Within-tree Spatial Patterns of *Platynota idaeusalis* (Lepidoptera: Tortricidae) on Two Apple Cultivars

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ABSTRACT Standard 'Golden Delicious' and 'Stayman' apple trees were sampled to determine spatial patterns of tufted apple bud moth, *Platynota idaeusalis* (Walker). Trees were divided into upper and lower levels vertically, and directionally into areas of the tree facing the row alleyway (BROW) and areas of the tree facing the tree row (WROW). In 1982 in unsprayed trees, significantly more summer-brood egg masses were deposited in the upper areas. Significantly more fall-brood egg masses were deposited in the upper and BROW areas. In 1983, low numbers of summer- and fall-brood egg masses were found, and there were no differences between levels or between row directions. Both broods of larvae were located more in the lower than upper levels. In sprayed trees, more larvae were found in the WROW areas, but in unsprayed trees there was no difference between row directions. Calculated sample sizes were large because of low proportions of infested spurs.

KEY WORDS *Platynota idaeusalis*, apple, spatial patterns

THE TUFTED APPLE bud moth (TABM), *Platynota idaeusalis* (Walker), was first described as an injurious pest of apple by Frost (1923). It was not observed again until 1969, when it caused fruit injury in commercial orchards in south central Pennsylvania (Bode et al. 1973). Since that time, TABM has become a major pest in these orchards and in other Cumberland–Shenandoah Valley orchards in Maryland, West Virginia, and Virginia. The larvae feed and cause injury to foliage and the fruit surface. Bode (1975, 1976) has described the life history and biology of this leafroller.

Stratified sampling techniques have been used on apple trees to sample various arthropods, including the eyespotted bud moth, *Spilonota ocellana* (Denis & Schiffermüller) (LeRoux & Reimer 1959, Legner & Oatman 1962); the fruittree leafroller, *Archips argyrospila* (Walker) (Paradis & LeRoux 1962); a mite predator, *Stethorus punctum* (LeConte), and its prey, the European red mite, *Panonychus ulmi* (Koch) (Hull et al. 1976); and the rosy apple aphid, *Dysaphis plantaginea* (Passerini) (Starner & Hull 1982). Koethe (1977) used a stratified sampling scheme for TABM egg masses and larvae in mature standard-sized 'Stayman' trees.

The objective of this study was to describe the within-tree spatial patterns of TABM on two apple cultivars and to determine sample size estimates and recommend a procedure for obtaining a representative population estimate. Two sampling techniques were used to characterize these patterns.

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Materials and Methods

The study was conducted in an orchard (0.7 ha) in Arendtsville, Pa., containing 27-yr-old trees arranged in mixed-cultivar rows. Cultivars of equal numbers included '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. Distance between the rows was 10.7 m, and distance between trees was 3.7 m.

The sample trees were divided into eight strata by staking posts around the trees and tying ribbons across diagonally to form an X. The ribbon height was ca. 1.8 m, vertically separating upper strata from lower strata and horizontally separating between-row (BROW) strata from within-row (WROW) strata. The BROW areas of the tree faced the row alleyway; the WROW areas of the tree faced the adjacent trees in the row. An attempt was made to equalize the amounts of foliage in each stratum by adjusting the positions of ribbons. Egg masses and larvae were sampled for both broods by examining every leaf on the tree, and each tree was only sampled once. Larvae and pupae were found sheltered in rolled or webbed leaves, leaves webbed to fruit, or, in some cases, a cluster of apples. Larval shelters were opened to identify the leafroller species present.

In 1982, 10 trees each of 'Golden Delicious' and 'Stayman' from the southern part of the orchard were sampled in late July–early August for summer-brood egg masses and larvae. During this period in the season, most TABM were either late instars or pupae, and the fall-brood egg masses had not yet been deposited (Bode 1975). Sampling was done at this time because late instars or pupae were

Table 1. ANOVA of summer-brood TABM egg masses and larvae in 'Golden Delicious' (GD) and 'Stayman' (S) trees, Arendtsville, Pa., 1982

Egg masses/tree			Larvae/tree		
Cultivar	Location	$\bar{x}$ ± SEM[a]	Cultivar	Location	$\bar{x}$ ± SEM
GD	Level—upper	5.3 ± 0.76*	GD	Level—upper	9.6 ± 1.33
	—lower	2.2 ± 0.57		—lower	6.1 ± 1.49
	Row—BROW	5.2 ± 0.96		Row—BROW	9.6 ± 1.62
	—WROW	2.3 ± 0.83		—WROW	6.1 ± 1.08
S	Level—upper	9.2 ± 2.15*	S	Level—upper	26.1 ± 6.43
	—lower	2.1 ± 0.82		—lower	18.0 ± 4.15
	Row—BROW	6.7 ± 1.65		Row—BROW	30.6 ± 7.62**
	—WROW	4.6 ± 1.14		—WROW	13.5 ± 2.64

*, $P < 0.05$; **, $P < 0.01$; significant differences between means within levels or row direction.
[a] Means based on sampling of 10 trees per cultivar.

easy to see and were the least likely to move within the tree if disturbed. This part of the orchard was left unsprayed with insecticides until mid-August. A standard fungicide spray schedule was applied to the entire orchard (Anonymous 1982). Eight 'Stayman' trees in the northern part were sampled during late September and early October for the fall brood. This part of the orchard was sprayed with routine applications of insecticides until late July and then left unsprayed except for fungicide sprays the remainder of the season.

In 1983 the same orchard and trees were again sampled for TABM egg masses and larval shelters. The trees were pruned to the same height and width as in 1982. Methomyl was applied at the stage of bud development known as "pink" (late April) to the entire orchard to control overwintering larvae of the obliquebanded leafroller (OBL), *Choristoneura rosaceana* (Harris) (Reissig 1978). Twenty trees each of 'Golden Delicious' and 'Stayman' were sampled each week from 2 June to 16 September so that the initial sampling would coincide with summer-brood egg mass deposition and the later sampling with the presence of fall-brood third to fifth instars (Bode 1975). The trees were stratified in a manner similar to that used in 1982. Ten randomly selected trees of each cultivar were sprayed with a combination of azinphosmethyl plus methomyl at recommended rates as cover sprays throughout the season (Anonymous 1983). Twenty-five fruiting or nonfruiting spurs (short, modified shoots) per each of the eight strata were selected at random and examined (200 per tree) (LeRoux & Reimer 1959). Detected egg masses and larval shelters (left undisturbed) were tagged so as not to be recounted at later observations. Egg masses and larval shelters found during weeks 1–10 (until 3 August) were considered summer brood. Egg masses and larval shelters found later in the season could not be separated by brood; thus, those found during weeks 1–17 were considered from both broods.

Egg mass and TABM larval data collected from each stratum were combined for comparisons between the upper and lower level, and the BROW and WROW row direction. The data were used in an analysis of variance (ANOVA) that allowed the partitioning of the effects by level and row direction (SAS Institute 1982). Spatial patterns of both broods in 1982 were analyzed separately. In 1983 spatial patterns were analyzed separately for unsprayed and sprayed trees of each cultivar (10 trees each). Comparisons of densities of egg masses or larvae between cultivars or between unsprayed and sprayed trees were $P < 0.05$. Sample sizes (estimated number of spurs) were calculated from the spur samples and were determined using the formula: $n = q/p \times C^2$, where p = the proportion of infested spurs, $q = 1 - p$, and C = the coefficient of variation of the mean (Karandinos 1976).

Results and Discussion

1982. Summer-brood egg masses located in the 'Golden Delicious' and 'Stayman' trees were found more in the upper levels than in the lower levels (Table 1). There were no significant row directional differences in either cultivar. Hogmire & Howitt (1979) found TABM egg masses deposited on the upper surfaces of leaves on scaffold limbs near the trunk of the tree. Similarly, Koethe (1977) found summer-brood egg masses located in the inside top of mature 'Stayman' trees. The data of Koethe (1977) and those reported here are in general agreement, even though the stratification schemes were different. The total number of egg masses found on the two cultivars was not significantly different ('Stayman', 113; 'Golden Delicious', 75).

The only significant difference in spatial patterns for summer-brood TABM larvae was in the 'Stayman' trees, where more were located in the BROW than in the WROW areas (Table 1). The 10 'Stayman' trees contained significantly more larvae (441) compared with the 10 'Golden Delicious' trees (157). Most of the larvae found in the shelters were TABM (76.5%); the remaining larvae were OBL.

The higher population of larvae on 'Stayman' trees, despite numbers of egg masses that were not significantly different, may possibly be attributed to several factors including leaf texture, leaf toughness, or chemical component differences between the cultivars. Cultivar differences in leaf and fruit characteristics have been known to influence the

Table 2. ANOVA of fall-brood TABM egg masses and larvae in 'Stayman' (S) trees, Arendtsville, Pa., 1982

Egg masses/tree		Larvae/tree	
Location	$\bar{x}$ ± SEM[a]	Location	$\bar{x}$ ± SEM
Level—upper	59.8 ± 9.30**	Level—upper	55.6 ± 9.36
—lower	33.0 ± 4.50	—lower	93.0 ± 9.24**
Row—BROW	64.9 ± 8.83***	Row—BROW	107.1 ± 9.90***
—WROW	27.9 ± 5.35	—WROW	41.5 ± 6.56

*, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$; significant differences between means within levels or row direction.
[a] Means based on sampling of eight trees.

susceptibility of apple to other pests, such as the codling moth, *Cydia pomonella* (L.) (Plourde et al. 1985). Also, the physical structure of the tree may possibly have influenced the larval population. Larvae on 'Golden Delicious' trees might possibly have a better chance of dispersing through and landing on the ground cover because the foliage is less dense.

Fall-brood egg mass densities were higher than those of summer brood. Although only eight 'Stayman' trees were sampled, 742 egg masses were found. More egg masses were found in the upper versus lower levels and BROW versus WROW areas (Table 2). Koethe (1977), in unsprayed trees, found fall-brood egg masses positioned in the inside top and outside bottom.

Higher densities of fall-brood TABM larvae were located in lower versus upper levels and BROW versus WROW areas (Table 2). More fall-brood larvae were found on eight 'Stayman' trees during September (1,189) than summer-brood larvae from 20 trees in late July (598). Only 0.9% of the fall-brood larvae found were not TABM. Historically, fall-brood larvae cause more apple injury than summer-brood larvae (Bode 1975, Hull et al. 1981). Although factors such as the discontinuation of insecticide applications and the vulnerability of the larger fruit are involved, our results suggest that one explanation for the difference in injury between the broods is the presence of more fall-brood larvae.

1983. There were no significant differences in level or directional spatial pattern with either the summer-brood or combined-brood egg masses. Low numbers of egg masses were found, with a mean of 2.9 egg masses per tree found during the summer brood. There was no difference in number of egg masses between cultivars. A mean of 10.9 combined-brood egg masses per tree was found, and 'Golden Delicious' contained significantly more egg masses per tree than 'Stayman' (12.5 compared with 9.4).

In sprayed and unsprayed 'Golden Delicious' and 'Stayman' trees, summer-brood larval shelters were located more in lower than in upper levels (Table 3). Horizontally, shelters were found more in the WROW than in the BROW areas in the sprayed 'Golden Delicious' and 'Stayman' trees, but in the unsprayed trees of the two cultivars there was no significant spatial pattern in the horizontal plane. An overall mean of 17.9 summer-brood larval shelters per tree was found, with more shelters found on 'Stayman' than on 'Golden Delicious' trees (24.5 compared with 11.3) and more found on unsprayed trees than sprayed trees (29.1 compared with 6.7). For ease of sampling, the larval shelters were not opened in 1983. Because most of the non-TABM larvae in 1982 were OBL, and because overwintering OBL were controlled with an early-season application of insecticides in 1983, it was assumed that the shelters contained TABM larvae.

Combined-brood larval shelters were found more in the lower than in the upper levels of the sprayed and unsprayed trees of both cultivars (Table 4). The location of the larvae or larval shelters in the lower levels of the trees was a result of their dispersing behavior. First instars were observed crawling to the edge of a leaf and spinning down to a

Table 3. ANOVA of summer-brood TABM larval shelters per tree in sprayed (+) and unsprayed (0) 'Golden Delicious' and 'Stayman' trees, Arendtsville, Pa., 1983

'Golden Delicious'			'Stayman'		
Spray	Location	$\bar{x}$ ± SEM[a]	Spray	Location	$\bar{x}$ ± SEM
+	Level—upper	1.6 ± 0.56	+	Level—upper	2.3 ± 0.50
	—lower	3.0 ± 0.76*		—lower	6.4 ± 1.13**
	Row—BROW	1.1 ± 0.38		Row—BROW	3.3 ± 0.67
	—WROW	3.5 ± 0.91**		—WROW	5.4 ± 0.92*
0	Level—upper	4.6 ± 0.72	0	Level—upper	14.2 ± 3.31
	—lower	13.3 ± 1.64**		—lower	26.0 ± 2.58**
	Row—BROW	9.4 ± 0.90		Row—BROW	20.3 ± 2.69
	—WROW	8.5 ± 1.11		—WROW	20.0 ± 3.08

*, $P < 0.05$; **, $P < 0.01$; significant differences between means within levels or row direction.
[a] Means based on sampling of 10 trees per cultivar per spray (200 spurs per tree).

Table 4. ANOVA of combined-brood TABM larval shelters per tree in sprayed (+) and unsprayed (0) 'Golden Delicious' and 'Stayman' trees, Arendtsville, Pa., 1983

'Golden Delicious'			'Stayman'		
Spray	Location	$\bar{x}$ ± SEM[a]	Spray	Location	$\bar{x}$ ± SEM
+	Level—upper	4.6 ± 1.02	+	Level—upper	6.9 ± 1.24
	—lower	11.1 ± 2.04**		—lower	14.8 ± 2.87*
	Row—BROW	4.8 ± 0.92		Row—BROW	6.9 ± 1.49
	—WROW	10.9 ± 1.94**		—WROW	14.8 ± 2.20***
0	Level—upper	14.4 ± 3.03	0	Level—upper	24.8 ± 5.80
	—lower	34.9 ± 2.72***		—lower	48.7 ± 4.36***
	Row—BROW	21.8 ± 1.80		Row—BROW	34.5 ± 4.65
	—WROW	27.5 ± 2.66**		—WROW	39.0 ± 5.76

*, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$; significant differences between means within levels or row direction.
[a] Means based on sampling of 10 trees per cultivar per spray (200 spurs per tree).

lower leaf. Young larvae were also observed being carried by the wind to these lower levels. In all trees except unsprayed 'Stayman', more shelters were found in the WROW than in the BROW areas. The mean number of combined-brood shelters for both cultivars was 40.1 per tree, with more found on 'Stayman' trees (47.6 compared with 32.5) and more found on unsprayed than on sprayed trees (61.4 compared with 18.7).

Koethe (1977) reported that regularly scheduled pesticide applications affected the distribution of TABM. In this study, larvae on sprayed trees were generally located in WROW areas; in unsprayed trees the spatial pattern was much more even. The WROW areas seemed to provide better protection for the larvae because they bordered the tree row and probably received less insecticides. In studies by Hull & Hickey (1978, 1980), the best spray coverage, and thus higher insecticide deposits, were achieved in the outside bottom areas of mature 'Stayman' trees. The resulting spatial pattern was probably due to the mortality of BROW larvae, rather than the migration of larvae to the WROW areas.

Table 5. Proportion of fruiting and nonfruiting spurs with summer-brood TABM egg masses or larvae for sprayed and unsprayed 'Golden Delicious' and 'Stayman' trees, and estimated number of spurs (in thousands) to sample based on selected percentages of mean density, Arendtsville, Pa., 1983

Stage Cultivar	Proportion	Estimated no. of spurs[a]			
		5%	10%	20%	50%
Egg masses					
'Golden Delicious'					
Sprayed	0.0013	307.3	76.8	19.2	3.1
Unsprayed	0.0017	234.9	58.9	14.7	2.3
'Stayman'					
Sprayed	0.0013	319.6	79.9	20.0	3.2
Unsprayed	0.0015	275.5	68.9	17.2	2.8
Larvae					
'Golden Delicious'					
Sprayed	0.0023	175.5	43.4	10.9	1.7
Unsprayed	0.0090	44.3	11.1	2.8	0.4
'Stayman'					
Sprayed	0.0044	91.6	22.9	5.7	0.9
Unsprayed	0.0201	19.5	4.9	1.2	0.2

[a] Estimated number of spurs was calculated from the spur samples.

Table 5 shows the estimated total number of spurs per orchard that are to be sampled to obtain selected levels of precision and was based on the sampling of 25 spurs per stratum, in eight strata, on 10 trees, for 10 wk. Sample sizes were estimated for summer-brood egg masses and larvae because these variables could be useful in population monitoring or predictive sampling of the fall brood (Meagher & Hull 1986). Because low proportions of egg masses and larval-infested spurs were found, high sample sizes were estimated. As the proportion of infested spurs increased, the estimated number of samples needed decreased. Thus, lower sample sizes would be needed when sampling for larvae than when sampling for egg masses. Also, estimated sample sizes for both variables were smaller for unsprayed than for sprayed trees.

We conclude from the results of both years' work that the sampling of summer-brood larvae and fall-brood egg masses and larvae can be concentrated in the lower levels of the tree, and sampling of summer-brood egg masses should be concentrated in the upper levels. For general sampling purposes, it is more practical to sample fruit trees by examining the lower areas because extra sampling equipment or agility skills (climbing) are not needed. The large size of the estimated samples, especially in sprayed trees, indicates that spur sampling may be too inefficient for TABM sampling. For sampling studies such as relating TABM to fruit injury (extensive studies), a relative sampling method is suggested. Relative sampling methods concentrate on searching for the insects and are especially useful in situations with relatively low population levels (Southwood 1978).

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