Entomol. exp. appl. **70**: 209–215, 1994.

Efficiency of variable-intensity and sequential sampling for insect control decisions in cole crops in the Netherlands

A. M. Shelton,[1] J. Theunissen[2] & C. W. Hoy[3]
[1] *Department of Entomology, New York State Agricultural Experiment Station, Geneva, NY 14456, USA;* [2] *Research Institute for Plant Protection (IPO-DLO) P.O. Box 9060, 6700 GW Wageningen, The Netherlands;* [3] *Dept. of Entomology, The Ohio State University, Ohio Agricultural Research and Development Center, Wooster, OH 44691, USA*

Accepted: June 25, 1993

Key words: insecta, *Brassica oleracea*, cabbage, economic threshold, sampling

Abstract

A total of 24 commercial fields of cabbages and Brussels sprouts were sampled in a grid fashion with 20–25 equally spaced cells with four plants per cell. Using this data base of 80–100 plants, we conducted computer stimulations to compare the treatment decisions that would be made for the major insect pests using published sequential sampling programs and a newly developed variable-intensity sampling program. Additionally, we compared the number of samples required to make the decision. At low thresholds (10–20%) for both Lepidoptera and cabbage aphids, variable intensity-sampling required a smaller sample size and provided more reliable decisions, while at high thresholds (40–50%) sequential sampling provided more reliable decisions. In both procedures, the occurrence of incorrect decisions was minimal. The number of cases in which a decision would not be reached after a 40-plant sample was lower for variable-intensity sampling. Considering the number of samples required to make a correct decision and the greater need for reliable decisions at lower thresholds, variable-intensity sampling was superior to sequential sampling. Additionally, variable-intensity sampling has the advantage of requiring samples to be taken in a greater area of the field and thus increases the probability of detecting localized infestations. Although variable-intensity sampling was not designed to classify pest populations for treatment decisions but rather to achieve sampling precision around the population mean, our present studies indicate that it can also be an effective method to aid in treatment decisions.

Introduction

In the Netherlands and the United States, various approaches for supervised control of foliage-feeding insect pests of cole crops have been developed. The basis for these programs has involved developing thresholds or tolerance levels and corresponding sampling methods for the insect complex in each area. In New York we documented that use of even rudimentary thresholds (Hoy *et al.*, 1986) and appropriate sampling strategies resulted in a 49% reduction in insecticide use without a decrease in cabbage quality (Andaloro *et al.*, 1983). Similar reductions have occurred in the Netherlands (Theunissen, unpublished). In New York thresholds have been based on the use of lepidopteran larval counts, combined with the species' foliage consumption rate, and expressed as the mean number of cabbage looper equivalents (CLE) per plant (Shelton *et al.*, 1982). The advantage of this system is that information on each species is obtained, thereby allowing the grower to select the most suitable insecticide. Additionally, changes in insect density after treatment can be obtained from subsequent samplings and the usefulness of the treatment can be evaluated. The disadvantage of this system is the time required to sample the entire plant. While this disadvantage can be overcome to some extent by sampling only part of the plant, an alternative method is the use of thresholds based on the proportion of plants infested. Researchers in the Netherlands have developed a series of tolerance levels for proportions of plants infested, based on the type of cabbage and its growth stage (Theunissen & den Ouden, 1985; Theunissen & den Ouden, 1987), and are implementing them into commercial cabbage programs (Theunissen & den Ouden, 1988) in which scouting is done by growers.

In our experience the major problem of implementing a supervised control program for cabbage pests is the time involved in sampling a field. An advantage of a threshold based on the proportion of plants infested is that examination of the sample unit (i.e. the plant) can be terminated once any insect is found. Thus, the higher the insect density the faster the sampling would proceed with the strategy of sampling based on the proportion of plants infested, and the slower the sampling would proceed for sampling based on insect counts. Despite the limited information on species density and composition when using a threshold based on proportion of plants infested, the potential advantage in sampling time has recently led the New York (Petzoldt & Koplinka-Loehr, 1992) and Wisconsin (Wyman, 1992) Cabbage IPM Programs to adopt thresholds based on the proportion of plants infested.

To minimize field sampling time even further, sequential sampling protocols have been developed for proportions of cabbage plants infested (Theunissen & den Ouden, 1987). The purpose of the sequential sampling protocol is to classify pest population density as either above or below a threshold density. Although the theoretical basis of a sequential sampling plan requires samples to be taken randomly in the field, this is not done. Scouts normally begin sampling at a corner of the field and continue moving into the field until the required number of samples for decision making is obtained. However, with this strategy there is a danger of making a decision based on sampling a small and unrepresentative part of the field (Theunissen & den Ouden, 1987).

Another approach to field sampling is variable-intensity sampling (Hoy *et al.*, 1983). The purpose of the variable-intensity sampling protocol is to estimate pest population density from samples taken throughout the field, but also to adjust the number of samples taken according to the need for precision in the estimate. The strategy is to estimate iteratively the underlying mean using all previous samples, determine the sample size desired for the estimated mean based on predefined precision requirements, and calculate the number of plants that should be sampled at the next site according to the desired final sample size. The precision requirements assume that sample precision and intensity should be greatest when the population is estimated to be within a critical range of densities at which treatment may be necessary, but less when the population estimates are well above or below that range. Thus, the goal of variable-intensity sampling is to achieve acceptable sample precision with minimal effort while sampling throughout a field. Variable-intensity sampling first was developed to estimate the number of larvae per plant, but has also been evaluated for estimation of proportions of plants infested (Hoy, 1991).

Although the goals of sequential and variable-intensity sampling are different, and consequently their operating characteristics are not directly comparable, in practical terms both could be utilized for management decisions based on a threshold. For variable-intensity sampling, a critical range of densities can be established by defining the center of the range to be the threshold and setting the upper and lower limits of the range either by experience or by a maximum allowable sample size (Hoy, 1991). Sequential sampling classifies the population density according to the threshold. Thresholds developed in the Netherlands utilize the proportion of plants infested and sequential sampling procedures have been published for use with these thresholds (Theunissen & den Ouden, 1987). This study was conducted in Netherlands to compare treatment decisions that would be made and the number of samples that would be collected if variable-intensity and sequential sampling procedures were used in the same commercial field and at the same threshold level.

Materials and methods

Field sampling. During the summer of 1986, the two senior authors sampled six commercial fields each of white, red and Savoy cabbages and six commercial fields of Brussels sprouts for a total of 24 fields. Each field was sampled once by dividing it into a grid with 20 or 25 equally-spaced cells and within each cell we sampled four plants. In three of the fields we sampled a total of 80 plants per field and in the remaining 21 fields we sampled 100 plants per field. To reduce variation among cells due to differences in sampling efficiency, each person sampled two plants in each cell. The insects that were sampled were the caterpillar complex which consisted of *Mamestra brassicae*, *Pieris rapae*, *Plutella xylostella* and *Evergestis forficalis* and the cabbage aphid, *Brevicoryne brassicae*. Plants were examined for the presence or absence of caterpillars and aphids. Over all fields the percentage of plants infested with caterpillars varied from 0–61 and for cabbage aphids from 0–83. The data from these 24 field samples were used to simulate sequential and variable-intensity sampling according to various thresholds and compare their results.

Comparison of sampling methods. For each of the six sampled fields for each crop, we defined different transects and then simulated sampling along those transects. Each transect simulated two passes through the field, with the second pass in the opposite direction from the first. The transects simulated were starting at one edge of the field, sampling at five sites on a path directly towards the opposite edge, walking down the opposite edge, and then sampling at five more sites while following a path directly towards the original edge. For the fields sampled on a 5×5 sample site grid, with four plant per site, passes were made along pairs of both columns and rows in the grid. The five combinations of both columns and rows used were 1 and 3, 1 and 4, 2 and 4, 2 and 5, and 3 and 5, i.e. adjacent pairs of rows or columns were not used. For either rows or columns, a single edge was used as the starting point for each simulated transect. This provided ten different transects, with 40 plants available for sampling along each transect, through each field. For fields sampled on a 4×5 sample site grid, transects were simulated only in the direction with 5 sites along each pass. Adjacent pairs of simulated passes were used (1 and 2, 1 and 3, 1 and 4, 2 and 3, 2 and 4, 3 and 4) providing six different transects for these fields. Within each sample site, the order of observations was the same for all simulations, the random order of data entry.

Simulations were conducted for thresholds of 10, 20, 40, and 50% of the plants infested with either Lepidoptera or cabbage aphids. The sequential sampling plans for each crop are those described by Theunissen & den Ouden (1987) in which alpha = 0.30 and beta = 0.10. The published tables were used to calculate intercepts and slopes for sequential sampling decision rules for each of the thresholds examined. The variable-intensity plans for each crop were devised according to the procedure described by Hoy (1991). The critical range of densities for which maximum sampling intensity is required was established by setting the center of the range at the threshold and calculating lower and upper limits for the range that provide a maximum sample size of 40 plants. Required intensity of sampling was calculated according to equations in the simulation code, rather than a sampling chart as is sometimes used in the field.

The number of correct and erroneous decisions to treat or not to treat using each sampling method were calculated after running the 48 simulations for Brussels sprouts and 60 simulations for the other crops. A correct or erroneous decision was based on comparing the decision that would be made using variable-intensity or sequential sampling to the decision that would be made using the large sample of 80–100 plants. For variable-intensity sampling the decision not to treat would be made when the estimated proportion of plants infested is smaller than the lower bound for the range in which the true economic threshold is assumed to lie; treatment would be indicated when the estimated proportion of plants infested is above the upper bound; no decision would be made when the estimated proportion is within the critical range, because it would depend on other factors in addition to pest population density (e.g. forecasted weather, scheduled farm operations, growing conditions, etc.). For sequential sampling the decision to treat or not to treat would be made when the proportion of plants infested would be classified as above or below, respectively, the given threshold with a predetermined level of precision; no decision would be made when the population could not be so classified after 40 samples. In addition to comparing treatment decisions, we calculated the mean and standard deviation of sample sizes required for each crop, pest, and threshold.

Results and discussion

Results of the simulations for Lepidoptera are given in Table 1. If the number of correct decisions not to treat are compared across all crops and thresholds, there were 772 correct decisions using variable-intensity and 594 for sequential sampling. There were, however, 16 incorrect decisions not to treat for variable-intensity sampling and none for sequential sampling. If the number of correct decisions to treat are compared across all crops and thresholds, there were 97 correct decision using variable-intensity and 104 for sequential sampling. There were also 11 and 13 incorrect decisions to treat for variable-intensity and sequential sampling, respectively. The number of times a decision could not be reached was 16 for variable-intensity and 201 for sequential sampling.

The pattern of results for simulations of sampling cabbage aphids are similar to those for sampling Lepidoptera (Table 2). The total number of correct decisions not to treat was considerably greater for variable intensity sampling than for sequential sampling (510 versus 411), but so was the number of incorrect decisions not to treat (38 versus 5). The total number of correct decisions to treat was similar for the two methods (312 and 319 for variable-intensity and sequential sampling, respectively). For aphids, however, the number of incorrect decisions to treat was considerably larger for sequential than for variable-intensity sampling (32 versus 14). The number of cases in which a decision could not be reached was much greater for sequential sampling (145 versus 38).

The comparatively large number of undecided cases and small number of decisions not to treat, both correct and incorrect, reflect the comparatively high precision required for the no treatment classification when using the sequential sampling protocol. Because the most serious consequences to the grower result from not treating when treatment is required, the sequential sampling procedure we used was designed to lessen the probability of making that error. Conversely, the consequences of treating when treatment is not yet necessary are of minor importance to the farmer: slightly higher pesticide costs, perhaps, but also lower risk of pest damage. The sequential procedure was also designed to take advantage of the lower sample sizes resulting from requiring less precision for the treatment classification. Variable-intensity sampling does not take the relative importance of classification errors into account, because the goal is not classification.

Most of the undecided cases for sequential sampling were cases in which no treatment would be required. In practice, Theunissen and den Ouden (1987) suggest that treatment be applied when the threshold is 10% infested and no decision can be reached by the sequential sampling protocol, and that no treatment be applied when

Table 1. Treatment decisions made for management of Lepidoptera when using variable-intensity sampling (VIS) or sequential sampling (SS) plans in Brussels sprouts and cabbage

Threshold	Decide no treatment				Decide to treat				Undecided[1]		Average sample size (S.D.)	
	Correct		Error		Correct		Error		VIS	SS	VIS	SS
	VIS	SS	VIS	SS	VIS	SS	VIS	SS				
Brussels sprouts (0–17% infested)												
0.1	41	0	0	0	5	4	0	0	2	44	18.52 (9.72)	39.33 (2.81)
0.2	46	40	0	0	0	0	1	0	1	8	17.00 (8.19)	25.83 (7.67)
0.4	48	48	0	0	0	0	0	0	0	0	13.83 (2.01)	9.21 (2.24)
0.5	48	48	0	0	0	0	0	0	0	0	13.38 (1.47)	5.71 (1.57)
Spring cabbage (1–31% infested)												
0.1	29	0	9	0	18	19	1	1	3	40	18.42 (8.66)	33.28 (10.92)
0.2	46	38	3	0	7	9	3	3	1	10	18.85 (8.11)	26.03 (9.43)
0.4	58	56	0	0	0	0	1	2	1	2	16.92 (8.05)	11.42 (7.41)
0.5	60	60	0	0	0	0	0	0	0	0	15.28 (5.97)	6.67 (4.56)
White cabbage (2–33% infested)												
0.1	29	0	2	0	27	26	0	0	2	34	23.13 (8.86)	29.87 (13.02)
0.2	44	30	0	0	10	10	5	4	1	16	23.73 (10.68)	25.82 (10.44)
0.4	59	57	0	0	0	0	0	2	1	1	20.02 (9.48)	13.5 (6.80)
0.5	60	60	0	0	0	0	0	0	0	0	15.98 (5.72)	8.23 (4.63)
Red cabbage (0–61% infested)												
0.1	50	0	0	0	10	10	0	0	0	50	14.68 (5.03)	34.35 (12.80)
0.2	50	50	0	0	10	10	0	0	0	0	13.77 (1.89)	20.13 (7.44)
0.4	50	50	0	0	8	10	0	0	2	0	14.35 (3.64)	9.12 (3.84)
0.5	50	50	2	0	7	10	0	0	1	0	15.45 (6.16)	6.83 (6.16)

the threshold is 20% or greater. Their reasons for this are to minimize the risk to the grower and to neutralize his tendency for risk aversion. If these guidelines were followed, the number of incorrect treatment decisions at the 10% threshold and the number of both correct and incorrect no treatment decisions at thresholds greater than or equal to 20% could increase considerably. Regardless of the protocol used, however, after 40 plants have been sampled the sample percentage infested is known. Experienced practitioners can base a reasonable decision on that estimate without requiring rigid decision rules.

Sample size required for the two protocols varied according to the threshold, crop and pest sampled. In general, lower thresholds resulted in greater sample sizes for both procedures. For the 10 and 20% thresholds, variable-intensity sampling tended to require smaller sample sizes; for the 40 and 50% thresholds, sequential sampling tended to require smaller sample sizes (Tables 1 and 2).

Considering both sampling effort and utility of resulting decisions, variable-intensity sampling is preferable for low thresholds (10–20%) and sequential sampling for high thresholds (40–50%) for the pests considered here. The practitioner must bear in mind that occasional erroneous decisions not to treat can occur with either procedure, but are more likely with the low thresholds when variable-intensity sampling is used. A common means of avoiding loss in these cases is requiring that the interval between field inspections be shortened if the population density is estimated

Table 2. Treatment decisions made for management of cabbage aphids when using variable-intensity sampling (VIS) or sequential sampling (SS) plans in Brussels sprouts and cabbage

Threshold	Decide no treatment				Decide to treat				Undecided[1]		Average sample size (S.D.)	
	Correct		Error		Correct		Error		VIS	SS	VIS	SS
	VIS	SS	VIS	SS	VIS	SS	VIS	SS				
Brussels sprouts (0–6% infested)												
0.1	43	0	0	0	0	0	1	1	4	47	17.56 (9.52)	39.65 (2.45)
0.2	48	47	0	0	0	0	0	0	0	1	15.79 (6.43)	23.23 (5.60)
0.4	48	48	0	0	0	0	0	0	0	0	13.60 (1.65)	8.50 (0.88)
0.5	48	48	0	0	0	0	0	0	0	0	13.19 (0.91)	5.38 (0.79)
Spring cabbage (3–100% infested)												
0.1	10	0	2	0	46	47	0	0	2	13	17.13 (6.42)	16.95 (14.56)
0.2	10	10	7	1	41	40	0	0	2	9	19.95 (9.42)	16.67 (13.79)
0.4	28	30	1	0	29	30	2	0	0	0	19.22 (8.90)	10.05 (7.94)
0.5	28	30	3	2	26	28	0	0	3	0	18.32 (8.12)	7.17 (4.94)
White cabbage (10–78% infested)												
0.1	0	0	9	0	46	48	0	0	5	12	18.27 (8.16)	15.82 (14.27)
0.2	16	8	4	0	35	36	4	5	1	11	20.95 (10.25)	17.53 (14.63)
0.4	30	29	0	2	28	28	0	1	2	0	21.50 (9.13)	12.68 (7.14)
0.5	35	34	0	0	18	20	2	5	5	1	21.67 (9.64)	9.32 (6.52)
Red cabbage (3–36% infested)												
0.1	10	0	12	0	34	32	0	0	4	28	23.32 (9.83)	28.23 (13.63)
0.2	40	21	0	0	9	10	4	7	7	22	24.45 (9.94)	27.23 (12.81)
0.4	57	52	0	0	0	0	1	7	2	1	19.32 (9.04)	12.92 (6.61)
0.5	59	54	0	0	0	0	0	6	1	0	17.00 (7.69)	8.27 (4.74)

to be close to a threshold. Incipient outbreaks, resulting from not treating when treatment was required, can still be detected before serious damage occurs.

A final consideration when selecting a protocol for use in the field is that, to sample efficiently, the sampling plant must allow for detection of all pests that can be detected by inspecting plants. In this regard, variable-intensity sampling has an advantage over sequential sampling because it requires that plants be inspected throughout the field. Even if sequential sampling plans for both Lepidoptera and aphids are followed simultaneously, sampling could be terminated before an unexpected or unusual insect, disease, or weed problem is detected in another part of the field. Variable-intensity sampling addresses the risk of localized occurrence of any possible pest problem by requiring the inspection of plants along the entire transect.

Acknowledgement

The senior author gratefully acknowledges the Netherlands Ministry of Agriculture which provided a fellowship for his support on this project.

References

Andaloro, J. T., C. W. Hoy, K. B. Rose & A. M. Shelton, 1983. Evaluation of insecticide usage in the New York processing cabbage pest management program. J. econ. Entomol. 76: 1121–1124.

Hoy, C. W., C. Jennison, A. M. Shelton & J. T. Andaloro, 1983. Variable intensity sampling: A new technique for decision making in pest management. J. econ. Entomol. 76: 139–143.

Hoy, C. W., A. M. Shelton & J. T. Andaloro, 1986. Action thresholds for processing cabbage, a short term solution to a long term problem. Agric. Ecosys. and Environ. 16: 45–54.

Hoy, C. W., 1991. Variable-intensity sampling for proportion of plants infested with pests. J. econ. Entomol. 84: 148–157.

Petzoldt, C. & C. Koplinka-Loehr (eds), 1992. A grower's guide to cabbage pest management, 4th edition. Cornell IPM Bull. 101b pp. 25.

Shelton, A. M., J. T. Andaloro & J. Barnard, 1982. Effects of cabbage looper, imported cabbageworm, and diamondback moth on fresh market and processing cabbage. J. econ. Entomol. 75: 742–745.

Theunissen, J. & H. den Ouden, 1985. Tolerance levels for supervised control of insect pests in Brussels sprouts and white cabbage. Z. angew. Ent. 100: 84–87.

Theunissen, J. & H. den Ouden, 1987. Tolerance levels and sequential sampling tables for supervised control in cabbage crops. Bull. Soc. Entomol. Suisse 60: 243–248.

Theunissen, J. & H. den Ouden, 1988. Implementation of supervised control in commercial cabbage growing. IOBC/WPRS Bulletin 1988 XI: 127 131.

Wyman, J. A., 1992. Management approaches for cruciferous insect pests in central North America. In: Diamondback Moth and Other Crucifer Pests (ed) N.S. Talekar. pp. 503–509 Proc. of the 2nd International Workshop pp. 603.