' trees, both samples of larval shelters and summer brood fruit injury were separately significant. The mean shelters per 6-week sample was a significant variable in sprayed 'Stayman' trees; together with summer brood fruit injury, these variables explained 93% of the variation in observed fall brood fruit injury. Unsprayed or sprayed 'Golden Delicious' trees did not have any independent variable that was significant in the regression models.

Summer brood larval shelters allowed estimation of the TABM population density during late July–early August. As a population parameter, summer brood fruit injury estimated the percentage of these larvae that actually caused apple injury. Based on larval association data, Meagher (1985) concluded that <15% of the larval population was causing fruit injury. Therefore, the summer brood larval population density in 'Stayman' and in unsprayed trees was high enough to allow the low percentage of injury-causing larvae to become statistically significant in the regression equations. This was not true for 'Golden Delicious' and sprayed trees, which had comparatively low larval numbers. Therefore, we do not recommend sampling of summer brood fruit injury in commercial orchards for predictive purposes.

Table 2. Predicted fall brood TABM fruit injuries estimated by selected numbers of mean larval shelters per 3- and 6-week 5-min timed count samples in GD, S, UN, and SPR trees, Arendtsville, Pa., 1983

Cultivar or spray	Larvae per 3 wk	% predicted injury (95% CL)	Larvae per 6 wk	% predicted injury (95% CL)
GD	1	9.8 (5.3–14.3)	1	9.5 (5.3–13.7)
	5	16.2 (13.4–19.1)	5	17.7 (14.8–20.5)
	10	24.3 (18.7–29.8)	10	27.9 (21.3–34.5)
S	1	11.9 (6.6–17.3)	1	11.4 (6.2–16.6)
	5	18.9 (15.0–22.9)	5	21.1 (17.6–24.7)
	10	27.7 (24.2–31.2)	10	33.3 (29.4–37.2)
UN	1	9.1 (1.1–17.1)	1	5.1 (−3.7–13.8)
	5	16.7 (11.1–22.3)	5	16.8 (11.5–22.0)
	10	26.1 (22.4–29.9)	10	31.5 (27.7–35.2)
SPR	1	9.5 (5.3–13.8)	1	8.6 (4.9–12.2)
	5	19.2 (14.3–24.2)	5	25.1 (18.6–31.2)

From the regression equations, percent fall brood fruit injury was predicted from numbers of mean summer brood larval shelters per 3 or 6 weeks (Table 2). The equations and subsequent predicted injuries were similar between cultivars and between unsprayed and sprayed trees. The r^2 values were higher in the 'Stayman' and unsprayed trees compared with the 'Golden Delicious' and sprayed trees. However, confidence intervals were generally larger around the 'Stayman' and unsprayed trees.

Optimum sample size is defined as the smallest sample size that assures the desired reliability of the estimate (Karandinos 1976). The number of trees per orchard needed to sample larvae (the estimate) was calculated using the standard deviation from an analysis of variance that removed the spray component variation. The reliability, or level of precision, was measured as the predetermined standard error as a decimal of the mean. The optimum number of 'Golden Delicious' and 'Stayman' trees to sample and the relative costs of sampling are shown in Table 3. These sample sizes were based on the sampling of 32 trees in a 0.7-ha orchard and were calculated to optimize the sampling for larval shelters. Sampling costs were based on an average of 7 min per tree (5-min sampling and 2-min intraorchard movement) for the optimum number of trees, at an hourly rate of $4.00.

Timed counts have been used successfully to sample for *Stethorus punctum* (LeConte), a coccinellid predator of the European red mite (Asquith & Colburn 1971). Timed counts limit only the amount of sampling time, not the sampling area. However, the timed counts only explained between 50 and 80% of the variation in observed fall brood fruit injury. Variation among trees was high, as indicated by the large confidence intervals around the predicted injuries. Much of this variation was due to the wide differences in TABM populations among trees. Sampling of more trees

Table 3. Optimum number of trees to sample and relative cost for 5-min timed counts based on selected percentages of mean density for TABM larval shelters per 3 weeks and larval shelters per 6 weeks in GD and S trees, Arendtsville, Pa., 1983

Cultivar	Estimated no. of trees					
	5%	Cost[a]	10%	Cost	20%	Cost
3-week sample						
GD	63.7	88.80	15.9	22.80	4.0	6.00
S	75.1	105.60	18.8	26.40	4.7	6.00
6-week sample						
GD	41.2	115.20	10.3	28.80	2.6	7.20
S	53.3	148.80	13.3	38.40	3.3	9.60

[a] Relative cost in dollars, based on an average of 7 min per tree (including sampling and interorchard movement) for the optimum number of trees at $4.00/h.

would increase the accuracy and precision in predicting injury.

Discussion

Hull et al. (1983) found an average of 2.9%, with a high of 12.4%, injured apples caused by TABM feeding in a survey of 16 Pennsylvania orchards. The amount of apple injury per tree found in the orchard that we sampled was much higher than the average found by Hull et al. (1983). This amount probably exceeded the economic threshold of a commercial fresh fruit grower but may not have exceeded the threshold of a processing fruit grower. In 1982, only 70 and 74% of the 'Golden Delicious' and 'Stayman' apples, respectively, would have been graded U.S. Fancy or U.S. No. 1, but all other fruit (30 and 26%) would have been U.S. No. 1 processing apples. In 1983, 77% ('Golden Delicious') and 70% ('Stayman') of the fruit were fresh-market quality, while the remainder were primarily high-quality processing fruit. Less than 0.2% of the fruit were U.S. No. 2 or culls in both cultivars. Grade percentages were determined by grading the fruit according to published standards (Anonymous 1964a,b).

The sample size data and resulting relative costs suggest that samples taken over the course of 3 weeks would be more efficient than samples taken over 6 weeks. Although the 6-week samples produced higher r^2 values in the regression equations, the differences in predicted fruit injury between the two sampling methods generally were not significant. To investigate the benefits of TABM sampling, more detailed economic analysis concerning the importance of TABM fruit injury in the fresh and processing markets needs to be studied.

Because of the mobility of this pest and because it has many alternate hosts, it may be impossible to predict fall brood fruit injury with a high level of precision. The predicted apple injuries and confidence limits in the timed counts support this conclusion. However, for a processing fruit grower, these predicted apple injury levels may be sufficiently precise to make management decisions concerning control of the fall brood. Sampling should be initiated in late July–early August so that there is sufficient time to make these decisions and, if needed, apply insecticides with the correct timing (Hull et al. 1985).

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