# Sequential decision plan for controlling *Mamestra configurata* in spring canola[1]

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**Abstract**—A sequential decision plan was developed for controlling larvae of the bertha armyworm, *Mamestra configurata* Walker (Lepidoptera: Noctuidae), in canola (*Brassica napus* L. and *B. rapa* L., Brassicaceae), using 0.25 and 0.5 $m^2$ sampling units. Fields in Manitoba were sampled from 1980 to 1994 to determine minimum sample sizes and upper and lower cumulative larval counts at three economic thresholds. Taylor's power law described most of the variation between mean larval density and variance for 0.25 $m^2$ ($r^2 = 0.926$) and 0.5 $m^2$ ($r^2 = 0.924$) samples. Larvae were found to have a moderately clumped distribution in canola ($b = 1.42$). Levels of precision ($D_0$) varying from 0.15 to 0.25 caused minimum sample sizes to vary between 6 and 21 for the 0.5 $m^2$ samples to between 9 and 31 for the 0.25 $m^2$ samples, for an economic threshold of 16–24 larvae/$m^2$ ($P = 0.20$). Mean sampling times ranged from 40–108 for the 0.25 $m^2$ samples to 49–126 min for the 0.5 $m^2$ samples. The sampling plan for the 0.25 $m^2$ samples was verified in 18 fields in 2006 and 2007. A correct decision was made in 87% ($D_0 = 0.25$), 91% ($D_0 = 0.20$), and 94% ($D_0 = 0.15$) of the fields when the recommendation was to spray if a decision could not be reached after a second sampling. The mean number of samples needed for making a decision was 14 ($D_0 = 0.25$), 19 ($D_0 = 0.20$), and 32 ($D_0 = 0.15$). We recommend that growers use a precision level of 0.20 to minimize error rates and sampling effort. In most years, the minimum number of 0.25 $m^2$ samples per field that growers would need to take is 14–17.

**Résumé**—Nous mettons au point un plan décisionnel séquentiel pour les larves de *Mamestra configurata* Walker (Lepidoptera: Noctuidae) dans le canola (*Brassica napus* L. et *B. rapa* L., Brassicaceae) comprenant des unités d'échantillonnage de 0,25 $m^2$ et de 0,5 $m^2$. Nous avons échantillonné des champs au Manitoba de 1980 à 1994 afin de déterminer la taille minimale des échantillons et les nombres cumulatifs minimaux et maximaux de larves à trois seuils économiques. La plus grande partie de la variation entre la densité larvaire moyenne et la variance dans les échantillons de 0,25 $m^2$ ($r^2 = 0{,}926$) et 0,5 $m^2$ ($r^2 = 0{,}924$) peut se décrire par la loi des puissances de Taylor. Les larves ont une répartition moyennement contagieuse dans le canola ($b = 1{,}42$). Des niveaux variables de précision ou $D_0$ de 0,15 à 0,25 entraînent une variation de MSS de 6–21 pour les échantillons de 0,5 $m^2$ et de 9–31 pour les échantillons de 0,25 $m^2$ pour un ET de 16–24 larves par $m^2$ ($P = 0{,}20$). La durée moyenne de l'échantillonnage varie respectivement de 40–108 et de 49–126 minutes pour les échantillons de 0,25 et de 0,5 $m^2$. Nous avons vérifié le plan d'échantillonnage pour les échantillons de 0,25 $m^2$ dans 18 champs en 2006 et 2007. Une décision correcte a été prise dans 87 % ($D_0 = 0{,}25$), 91 % ($D_0 = 0{,}20$) et 94 % ($D_0 = 0{,}15$) des champs, lorsqu'il était recommandé de faire un arrosage dans les cas où une décision ne pouvait être prise après un second échantillonnage. Le nombre moyen d'échantillons requis pour en arriver à une décision est de 14 ($D_0 = 0{,}25$), 19 ($D_0 = 0{,}20$) et 32 ($D_0 = 0{,}15$). Nous recommandons aux producteurs d'utiliser un niveau de précision de 0,20

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afin de minimiser les taux d'erreur et l'effort d'échantillonnage. La plupart des années, les producteurs auraient à prélever un minimum de 14–17 échantillons de 0,25 $m^2$ par champ.

[Traduit par la Rédaction]

## Introduction

The bertha armyworm, *Mamestra configurata* Walker (Lepidoptera: Noctuidae), is a destructive insect pest of canola (*Brassica napus* L. and *B. rapa* L., Brassicaceae) oilseed crops in parkland regions of western Canada (Turnock and Philip 1977). Outbreaks are infrequent and localized (Mason *et al.* 1998). Growers are notified of possible outbreaks based on the results of regional monitoring of adult moths in pheromone traps, which accurately determine the presence of adults but do not predict pest levels in a particular field (Turnock 1987).

Bracken and Bucher (1977, 1984) developed economic thresholds for larvae in both *Brassica* species to guide growers' decisions regarding control. Turnock and Bilodeau (1985) found that counting larvae in a 0.5 $m^2$ sampling unit was the most efficient and accurate method of determining larval densities. However, no sequential sampling plans that provide precise information about pest abundance using minimal sampling effort (Binns and Nyrop 1992) are available for the integrated management of bertha armyworm on canola.

Profit margins per unit area for canola are often low (Canola Council of Canada 1991). The crop is seeded in narrow rows (15–20 cm width) and can become thick and tangled during early pod growth (stages 5.1–5.2; Harper and Berkenkamp 1975), when sampling for bertha armyworm larvae should be done (Turnock and Bilodeau 1985). This makes walking through the crop difficult and growers may be reluctant to adopt the sampling plan.

Turnock and Bilodeau (1985) developed sampling methods for assessing larval abundance in canola fields, but their study did not include measures of sampling precision or utility. The objectives of our study, therefore, were to develop a sequential sampling plan for controlling bertha armyworm in canola based on counts of larvae and to evaluate the suitability of the sampling-plan methods for operational use.

## Materials and methods

A three-sided metal frame was used to outline each sampling unit and determine the density of bertha armyworm larvae in commercial canola fields from 1980 to 1994 in the northwest and central parkland regions of Manitoba (50°–52°N, 97°–101°W) (Turnock and Bilodeau 1985). Plants within each sampling unit were shaken by hand and plant material on the soil surface was then removed to expose larvae. A 0.5 $m^2$ sampling unit was used in all fields in all years. A 0.25 $m^2$ sampling unit was also used during 1980–1986. Larval counts for the 0.25 $m^2$ sampling unit were taken from the left half of the 0.5 $m^2$ sampling unit. The counts from fields where larval densities were $\geq 0.8/m^2$ (*i.e.*, two larvae for ten 0.25 $m^2$ sampling units) were used to develop sequential sampling methods. Fields with suitable larval densities were found in 10 of the 15 years and were included in the data. A minimum of 10 suitable fields were found each year, except for 2 years when only five and eight suitable fields were sampled. In total, 142 and 87 fields were used to determine sampling methods for the 0.5 and 0.25 $m^2$ sampling units, respectively.

The relationship between the variance ($s^2$) and mean ($x$) of larval density per sampling unit was determined using Taylor's power law (Taylor 1961):

$$[1] \quad \log_e s^2 = \log_e a + b \log_e (x)$$

where the intercept, $\log_e a$, and the slope, $b$, of the equation were calculated by means of linear regression (SAS Institute Inc. 1990). Analysis of covariance was used to compare slopes and intercepts among years for both sampling units. Minimum sample sizes for both sampling units were estimated at three levels of precision ($D_0$), 0.15, 0.20, and 0.25, using Green's (1970) modification of Kuno's (1969) method for sequential sampling at fixed precision levels. The sequential decision plan for counts of bertha armyworm larvae was formulated from

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Iwao's (1975) method with Taylor's power law as the measure of dispersion:

$$[2] \quad T_0 = qm_0 \pm t\sqrt{qam_0{}^b}$$

where $T_0$ is the lower or upper limit of the cumulative larval count; $q$ is the number of samples; $m_0$ is critical larval density; $t$ is Student's statistic at the desired confidence interval ($P = 0.20$); and $am_0{}^b$ is the expected population variance. A $P$ value of 0.20 or 0.25 is acceptable for estimating population densities for pests that exhibit population changes 10-fold or higher in a single season (Southwood 1966). An upper and a lower limit of cumulative larval count were computed at a range of critical densities of 16, 20, and 24 larvae/m$^2$ for the two sampling units.

For each sampling unit the cost of sampling was determined for a range of economic thresholds at the three levels of precision, and was primarily a function of time needed to complete sampling. The different sampling times for the two sampling units at each level of precision were computed from the time required by inexperienced personnel to sample (established by Turnock and Bilodeau 1985).

To verify the sampling scheme, a total of 8 commercial canola fields in 2006 and 10 in 2007 in Manitoba (50°–51°N, 99°–101°W) were surveyed at the early green pod growth stage. Fields were sampled as described by Turnock and Bilodeau (1985) using the 0.25 m$^2$ sampling unit. At least 20 samples per field (Nyrop and Simmons 1984) were taken in 2006 and 40 per field in 2007. An equal number of samples were taken in each field by either two samplers (10 per sampler) or four samplers (5 or 10 per sampler). The parameters of the sequential sampling model were compared with the intercept and slope estimated for these fields by analysis of covariance. To estimate the accuracy of the sequential plan, pest-control decisions made on the basis of the minimum sample sizes in the sequential plan were compared with decisions made using all samples from each field. The individual larval counts were selected randomly from each field to determine accumulated totals for minimum sample sizes.

## Results

### Spatial distribution

Most of the variation in the relationships between variance and mean for the 0.25 m$^2$ ($r^2 = 0.926$) and 0.5 m$^2$ ($r^2 = 0.924$) sampling units was described by Taylor's power law (Fig. 1). Mean–variance relationships were also significant ($P < 0.05$) for both sampling units in all years except the year in which only five fields were sampled ($P = 0.71$). However, analysis of covariance showed that for the 0.25 and 0.5 m$^2$ sampling units, slope ($P = 0.020$ and 0.009, respectively) and intercept ($P = 0.001$ and 0.001, respectively) varied among years.

Sampling parameters varied among years because larval densities in all fields sampled in a year were either above or below economic thresholds. Consequently, data for all years were pooled and parameters were estimated for the 0.25 m$^2$ ($b = 1.417 \pm 0.043$, $\log_e a = 1.225 \pm 0.101$, $r^2 = 0.926$, $n = 86$) and 0.50 m$^2$ sampling units ($b = 1.420 \pm 0.034$, $\log_e a = 0.824 \pm 0.073$, $r^2 = 0.924$, $n = 142$). The intercept, $\log_e a$, is a sampling factor and depends on sampling-unit size (Taylor 1961). The smaller value for the 0.50 m$^2$ than for the 0.25 m$^2$ sampling unit denotes a lower population variance for the larger sampling unit.

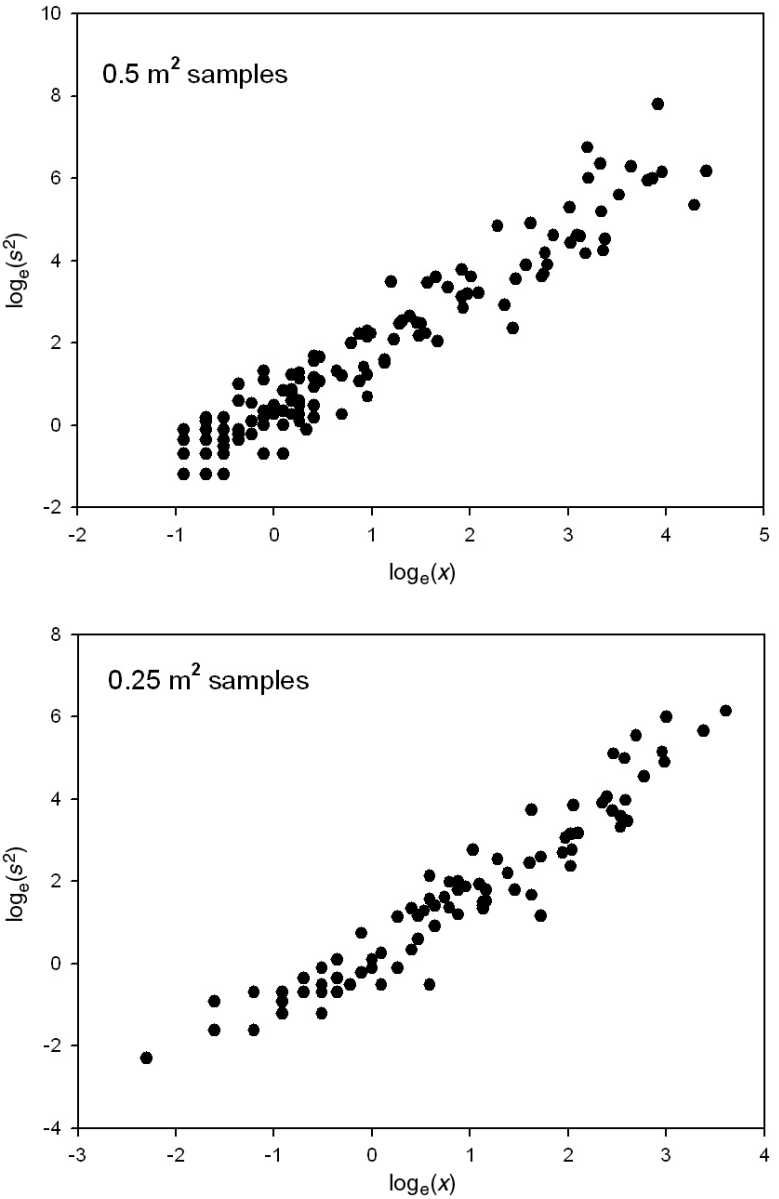
### Sequential sampling plan for larval counts

In most years in Manitoba the economic threshold for canola is 20 ± 4 larvae/m$^2$, based on crop prices and the cost of an insecticide application by aircraft. Hence, the minimum sample size and cumulative total number of larvae ($T_0$ range) were calculated at economic thresholds of 16, 20, and 24 larvae/m$^2$ for sampling units of 0.25 and 0.5 m$^2$ (Table 1). Minimum sample sizes at these economic thresholds at sampling-precision levels of 15%–25% varied from 9 to 31 for the 0.25 m$^2$ sampling unit and from 6 to 21 for the 0.5 m$^2$ sampling unit ($P = 0.20$). A control decision made at an economic threshold of 20 larvae/m$^2$ can be made at $D_0 = 0.25$ if the cumulative larval count, or $T_0$ range, is <17 or >83 for the 0.25 m$^2$ samples or <35 or >105 for the 0.5 m$^2$ samples (Table 1). The $T_0$ range for a control decision made at an

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**Fig. 1.** Observed relationship between mean count ($x$) and variance ($s^2$) for bertha armyworm (*Mamestra configurata*) larvae in 0.50 and 0.25 $m^2$ sampling units in canola fields in Manitoba.




economic threshold of 20 larvae/$m^2$ increases to <84 to >186 for the 0.25 $m^2$ samples and <128 to >232 for the 0.5 $m^2$ samples at $D_0 = 0.15$ (Table 1). Fields with cumulative larval counts below the $T_0$ range require no further action, whereas those above this range should be sprayed immediately with an insecticide. Sampling in fields with larval densities that fall within the $T_0$ range should continue until a decision can be made (Fig. 2). If larval densities remain within the $T_0$ range after a second complete assessment (Fig. 2), these fields should be treated with an insecticide.

### Sampling-time requirements

Sampling times for each sampling unit at the three levels of precision were calculated at

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**Table 1.** Minimum sample sizes (MSS) and cumulative larval counts of bertha armyworm (*Mamestra configurata*) on canola at three economic thresholds and three precision levels ($D_0$) for sampling units of 0.25 and 0.5 $m^2$.

| Economic threshold (number of larvae/$m^2$) | $D_0 = 0.25$ | | $D_0 = 0.20$ | | $D_0 = 0.15$ | |
|---|---|---|---|---|---|---|
| | MSS | $T_n$ range[a] | MSS | $T_n$ range[a] | MSS | $T_n$ range[a] |
| **0.25 $m^2$ samples** | | | | | | |
| 16 | 11 | 15–73 | 17 | 33–103 | 31 | 78–170 |
| 20 | 10 | 17–83 | 15 | 36–114 | 27 | 84–186 |
| 24 | 9 | 18–90 | 14 | 41–127 | 24 | 89–199 |
| **0.5 $m^2$ samples** | | | | | | |
| 16 | 8 | 33–95 | 12 | 59–133 | 21 | 121–217 |
| 20 | 7 | 35–105 | 11 | 68–152 | 18 | 128–232 |
| 24 | 6 | 34–110 | 10 | 74–166 | 17 | 146–262 |

*Lower and upper ranges of cumulative larval counts required for making a control decision ($P = 0.20$).

an economic threshold of 20 larvae/$m^2$. The mean time taken to count larvae and move to the next site within a field by an inexperienced sampler is about 7 and 4 min for each 0.5 $m^2$ and 0.25 $m^2$ sample, respectively (Turnock and Bilodeau 1985; R.J. Bilodeau, personal communication). Hence, sampling-time requirements at precision levels of 0.15−0.25 ranged from 49 to 126 min for the 0.5 $m^2$ sampling unit range and from 40 to 108 min for the 0.25 $m^2$ sampling unit.

### Verification of the sampling plan

The relationship between variance and mean for fields sampled to verify the sampling plan fitted Taylor's power law ($b = 1.479 \pm 0.075$, $\log_e a = 0.859 \pm 0.175$, $r^2 = 0.96$, $n = 18$). The slopes for the 0.25 $m^2$ sampling unit for these fields were similar ($P = 0.578$) to those for fields in the sequential sampling plan, but the intercept, $a$, was lower ($P \leq 0.0001$) because of the 2- to 4-fold increase in the number of samples taken in each commercial field.

When the sampling plan was tested in these fields, the correct decision as to whether or not to spray after the minimum sample was taken was made in 57% ($D_0 = 0.25$), 78% ($D_0 = 0.20$), and 85% ($D_0 = 0.15$) of the 18 fields at economic thresholds of 16, 20, and 24 larvae/$m^2$, respectively (Table 2). A second sampling (minimum sample size × 2) of fields increased the number of correct decisions to 87% ($D_0 = 0.25$), 91% ($D_0 = 0.20$), and 94% ($D_0 = 0.15$) of the 18 fields. A recommendation to spray after the second sampling, if a decision could not be made, would have resulted in an incorrect decision to spray in 13% ($D_0 = 0.25$), 9% ($D_0 = 0.20$), and 6% ($D_0 = 0.15$) of the fields at economic thresholds of 16, 20, and 24 larvae/$m^2$, respectively. The mean number of samples per field taken to enable a decision in the 18 fields was 14 ($D_0 = 0.25$), 19 ($D_0 = 0.20$), and 32 ($D_0 = 0.15$), respectively.

## Discussion

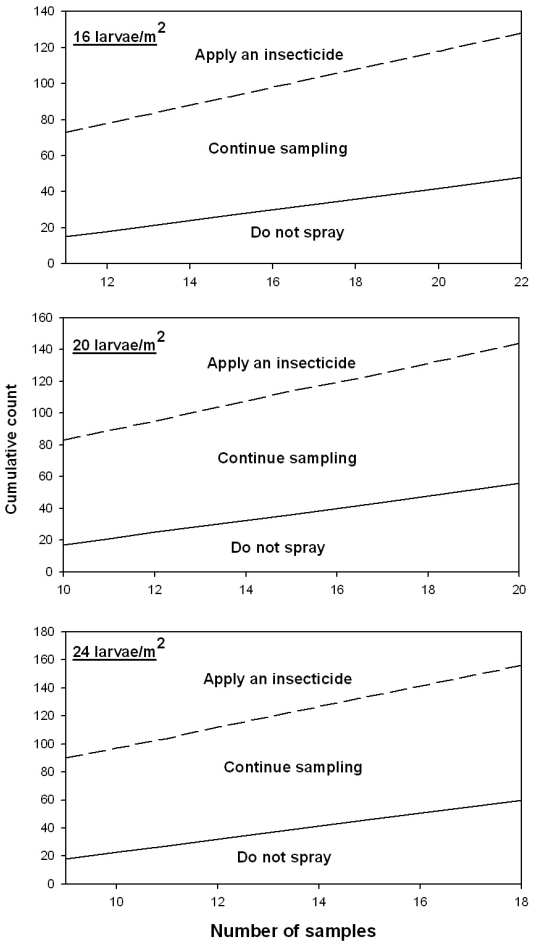
The spatial distribution of bertha armyworm larvae on canola was density-dependent, as with many organisms (Taylor *et al.* 1978), and was accurately described over the range of population densities found in the field ($r^2 > 0.92$). The aggregation index, $b$ from Taylor's power law, was 1.42, indicating that larvae are moderately aggregated in canola fields and have a more clumped distribution than do larvae of another noctuid pest of crucifers, the cabbage looper, *Trichoplusia ni* Hubner (Harcourt 1965). The higher aggregation index for bertha armyworm larvae can be attributed to the egg-laying habits of adult females. Bertha armyworm eggs are usually laid in patches of about 100 (King 1929) to several hundred (Ulmer *et al.* 2003), but female *T. ni* lay eggs singly on crucifer leaves (Shorey *et al.* 1962).

Precision, ease of application, and cost are three factors to consider in selecting a

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**Fig. 2.** Lower and upper cumulative counts of bertha armyworm (*Mamestra configurata*) larvae in canola fields used for making a control decision ($P$ = 0.20) based on 0.25 $m^2$ samples at three economic thresholds.




sampling program. Cost arises primarily from the time and labour required to sample, but the potential for yield losses due to delays in insecticide application should also be considered. Bracken (1987) found that 34% of total canola yield losses from feeding by fifth-instar larvae occurs within their first 3 days. Thus, a sampling plan should allow growers to reach a control decision (preferably during the day of sampling) when fifth-instar larvae are found.

Canola growers in western Canada typically seed two or more fields each year. This makes the decision-plan model for $D_0$ = 0.15 (108 and 126 min for 0.25 and 0.5 $m^2$ sampling units, respectively, at an economic threshold of 20 larvae/$m^2$) only marginally acceptable and excludes any possibility that a model with a higher precision level would be used. Both decision-plan models with lower precision ($D_0$ = 0.20 or 0.25) can be completed within 60 min for 0.25 $m^2$ sampling units and within 77 min for 0.5 $m^2$ sampling units if further sampling is not required.

The shorter sampling times with 0.25 $m^2$ sampling units than with 0.5 $m^2$ sampling units, when travel time between fields is included, may enable growers with many fields to sample one or two more fields per day. The 0.25 $m^2$ sampling unit is also easier to use because the periods of searching for larvae are shorter. Finding and counting larvae require bending over at the waist or being on one's knees, depending on whether larvae are on stems or under leaf litter on the soil surface. Larvae tend to feed lower down on plants, and generally only about 20% of larvae are visible on pods or upper leaves (Bracken 1984).

The costs of sampling, as indicated by sampling times at different precision levels, are affected more by changes to sampling precision than to the sampling unit. At the highest precision level selected ($D_0$ = 0.15), growers would be able to sample about four fields per day (approximately 2 h per field). Growers with five or more fields to examine, using either sampling unit, would have to increase sampling costs by taking another day to sample or by hiring samplers. Growers who are unwilling to increase their sampling costs could use a sampling scheme in which only six to eight 0.5 $m^2$ samples or nine to eleven 0.25 $m^2$ samples are required at economic thresholds of 16–24 larvae/$m^2$. A decision on whether to spray could readily be reached for 8–10 fields in 1 day, depending on distance between fields. This level of sampling has a 25% probability of yielding an incorrect population assessment, which represents a higher frequency of sequential decision errors than sampling programs at the two higher precision levels (Nyrop and Simmons 1984), a >40% likelihood of having to resample, and a 13% possibility of making an incorrect control decision in fields. The latter two

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**Table 2.** Numbers of fields for which correct decisions were made with the sequential decision plan for controlling bertha armyworm (*Mamestra configurata*), using 0.25 $m^2$ sampling units at three economic thresholds and three precision levels ($D_0$), out of 18 commercial canola fields in southern Manitoba, 2006–2007.

| Economic threshold (number of larvae/$m^2$) | $D_0 = 0.25$ | | | $D_0 = 0.20$ | | | $D_0 = 0.15$ | | |
|---|---|---|---|---|---|---|---|---|---|
| | MSS[a] | RS[a] | ID[b] | MSS[a] | RS[a] | ID[b] | MSS[a] | RS[a] | ID[b] |
| 16 | 10 | 14 | 4 | 12 | 15 | 3 | 13 | 16 | 2 |
| 20 | 10 | 16 | 2 | 14 | 17 | 1 | 16 | 18 | 0 |
| 24 | 11 | 17 | 1 | 16 | 17 | 1 | 17 | 17 | 1 |
| Percentage of fields | 57 | 87 | 13 | 78 | 91 | 9 | 85 | 94 | 6 |

[a]Correct decisions made after taking the minimum sample size (MSS) and resampling (RS = MSS × 2).
[b]Incorrect decision (ID) to spray made after resampling.

assessments, though, were from fields that were selected because the probability of their larval populations being near or above economic thresholds was higher. In areas where growers are notified to sample, fields typically have larval populations well below the economic threshold, and a correct control decision can be reached with the minimum sample size. Hence, we recommend that sampling parameters at a precision level of 0.25 be used by growers when fields have larval populations mostly well below economic thresholds. This sampling program could help to alleviate the need for pesticide use in fields with very low larval densities, a frequent occurrence even during outbreak years (Bracken and Bucher 1984).

In years when populations are likely to be near or above economic thresholds, we recommend that growers use sampling parameters at a precision level of 0.20 to minimize error rate and sampling effort. In most years, the number of 0.25 $m^2$ samples that growers would need to take is 14–17. The frequency of resampling would be about 22% and incorrect control decisions <10%. Sampling time using two transects per field (Turnock and Bilodeau 1985) would be about 1.25 h per field at thresholds of 16–24 larvae/$m^2$. The small improvements in sampling accuracy and decision-making for sequential sampling plans at a precision level of 0.15 are considered insufficient to overcome the near doubling in time requirements compared with plans at a precision level of 0.20.

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