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Transect Sampling to Enhance Efficiency of Corn Rootworm (Coleoptera: Chrysomelidae) Monitoring

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ABSTRACT Crop monitoring for adult corn rootworms, *Diabrotica virgifera virgifera* LeConte and *D. barberi* Smith and Lawrence, remains the best means to assess fields at risk from this pest if replanted to corn, *Zea mays* (L.). Improvements in sampling methodology including the development of a sequential sampling plan have reduced the minimum sampling time required to make a management decision to 20 minutes or less per field per visit to make a management decision. Many growers and scouts still find this time commitment a constraint to repeated scouting. A common currently used sampling method involves systematically covering most of the field following a "W" pattern. The feasibility of replacing the current sampling pattern with a simpler and less time-consuming transect (straight line) pattern was assessed. Computer simulations demonstrated that treatment decisions based on transect sampling would have an acceptably low error rate (10%) over a range of realistic CRW densities (0 to 2 adults per plant). This error rate represented a decrease in accuracy of less than 1% compared to systematic sampling. Field trials using transect, systematic "W", and random sampling methods in each field were used to compare the categorization of adult CRW densities into "above" or "below" threshold with a sequential sampling plan. Efficiency measured in time to reach a decision, number of corn plants evaluated, and sampling time per plant were compared between sampling methods. The three methods did not differ significantly in the number of plants evaluated or in the categorization of CRW populations. Transect sampling resulted in significantly shorter mean sampling time per plant (38 s) than either systematic (78 s) or random sampling methods (166 s). Based on these results transect sampling reduces sampling time per plant by 40 s or 51% compared to systematic sampling and thus could reduce total sampling times substantially.

KEY WORDS western corn rootworm, sampling, efficiency

Over the past decade, the western corn rootworm (WCR), *Diabrotica virgifera virgifera* LeConte (Coleoptera: Chrysomelidae), has become established as the predominant insect pest of field corn *Zea mays* (L.) in New York. The more assertive nature and greater capacity to cause economic damage of WCR, compared to the previously dominant northern corn rootworm (NCR), *D. barberi* Smith and Lawrence, has increased grower awareness and concern of potential risks of corn rootworms (CRW). In New York and other states in the northeastern United States, the majority of corn is grown as feed for dairy cows and thus is often grown for silage which is at particular risk from WCR injury (Davis 1994). WCR is also responsible for dramatic increases in overall soil insecticide use. A pesticide survey conducted in 1985 reported that 13.8% of the New York acreage received a soil insecticide (Specker et al. 1986). By 1989 this figure had nearly doubled to 24.8% of the New York acreage being treated with a soil insecticide (E. J. S. unpublished). In 1994, a NAPIAP survey of growers in New York found that 70.3% of grain corn acres and 17.3% of silage corn acres were routinely treated with an insecticide (Partridge et al. 1995). Presumably, a large proportion of insecticide use was targeted towards CRW control.

The NAPIAP survey also found that New York growers utilized pest presence based on scouting as their criteria in making insecticide-use decisions on 51.7% of grain and 50.3% of silage corn acres. In a 1998 survey of 1,074 New York growers, Waldron (unpublished) found that 77% monitored their field corn. Forty-two percent of those monitoring did so two or three times per season, 21% monitored more than four times per season, and 8% did so weekly. Nearly 60% of those surveyed expressed concern (26% low, 20% moderate, and 13% high level of concern) for the amount of time required to monitor crops for pest problems. Clearly, growers are interested in monitoring as a means to enhance pest management decisions but feel time required to do so is an element of concern.

Prior to 1991, CRW monitoring procedures required an assessment of CRW beetle numbers on five plants in each of eleven areas within a field. This activity could take as much as ninety minutes per field (Sawyer 1985). To simplify this protocol and time commitment, Shields et al. (1991) developed a sequential CRW sampling method enabling producers to assess a twenty acre or smaller field for CRW in twenty minutes or less. This sampling method has helped increase adoption of IPM practices to optimize management of CRW.

It may be possible to reduce sampling time even further while maintaining the current level of accuracy in characterizing adult CRW densities as above or below threshold. In the currently used sequential sampling method the sampler counts the CRW beetles on a single stalk and then moves on to a new site in the field (Shields et al. 1991). Using this method, samplers typically cover most of the field in a “W” pattern. Sawyer (1985) estimated that walking between sites took an average of 0.75 minutes. Thus, a substantial proportion of the time spent in the field is taken by walking between sites. Within a cornfield more time is taken to cross a row then to walk the same distance within a row. The time taken in travel between sites is largely a function of the absolute distance and the number of rows that are crossed.

Taking each sample in a different location is necessary for accurate data if pests are highly aggregated or clumped. Adult CRW distributions vary widely in their level of aggregation (Shields et al. 1991) so a simpler sampling method involving less walking may be possible. Specifically, if adult CRW in a given field were randomly distributed then “the presence of one individual does not influence the distribution of another” (Southwood 1978). A range of factors can influence how adult CRW are distributed in the field including relative maturity of plants, planting depth, soil type, soil moisture and fertility (Davis and Coleman 1997, Allee 2001). Data from several studies indicates that a significant proportion of fields have CRW populations that are randomly or even more widely (nearing uniformity) dispersed (Sawyer 1985, Steffey and Tollefson 1982). This implies that it may be possible to obtain accurate CRW population estimates by sampling closely spaced stalks in a row or “transect”. The transect sampling method would minimize travel time between sites. The goal of this research was to determine how well the transect method compared to the current systematic “W” method.

The specific objectives of this research were: 1) to determine the range of CRW population parameters across which transect sampling provides acceptably accurate results, compared to systematic “W” and random sampling, using a computer simulation, and, 2) to test the accuracy (in terms of decision-making) and efficiency (in terms of time saved) of transect sampling compared to systematic "W" and random sampling in the field.

Materials and Methods

Construction and Utilization of the Simulation Model.

Simulating a Corn Field and a CRW Population. The simulation software performs comparisons of three different sampling methods (transect, systematic "W", and random) on a simulated corn field over a range of possible density and dispersion coefficients. The software utilizes mathematical functions from Cephes math library (http://www.moshier.net/index.html). Each run of the model begins by creating a field with a known average density of CRW per stalk. The field values were designed to emulate a square 4.05 ha field with a density of approximately 69,000 plants per ha. Specifically, field parameters were: 204.4 m width, 204.4 m length, 264 rows, and 1,056 stalks per row. The number of beetles per each stalk were assigned according to the negative binomial distribution with 14 average densities per stalk (0.0, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, 1.3, 1.4, 1.6, 2.0). The dispersion (k) coefficient was set to 2.45 following Shields et al. (1991).

Sampling the Simulated CRW Populations. Each simulated CRW population was sampled with the three sampling methods, transect, systematic "W", and random sampling. To simulate transect sampling one row was chosen randomly and every 10th plant in that row was sampled. The simulation of systematic sampling emulated the zigzagging motion of the "W" pattern using 54 pre-calculated motion matrix coordinates. These pre-calculated parameters start at a corner of the field and traverse it twice (two "V's") from one side to the other on an angle of approximately 22^{o}. Individual plants to sample are specified by row and plant number within the row, the first nine plants counted were: (row, plant): 1, 1; 5, 82; 10, 163; 15, 244; 20, 325; 25, 406; 30, 487; 35, 568; 40, 649. Random sampling was simulated by evaluating plants randomly chosen from the entire field. Three sets of 100,000 simulations were run at each density to ensure convergence had been achieved. Sets of simulations for a single density never varied more then 0.005 for any given parameter.

Evaluating Sampling Methods. Based on the CRW numbers generated from each sampling method a treatment decision is reached using the Cornell guidelines (Shields et al. 1991) a sequential sampling plan with an action threshold of one CRW beetle per stalk. For each simulated density the decisions made by the three methods are compared to the decision based on the actual density of the field and three values are generated for each comparison (total error, type I error, type II error). Type I errors represent decisions to treat when CRW density is less then one beetle per stalk and type II errors represent decisions not to treat when densities are greater or equal to one. The difference in total error between sampling methods was calculated by subtracting the total errors of each pair of methods for each run of 100,000 simulations at each density.

Field Comparison of Sampling Methods. Field trials were conducted in 3 fields at the Cornell Animal Science Teaching and Research Farm, Harford, NY. CRW were sampled using transect, systematic "W", and random sampling methods by five, six, and seven observers with each using all three methods in every field. Fields were sampled on 27 August 2001. A rectangular area of 160 corn rows by 1056 corn plants per row was sampled for each field. With spacings of 76.2 cm between rows and 22.86 cm between plants this equates to a rectangle 122 m wide by 229 m long and a total area of approximately 28,000 m^2. For all methods the sequential sampling scheme developed by Shields et al. (1991) was used to categorize the CRW population into above or below the recommended threshold of one beetle per plant. Plants were successively chosen using one of the three methods until the upper or lower stop point was reached. For the transect method, a row was randomly selected excluding the five outermost rows and every tenth plant was counted. For the systematic "W" method observers started on the first row and within the first 10 plants and designated that location 1,1. From this initial location the "W" pattern was executed by crossing over three rows and advancing 81 plants for each successive plant until four passes were made back and forth across the field. Thus, the first nine plants counted were: (row, plant) 1, 1; 3, 82; 6, 163; 9, 244; 12, 325; 15, 406; 18, 487; 21, 568; 24, 649. Plants to be counted in the random method were selected using random coordinates that were generated and scaled such that each pair represented a specific row and a plant within the 100,000 plants sampled.

The effect of sampling method on total sampling time, number of plants, and sampling time per plant were analyzed with an analysis of variance (PROC MIXED; SAS Institute 1996). Field and observer were included in the model as blocking factors. Total sampling time and sampling time per plant were log-transformed to alleviate heteroscedasticity. Treatment means were compared using *t*-tests with Tukey's adjustment to control experimental error.

Results

The results of the computer simulations indicate that transect sampling is very accurate (<10 % total error) at densities at least 0.3 beetles per stalk greater or less than the threshold of one beetle per stalk (Fig. 1). The total error rate rose exponentially as densities neared the threshold reaching a maximum of 48 % (Fig. 1). Average total error across all 14 densities for transect sampling was 10±2%.

The performance of the transect method was very similar to the other two methods (Fig. 2). The average difference in accuracy between transect sampling and the other sampling methods across densities was 0.45±0.08% and 0.24±0.05% respectively for systematic 'W' and random sampling. The highest percentage difference between transect sampling and the other methods occurred at densities just above the threshold of one beetle per stalk reaching a maximum of 1.5±0.02% more error compared to systematic 'W' sampling at a density of 1.1 beetles per stalk (Fig. 2). At densities of 0.5 and 2.0, transect sampling had a lower percentage error then systematic sampling and random sampling although the differences were very small. For all three methods only type I errors were made at densities below 1.0 beetles per stalk and only type II errors were made at densities equal to or greater then 1.0.

Based on the results of field trials, the three sampling methods did not differ in their categorization of CRW populations using the sequential sampling. Each observer categorized each CRW population the same way using all three methods.

In the field, the three sampling methods differed significantly in total time to make a decision (F = 44.76; df = 2, 39; P = 0.0001). Transect sampling resulted in shorter total time to make a decision than systematic "W" (t = -3.49; df = 1, 39; P = 0.0034) or random sampling methods (t = -9.36; df = 1, 39; P = 0.0001) (Table 1).

Mean sampling time per plant also differed significantly between sampling methods (F = 69.30; df = 2, 39; P = 0.0001). Transect sampling resulted in shorter times per plant to make a decision than systematic "W" (t = -5.29; df = 1, 39; P = 0.0001) or random sampling methods (t = -11.75; df = 1, 39; P = 0.0001) (Table 1). Transect sampling resulted in significantly shorter mean sampling time per plant (38 s) than either systematic "W" (78 s) or random sampling methods (166 s). Based on these results transect sampling reduces sampling time per plant by 40 s or 51% compared to systematic "W" sampling.

The three methods did not differ significantly in the number of plants evaluated to make a decision (P = 0.3949) (Table 1). Thus the reduction in sampling time per plant was due to reduced travel between plants not time at each plant.

Discussion

The results of our simulations clearly indicate that transect sampling provides acceptable accuracy across a range of realistic densities. The loss in accuracy compared to systematic 'W' sampling is less than half a percent across the range of densities we simulated and reached a maximum less than 2% at densities near the economic injury level of one CRW per plant. Although we only simulated densities up to two CRW per plant, field densities can be as high as 9 beetles per plant (Shields et al. 1991) and extrapolating from our data it seems very likely that total error from transect sampling would be equal or lower than error from the other methods at all densities greater then two beetles per plant.

Error was concentrated near the EIL for all three sampling methods. It is important to note that this is also where the "cost" of an incorrect decision is lowest (Fig. 1). At densities below the EIL the cost of an incorrect decision to treat would equal the cost of control minus the value of yield saved by the treatment. At densities above the EIL the cost of an incorrect decision not to treat would equal value of yield lost by not treating minus the unexpended cost of control. Thus with a value for the cost of control ($29.65 per h), relationship of density to yield loss (1.54 + 1.03 x number of adults), and value per unit yield ($11.81 per quintal) (values from Foster et al. 1986) we can calculate the cost of an incorrect decision for each CRW density. On this basis it is clear the transect method performs extremely well at densities farther from the EIL where stakes are high and that most of the error generated is at densities near the EIL where making an incorrect decision is not very costly.

Sampling populations of CRW in the field confirmed the accuracy of the transect sampling method. In 17 comparisons in which individual observers sampled the same CRW population with all three methods the same decision was always reached for each method. While this represents a relatively narrow range of conditions it does demonstrate that the transect sampling method can provide accurate data for categorizing CRW populations.

In field trials, the accuracy of transect sampling method was coupled with increased efficiency compared to other methods. Transect sampling reduced total time per field by almost 6 minutes (44%) which equates to an average reduction of 40 s (51%) of sampling time per plant compared to systematic "W" sampling. The amount of time saved in a given field will be a function of the sampling time per plant and the number of plants sampled. The number of plants sampled did not vary significantly across sampling methods but for an individual field it will be determined by CRW spatial distribution and relationship of CRW density to the EIL (e.g. more plants sampled closer to the EIL).

This level of time savings could equate to substantial monetary savings for growers and scouts. Based on saving almost a minute per plant using transect sampling compared to sequential "W" sampling, an average of 18 plants required to make a decision in New York

(Shields et al. 1991), and a value of $40 per hour for sampling (D. DeGolyer, personal communication), transect sampling would result in a savings of over $8 per visit to a field. This magnitude of savings could be especially important for trained pest management consultants who can routinely visit over 14 fields in a day. With fields sampled for CRW as many as four times in a season this could represent savings of over $30 per field over the season.

An additional benefit of transect sampling is that by reducing the amount of time in the field and the number of crosses between rows, this method has the potential to reduce sampler fatigue. It may be possible to further increase the efficiency of transect sampling by decreasing the distance between sampled plants. We sampled every tenth plant but it may be possible to count plants sequentially in a row if it is determined that this does not bias counts by causing beetles to flee.

One of the most attractive attributes of transect sampling is that it could be could be integrated directly into CRW IPM programs. Since transect sampling represents a simplification of the current sampling protocol, existing materials from the sequential plan could still be utilized.

This study compared the three sampling methods over a range of densities but used only one set of dispersion conditions (single plant and k=2.45). Although several studies have addressed spatial dispersion of CRW adults in corn, all of these studies also measured dispersion on the basis of individual plants. While this provides useful information it does not address dispersion patterns where CRW adults are aggregated in larger spatial patterns. Many other herbivores have been shown to aggregate in clumps or hotspots that encompass groups of plants of various sizes. In the absence of this data we can simulate aggregations at several scales to determine the impact of this higher scale aggregation on the accuracy of the three sampling methods. We are currently developing a program that can simulate dispersion across a wide range of spatial scales (e.g. clumps of 10, 100, or 1000 plants). In the future we plan to expand the present study over this range of possible aggregation sizes to determine if the scale of aggregation has a major impact on the relative accuracy of sampling methods for CRW. Coupling these simulations with intensive field monitoring of CRW spatial distributions will help to determine how likely they are to be distributed in a way that will allow the accuracy we found with this first field test of transect sampling. In addition, this type of spatially explicit data will be useful for insect resistance management and precision agriculture.

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Table 1. Field comparison of sampling method efficiency (mean ± S.E).

	Transect	Systematic "W"	Random
Total time (min)	7.24 ± 0.99 a	13.00 ± 2.04 b	32.24 ± 2.93 c
Time per plant (min)	0.63 ± 0.05 a	1.30 ± 0.21 b	2.77 ± 0.33 c
Plants counted	12.41 ± 1.78 a	11.05 ± 1.31 a	13.12 ± 1.41 a

[1]Different letters within a row indicate a significant difference between treatments, $P \leq 0.05$; Tukey's *t*-tests, n = 17.

Fig. 1. Total error from transect sampling at densities of 0 – 2 corn rootworm (CRW) per plant from computer simulations (solid line) and cost of making an incorrect decision (dashed line).

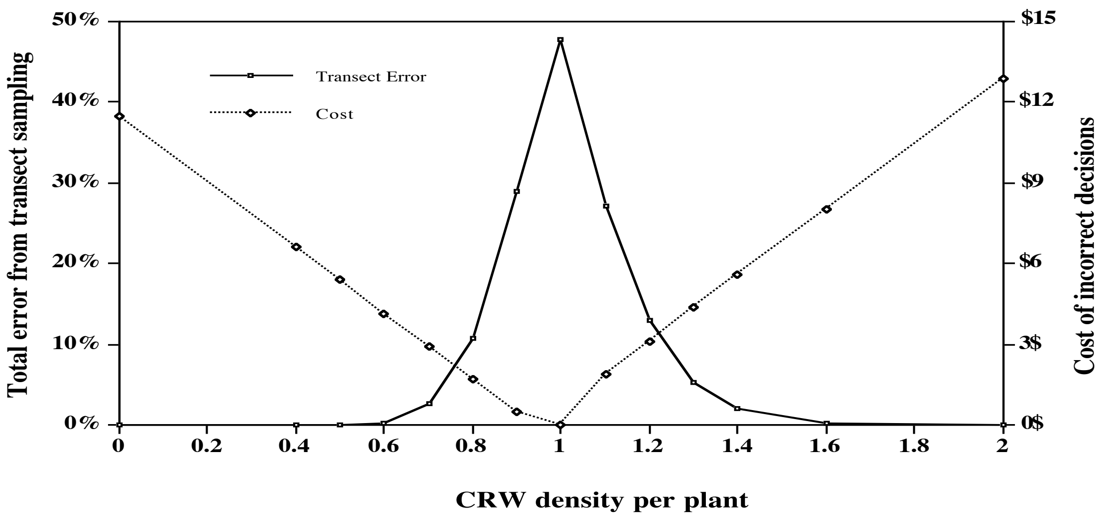

Fig. 2. Mean difference in error between sampling methods at densities of 0 - 2 corn rootworm (CRW) per plant from computer simulations. Columns represent the difference between errors generated with simulations of transect versus systematic (solid bars) and transect versus random sampling methods (open bars). Error bars represent the variation in differences generated from three sets of simulations at each density.