Evaluation of Partial Plant Sampling Procedures and Corresponding Action Thresholds for Management of Lepidoptera on Cabbage

M. K. SEARS,[1] A. M. SHELTON,[2] T. C. QUICK,[3]
J. A. WYMAN,[3] AND S. E. WEBB[2]

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ABSTRACT Within-plant sampling procedures, coupled with action thresholds for cabbage-feeding caterpillars, were evaluated for accuracy and efficiency in New York, Ontario, Canada, and Wisconsin in 1982. When results were averaged over the three sites, use of all thresholds required fewer insecticide applications than a fortnightly schedule, while the total percentage of marketable heads did not differ significantly. However, use of the thresholds based on feeding-damage evaluation and 75% of the plants infested resulted in significantly fewer marketable no. 1 heads than did the other treatments. Inspecting only the head plus 10 surrounding leaves required ca. 50% less time than inspecting the entire plant in two of the locations, yet the marketability, averaged over all locations, was reduced. In treatment plots over all locations, there was no significant correlation between the larval populations (as determined by cabbage looper equivalents) on the head plus 10 leaves and the number of larvae on the entire plant. Thus, the sampling procedures did not accurately predict that portion of the plant on which the larvae would predominantly occur, nor did they predict the abundance of larvae on the entire plant based on counts from the head and surrounding leaves.

CROP PROTECTION entomologists must often recommend certain guidelines, if not discrete action thresholds, for pest management decisions. Sometimes, however, crop protection programs based on insecticide applications applied on a calendar schedule may provide crop marketability similar to that in programs based on an action threshold; but, in the former program, applications may be unnecessary, poorly timed, or the insecticide used may be inappropriate for the particular pests present. To avoid these problems and reduce the risk of crop loss, cooperative efforts in the Great Lakes region have promoted the use of both time-efficient sampling techniques and action thresholds for decision making in cabbage crops. Hence, in 1981, Shelton et al. (1983) compared five different action thresholds, developed for different areas, in three locations in the northeast for control of the lepidopterous complex (imported cabbageworm *Artogeia rapae* [L.]; cabbage looper, *Trichoplusia ni* [Hübner]; and diamondback moth, *Plutella xylostella* [L.]). In that earlier study, thresholds that were based on different decision criteria were compared for effectiveness in providing marketable cabbage at harvest, as well as for efficiency in expenditure of time for making a treatment decision. Each threshold had certain advantages and faults. One threshold was particularly efficient in terms of sampling time, but did not result in an acceptable percentage of marketable heads. The other thresholds provided acceptable percentages of marketable heads, but were not nearly as efficient in terms of sampling time for the corresponding sampling procedures.

In this study, different sampling procedures and thresholds were proposed and tested for their ability to provide acceptable percentages of marketability. The most important change from the 1981 experiments (Shelton et al. 1983) was the inspection of only part of the plant for decision making and a comparison of the larval population on the frame leaves and head zone. We hypothesized that, since only the head and four wrapper leaves are harvested, the critical area for detecting and controlling larvae was in this area and a buffer zone of six more leaves. If such an evaluation technique were appropriate, a substantial savings of scouting time would result. Previous studies in cabbage sampling have shown the necessity of scouting individual fields (Andaloro et al. 1982). With this in mind the technique of variable-intensity sampling (Hoy et al. 1983) was used to develop a sampling method that could save time. This technique could easily be modified with partial-plant sampling, as tested here, to reduce further the time spent sampling.

Materials and Methods

During 1982, experiments were conducted in three locations: Robbins Vegetable Research Farm near Geneva, N.Y.; University of Guelph Horticulture Research Station, Hespeler, Ont.; and University of Wisconsin, Arlington Experimental Farm. Cabbage, cv. Roundup, was transplanted

[1] Dept. of Environmental Biology, Univ. of Guelph, Guelph, Ont. N1G 2W1.
[2] Dept. of Entomology, Cornell Univ., Geneva, NY 14456.
[3] Dept. of Entomology, Univ. of Wisconsin, Madison, WI 53706.

into four blocks of 48 rows each on 24 June in New York, 22 June in Ontario, and 17 June in Wisconsin. Rows were 12 m long and each block was separated by 5 m of fallow land. Before heads formed (>7 cm ball) 100 plants over the entire field were examined each week for the presence of larvae. If more than two larvae of any lepidopterous species were found per plant the field was treated with 0.05 kg (AI)/ha permethrin. Once head formation was initiated and thresholds were exceeded, the threshold treatments were assigned to one of four treatment plots consisting of eight rows in each block completing a randomized complete block design.

Treatments consisted of four sampling-method, action-threshold procedures, a fortnightly scheduled application, and an untreated control. The threshold criteria used in the first four treatment decisions were: 50% of plants infested with larvae of any of the three species on the head + 10 wrapper and frame leaves (PPI no. 1); 75% of plants infested with larvae on the head + 10 wrapper and frame leaves (PPI no. 2); 0.5 cabbage looper equivalent (CLE) (Harcourt 1954) per plant on the head + 10 wrapper and frame leaves (LC); and 0.5 new feeding site (>3 mm) on the head plus four successive wrapper leaves (FDE). Modifications from the 1981 study (Shelton et al. 1983), in addition to partial plant sampling, were to deemphasize infestations of *P. xylostella* by considering plants infested only if more than five larvae per plant were present and to lower the FDE threshold from 1.0 to 0.5 new feeding sites, since the level of 1.0 new site resulted in low marketability in 1981.

Treatments were evaluated on a weekly basis using a nondestructive, 10-plant sample from the middle four rows of each plot. Time spent evaluating the threshold criteria were recorded for each treatment, and the additional time necessary to examine the remaining leaves of the sample plants also was noted. In all treatments, larvae found on the head + 10 leaves, as well as on the remainder of the plant, were recorded. In the FDE threshold plots, the same 10 plants were examined each week, while a sample of 10 plants was selected at random from the other plots. When thresholds (based on the average of four replicates) were exceeded, permethrin was applied at 0.05 or 0.10 kg (AI)/ha using a tractor-mounted boom sprayer with three nozzles per row to the middle six rows of all plots of each treatment that exceeded thresholds. The higher rate was applied only if cabbage loopers represented >50% of the species present.

A sample of 100 plants per treatment was evaluated for damage at harvest (4 Oct., New York; 4 Oct., Ontario; 3 Sept., Wisconsin). The head and wrapper leaves were graded according to four categories of marketability. The four categories used were: marketable no. 1, no damage from Lepidoptera; marketable no. 2, damage did not exceed one hole or a series of holes >1.5 cm in diameter on the head, or four wrapper leaves with a total of not more than four 1.5-cm diameter holes, or the presence of insect parts or frass on the head or four wrapper leaves; not marketable no. 3, moderate damage; and not marketable no. 4, severe damage.

For each location, analysis of variance and a mean separation test (Duncan's multiple range test) (Duncan 1955) were performed on the population indices (CLE), percentage of marketable heads, and mean time to evaluate each replicate (10 plants) averaged over the number of sampling dates. Differences among treatment regimes were tested at $P \leq 0.05$. Analysis of variance and mean separation tests were also performed on these parameters on data combined for all locations by partitioning out the effects of location. The differences in population density among locations was eliminated. Data were analyzed by using the general linear models procedure of SAS (Freund and Littell 1981).

Results and Discussion

A single application of permethrin (0.05 kg [AI]/ha) was applied to control Lepidoptera before heads formed in New York and Ontario. Populations of larvae from head initiation until harvest were greater in New York and Wisconsin than in Ontario as shown by the average number of CLE in control plots (Table 1). The impact of treatments on suppression of the larval populations over the three locations is apparent, when population density is expressed as CLE on the head and 10 surrounding leaves. In New York and Ontario, in all but the PPI no. 2 threshold, larval populations were significantly reduced from those in the control plots. In Wisconsin, use of all thresholds reduced larval populations compared with those in control plots. In control plots in each location, the majority of CLE during the season were found on the head and 10 surrounding leaves. In all treatment plots in Ontario and Wisconsin, the same was also true, but in New York, only in plots governed by the PPI no. 2 threshold, were the majority of larvae on the head plus 10 wrapper leaves. In the treatment plots over all locations, there was no strong correlation ($r^2 = 0.004$; df $= 16$) between number of CLE on the head plus 10 leaves and number of CLE on the entire plant. Thus, we conclude that in the treatments we tested we could not accurately predict on which portion of the plant the CLE would predominantly occur, nor could we predict the abundance of CLE on one section based on counts from the other section.

The FDE threshold required the least amount of time to evaluate in New York and Ontario (Table 1). In these two locations, the threshold based on damage by larvae to the head and surrounding 10 leaves, required nearly 50% less time than other treatments. In Wisconsin, however, that treatment required as much time to evaluate as the others.

Table 1. Average seasonal values of cabbage looper equivalents (CLE), and evaluation time for treatments comparing action thresholds for fresh-market cabbage

Treatment	CLE			Evaluation time (min : s)	
	Head + 10 leaves	Outer leaves	Head + 10 leaves (% of total)[a]	Head + 10 leaves	Total plant
			New York		
PPI (no. 1)	0.28b	0.58ab	38.4ab	4:32a	12:29a
PPI (no. 2)	0.66a	0.44bc	53.2a	4:01a	13:22a
Larval count	0.29b	0.54ab	36.0ab	4:42a	11:42ab
FDE	0.09b	0.38bc	25.4b	1:56b	11:46ab
Fortnightly	0.18b	0.21c	33.7b	—	9:57b
Control	0.95a	0.76a	54.7a	—	13:57a
			Ontario		
PPI (no. 1)	0.13bc	0.02ab	88.7a	4:13b	7:48a
PPI (no. 2)	0.34ab	0.08a	87.1a	4:32ab	8:52a
Larval count	0.08c	0.01b	86.6a	5:03ab	7:56a
FDE	0.13bc	0.06ab	65.0b	2:15c	7:44a
Fortnightly	0.17bc	0.02b	90.4a	4:49ab	7:50a
Control	0.39a	0.04ab	93.5a	5:16a	8:25a
			Wisconsin		
PPI (no. 1)	0.48b	0.25b	67.7a	6:57a	11:18bc
PPI (no. 2)	0.42b	0.18b	72.3a	7:41a	12:29bc
Larval count	0.42b	0.22b	54.6a	6:30a	10:37bc
FDE	0.67b	0.54ab	68.4a	6:17a	13:37ab
Fortnightly	0.46b	0.27b	52.6a	6:20a	12:40ab
Control	1.20a	0.87a	60.4a	8:47a	15:41a
			Mean of three locations		
PPI (no. 1)	0.29c	0.31b	38.7c	4:55b	10:28bc
PPI (no. 2)	0.51b	0.25b	53.9b	4:59b	11:29ab
Larval count	0.25c	0.28b	33.6c	5:13b	10:05bc
FDE	0.22c	0.30b	34.9c	2:58c	10:43bc
Fortnightly	0.25c	0.14b	38.2c	5:22b	9:45c
Control	0.81a	0.52a	65.3a	6:32a	12:25a

Column means for each location followed by the same letter are not significantly different ($P \leq 0.05$; Duncan's [1955] multiple range test).
[a] Percentages calculated from sum of seasonal observations and transformed by arcsine$\sqrt{x}$ before analysis.

In a management program, a savings in time is of considerable importance in improving the cost effectiveness of a scouting effort. Such a threshold may be more easily adapted by a grower because he does not need to differentiate species. In spite of these advantages, several drawbacks remain. The pest that causes the injury is not known and thus, proper selection of insecticide is difficult; the effectiveness of each application on pest reduction cannot be evaluated; and the differentiation of new and old damage is difficult.

Use of the PPI no. 2 procedure required the least number of insecticide applications, while fortnightly applications required the most (Table 2). On the average, all sampling-method, action-threshold procedures resulted in fewer applications than did the fortnightly schedule. Additionally, no statistically significant differences in total percentage marketable heads were found among treatments. However, the FDE and PPI no. 2 procedures resulted in fewer heads with no. 1 grade than were obtained with the fortnightly schedule, and this would be unacceptable to fresh market growers. The lower number of marketable heads in plots treated according to the FDE threshold was due to occasional cosmetic damage resulting from feeding holes on the head. Apparently, the PPI no. 2 threshold was too high since, by the time 75% of the plants examined had larvae present, considerable damage had occurred. In spite of the apparent usefulness of the PPI no. 1 and LC procedures based on trends over all locations, marketability of heads in these plots compared with those from plots sprayed on a fortnightly basis was highly variable. For example, in each location the LC and PPI no. 1 thresholds provided similar (i.e., within 9%) marketability of no. 1 heads. However, in New York, use of these thresholds resulted in 27 and 21%, respectively, fewer no. 1 heads than did the fortnightly spray. Thus, while these two thresholds may appear useful, there was enough variation among locations to be of concern. This variation at different locations may be attributable to different pest population pressure, insecticide effectiveness, species composition of the pest complex, or pest behavior. In any case, singly or combined, these factors negate the usefulness of these thresholds for fresh market standards under many different conditions.

In a previous study (Shelton et al. 1983) thresh-

Table 2. Marketable heads and number of insecticide applications for treatments comparing action thresholds for fresh-market cabbage

Treatment	% Marketable heads			No. sprays
	No. 1	No. 2	Total	
	New York			
PPI (no. 1)	72ab	21abc	93a	2
PPI (no. 2)	27bc	39a	66a	1
Larval count	66ab	30a	96a	2
FDE	70ab	27ab	97a	2
Fortnightly	93a	7bc	100a	4
Control	0c	3c	3b	0
	Ontario			
PPI (no. 1)	94a	5b	99a	1
PPI (no. 2)	68ab	26ab	94a	1
Larval count	92a	6b	98a	1
FDE	77a	19ab	96a	1
Fortnightly	99a	1b	100a	4
Control	38b	38a	76b	0
	Wisconsin			
PPI (no. 1)	85ab	14b	99a	3
PPI (no. 2)	79ab	19b	98a	1
Larval count	94a	6b	100a	2
FDE	44b	46a	90a	2
Fortnightly	90a	10b	100a	2
Control	0c	1b	1b	0
	Mean of three locations			
PPI (no. 1)	84ab	13b	97a	2.0
PPI (no. 2)	58c	28a	86a	1.0
Larval count	84ab	14b	98a	1.7
FDE	64bc	31a	95a	1.7
Fortnightly	94a	6b	100a	3.3
Control	13d	14b	27b	0

Column means for each location followed by the same letter are not significantly different ($P \leq 0.05$; Duncan's [1955] multiple range test). Percentages transformed by arcsine$\sqrt{x}$ before analysis.

olds analogous to those in the present study, but based on whole-plant samples, provided acceptable marketability in all locations. Under the FDE procedure, lowering the action threshold by 50% in an attempt to increase the resulting percentage of marketable cabbage was not successful. In addition, the subsequent marketability, based on partial plant sampling used in our study did not compare favorably with whole plant sampling described in Shelton et al. (1983). Concentrating the search for larvae on the head plus surrounding 10 wrapper and frame leaves provided a considerable savings in time, yet reduced the percentage of marketable no. 1 heads compared with that in their study. In Shelton et al. (1983), where experiments were conducted in the same locations as our study, the mean percentage of marketable no. 1 heads in the control plots was 16.3%, compared with 13% in our trial, and 92% in the fortnightly treatment, compared with 94% in our study. Thus, under similar levels of damage potential in both years, comparable thresholds resulted in ca. 10% fewer marketable no. 1 heads when based on the head plus 10 surrounding leaves, rather than on the entire plant. For fresh-market cabbage, where cosmetic appearance is most important to the consumer, marketable no. 2 cabbage would be at a disadvantage. Thus, the thresholds tested here would be inappropriate for fresh-market cabbage but may be useful for storage cabbage, in which slight feeding injury to the wrapper leaves and heads is often acceptable. For fresh market cabbage, the outer leaves should be inspected to minimize risk of loss.

We had assumed that head and wrapper leaf injury could be avoided by instituting control procedures when larvae or damage on the head, wrapper leaves, and a buffer of six surrounding leaves exceeded predetermined thresholds. Our data show some problems with this approach. Larvae move more rapidly into the head than we anticipated because of variations in environmental conditions, oviposition may occur closer to the head than we previously thought, or larvae in the head are older and therefore harder to control. The present study points to further questions regarding interaction between the pest complex and host plant which must be answered if we are to utilize thresholds for control of lepidopterous pests on cabbage.

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