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Sequential Sampling Plans for the Red Sunflower Seed Weevil (Coleoptera: Curculionidae) in Oilseed Sunflower[1]

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ABSTRACT Decision making on control of the red sunflower seed weevil, *Smicronyx fulvus* LeConte, requires a reliable and efficient method for classifying the pest population. The objective of this study was to develop sequential sampling plans for red sunflower seed weevil control in oilseed sunflower. Sequential classification sampling plans were developed from Wald's sequential probability ratio test (SPRT) by using a negative binomial distribution. Operating characteristic and average sample number functions were computed for a range of k values. Two sampling plans were developed for the economic thresholds of six and eight weevils per sunflower head, based on a k value of 0.525. Compared to the fixed-sample-size plan that growers use, the sequential sampling plans reduce the average size by 20% to 35% when the weevil population is low or high. The sequential sampling plans require significantly more samples as the weevil population densities approach the thresholds, suggesting that the fixed-sample-size plan does not provide the adequate precision in the densities near the thresholds.

KEY WORDS Coleoptera, Curculionidae, *Smicronyx fulvus*, *Helianthus*, sampling

The red sunflower seed weevil (*Smicronyx fulvus* LeConte) is a major pest of cultivated sunflower, *Helianthus annuus* L., in the northern Great Plains (Oseto & Braness 1979, Oseto & Korman 1986, Lamey et al. 1993). Adult weevils oviposit in the developing achenes, and larvae feed on the developing kernels (Oseto & Braness 1979). Damage caused by larval feeding includes weight loss and oil content loss of the achenes (Oseto & Braness 1980, Peng & Brewer 1995a). Control of the weevils is directed at adults before oviposition because eggs and larvae are protected within the achene. The density of adult weevils at which economic losses may occur depends upon many factors (i.e., market price, plant population density, and control cost) and can vary from four to nine weevils per sunflower head (Peng & Brewer 1995a). Insecticides are used to control the weevil (Oseto & Burr 1990) despite recommendations for early planting (Oseto et al. 1987) or tillage (Gednalske & Walgenbach 1982) to reduce weevil damage.

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Reliable and effective sampling plans are essential for accurate decisions for the management of the weevil since economic thresholds have been established. Sequential sampling plans based on Wald's sequential probability ratio test (SPRT) (Wald 1947) have been used in forest (Tostowaryk & McLeod 1972, Carter et al. 1994) and agricultural cropping systems (Lye & Story 1989). In general, Wald's SPRT plans require an average of 40% to 60% as many observations as equally reliable fixed-sample-size methods (Fowler & Lynch 1987). To develop such plans, the distribution of sample observations must be described by a probability model (i.e., binomial, normal, Poisson, and negative binomial) (Nyrop & Binns 1991). The weevil counts per sunflower head follow a negative binomial distribution (Peng & Brewer 1994). This paper reports sequential sampling plans for the red sunflower seed weevil for making control decisions in oilseed sunflower.

Materials and Methods

Source of field data. A total of 17 data sets consisting of weevil counts per sunflower head was obtained from five fields in North Dakota during 1992 and 1993. The field sizes ranged from 0.4 ha to 4.0 ha. Each field was planted with the sunflower hybrid "DO 855", or "Interstate 894", or "Northrup King 265". Of those 17 data sets, 13 data sets each contained a sample size of 108 sunflower heads from nine quadrats with 12 heads from each quadrat. The other four data sets each contained a sample size of 240 sunflower heads from 20 quadrats with 12 heads from each quadrat. Details of this sampling procedure have been reported by Peng & Brewer (1994).

Development of sequential sampling plans. Sequential sampling plans were developed by using Wald's SPRT (Wald 1947). A single Wald's SPRT tests the null hypothesis (H_o: $m = m_o$) against the alternative hypothesis (H_1: $m = m_1$) ($m_o < m_t < m_1$), where m_t is the economic threshold, and m_o and m_t are parameters that are used to define an acceptable SPRT (Binns & Nyrop 1992). If the null hypothesis is accepted, then it is interpreted that $m < m_t$. The converse is accepted if the null hypothesis is rejected. When the distribution of sampling observations is described by a probability model, stop lines for sequential sampling plans can be computed by using predetermined lower and upper limits of economic thresholds (m_o and m_1) and risk levels for making type I (α) and type II (β) errors. The α is the probability of accepting the alternative hypothesis when the null hypothesis is correct, and β is the probability of accepting the null hypothesis when the alternative hypothesis is correct.

These probabilities (α and β) are not considered as error rates but as parameters that are used to determine an acceptable SPRT, as defined by its operating characteristic (OC) and average sample number (ASN) functions (Binns & Nyrop 1992). The OC and ASN functions describe the performance of the sampling plans. The OC function is the probability of accepting the null hypothesis, given any true mean. The ASN function is the average number of observations needed to make a classification, given any true mean (Nyrop & Binns 1991).

The dispersion parameter k of the negative binomial distribution (NBD) for weevil counts per sunflower head ranged from 0.1267 to 1.1331 for 12 of the 17

data sets in which the weevil populations were high enough to determine the dispersion accurately, and a common k was 0.5255 calculated by using Elliot's (1977) method. One of the limitations of the SPRT based on NBD is the requirement that the only parameter allowed to change from one sample location or time to another is the mean density. This means that the dispersion parameter k must remain constant. However, variations in k may not discount the use of the SPRT in a sequential sampling program as long as the OC and ASN functions are not sensitive to changes in k (Nyrop & Binns 1991). A sensitivity analysis was conducted to determine the effect of changes in the value of k on the OC and ASN functions. The k values chosen for sensitivity comparison were 0.130, 0.260, 1.133, and 0.525, which approximate the lowest, third lowest, highest, and common k value, respectively. The OC and ASN functions were computed from 1,000 Monte Carlo simulations.

The economic injury levels for the weevils in oilseed sunflower vary with the market price, plant population density, and cost of control (Peng & Brewer 1995a). The market price is the major factor in determining the economic injury levels because changes in plant population density and cost of control are small. An increase in the market price decreases the economic injury levels. From 1981 to 1992, the market price of oilseed sunflower ranged from \$0.15 to \$0.30 per kg (North Dakota Agricultural Statistics Service 1991, 1993). During those 12 yr, the price was between \$0.15 to \$0.20 per kg 6 yr, between \$0.20 to \$0.25 per kg 5 yr, and above \$0.25 per kg 1 yr. The economic injury levels for the ranges of market price between \$0.15 to \$0.20 per kg and \$0.20 to \$0.25 per kg approximated 8 (± 1) and 6 (± 1) weevils per sunflower head, respectively (Peng & Brewer 1995a). We set the economic thresholds equal to the economic injury levels for development of sampling plans. Type I and type II errors were set at 0.15. The formulae for the calculation of the lower intercepts, higher intercepts, and slope of the stop lines were from equations reported by Fowler & Lynch (1987).

We used the analysis of variance to determine any added variance component among quadrats (SAS Institute 1987). If the variation is not significant among quadrats, this means that the location and number of sampling sites are not important factors to influence the precision of sampling plans.

Results and Discussion

A sensitivity analysis indicated that a decrease in k (i.e., the population is more aggregated) resulted in flatter OC and ASN functions (Fig. 1). A flatter OC function means less robustness and precision of the sampling plans. A flatter ASN function means that fewer samples are required to classify pest population density. Among four k values used for sensitivity comparison, a k value of 0.130 spread the OC function over a relatively wider range of densities, but it reduced the average number of samples. The other three k values gave similar OC functions that spread over a narrow density range near the economic thresholds, but the average number of samples increased. There is a tradeoff between increased precision and increased sample size. When k = 1.133, the average number of samples may become excessive as the population

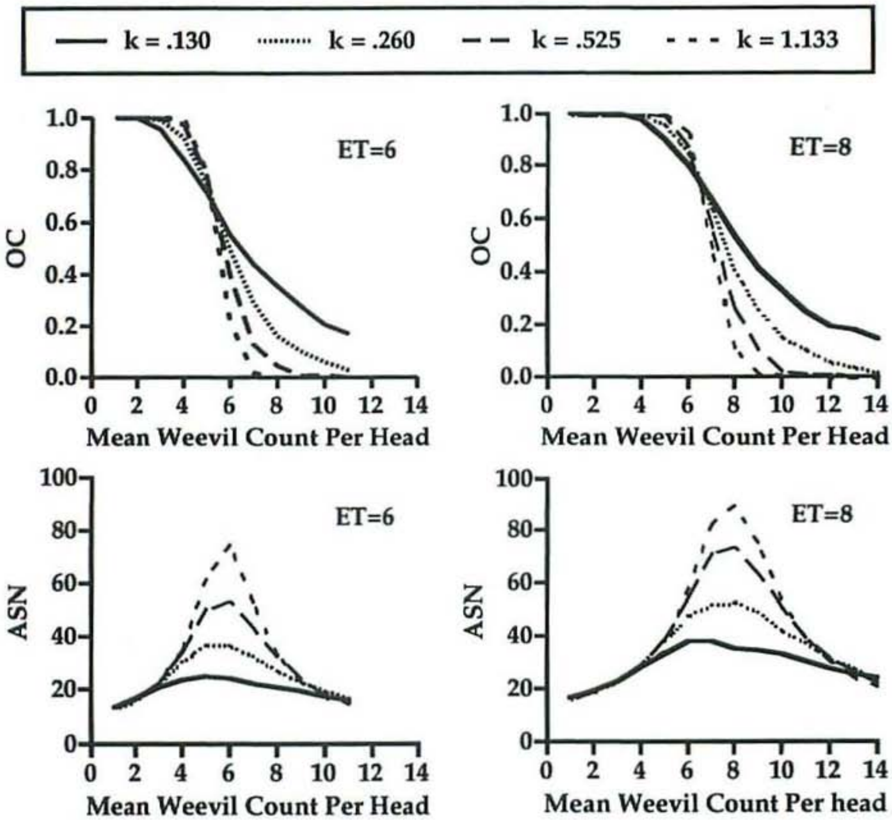

Fig. 1. Influence of changes in k on the operating characteristic (OC) and average sample number (ASN) functions for two sequential sampling plans based on the economic thresholds (ET) of six and eight red sunflower weevils per sunflower head.

means approach the economic thresholds, although the OC function is more robust. We selected a k value of 0.525 for development of sampling plans because most k values are likely to be around 0.525 in the actual field sampling (Peng & Brewer 1994), and a k value of 0.525 gives a robust OC without an excessive ASN near the thresholds (Fig. 1).

Two sampling plans were developed (Fig. 2) to correspond to the economic thresholds of six and eight weevils per head. If the total number of weevils is less than the lower critical value, sampling is discontinued and no action is recommended. If the total number of weevils is greater than the upper critical value, sampling also is discontinued and insecticide treatment is recommended. However, stop boundaries do not guarantee a decision will be reached within any given sample size (heads). Based on the ASN function when $k = 0.525$, we set an upper limit of 55 samples (heads) for the sampling plan based on the threshold of six weevils per head, and 75 samples for the sampling plan based

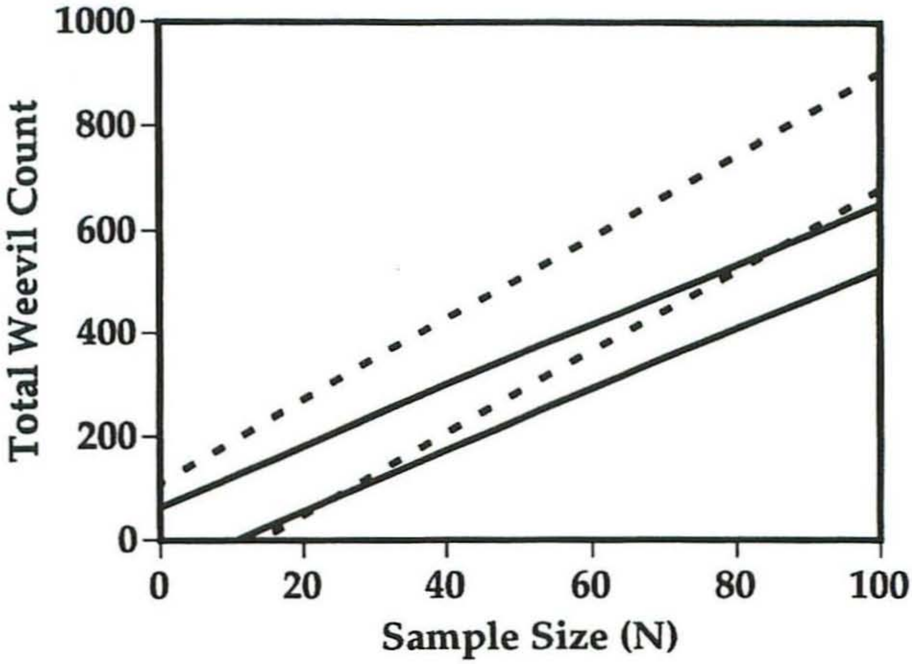

Fig. 2. Decision boundaries for the sequential sampling plans for classifying populations of the red sunflower seed weevil based on the economic thresholds of six weevils per head (solid lines, intercepts = ± 63.02, slope = 5.89) and eight weevils per head (dashed lines, intercepts = ± 11.01, slope = 7.92).

on the threshold of eight weevils per head. If 55 or 75 samples are taken without making a classification, the estimated weevil density is compared with the corresponding thresholds and density classified accordingly.

The currently recommended fixed-sample-size method samples a total of 25 sunflower heads to estimate the weevil density. The estimated weevil density was compared with the thresholds, and a control decision was made (McBride et al. 1992). Compared with the fixed-sample-size plan, the sequential sampling plan for the threshold of six weevils per head, on the average, reduced sample size by about 35% when the weevil density was less than two or higher than 11 weevils per head. The sequential sampling plan for the threshold of eight weevils per head, on the average, reduced sample size by about 20% when the weevil density was less than two or higher than 14 weevils per head. When the weevil densities approach the thresholds, the sequential sampling plans require significantly more samples for a classification of population density than the fixed-sample-size plan, suggesting that the fixed-sample-size plan does not provide adequate precision in the densities near the thresholds.

To apply the sampling plans to field sampling, the first questions are when and where samples should be taken. The economic thresholds used in the

development of the sampling plans are based on the weevil counts taken when most of the sunflower plants in the field are at stages R5.1 to R5.3 [10% to 30% completion of anthesis (Schneiter & Miller 1981, Peng & Brewer 1995a)], and field sampling should be initiated then. In regard to where in a field to sample, analysis of variance indicated that there was no significant ($P < 0.01$) added variance component among quadrats in 15 of 17 data sets (Table 1), suggesting an even distribution of adult weevils within fields. Thus, the selection and number of sampling sites within a field were not critical for classifying the population density.

Charlet & Oseto (1982) reported that weevil damage decreased from the margin of the field inward, suggesting possible higher weevil density at the edges of fields. We did not detect a significant ($P < 0.01$) difference in mean number of weevils per head among quadrats in 15 of 17 data sets (Table 1) or mean number of damaged seeds per head among quadrats (Peng & Brewer 1995b). The difference between our data and those of Charlet & Oseto (1982) is due to differences in the way samples were collected. They sampled a 15-m-wide strip of the field margin (at the margin, 7 m and 15 m from the margin). Our samples were taken throughout the fields, and samples taken in the quadrats near the edges of fields were at least 10 m from the field margin. Samples in the central quadrats were at least 20 m away from the field margin. Therefore, we recommend that samples should be taken at least 10 m away from the field margin.

Unlike selection and number of sampling sites, selection of sampling units (sunflower heads) is important. Adult weevils have a strong preference for particular plant stages (Brewer 1991, Peng & Brewer 1994). More weevils are present on plants at anthesis stages than on plants at bud stages. Plants in later anthesis stages (> R5.4) are more attractive to adult weevils than plants in earlier anthesis stages (< R5.4). Sunflower heads for weevil counts must be randomly selected and represent sunflower plant population in a field. Any bias selection of sunflower heads could result in a severe under- or overestimation of the population density, thus misclassifying the population density.

The economic thresholds used in the development of the sampling plans are based on the number of weevils counted in the laboratory (absolute counts). In field sampling, weevil counts will probably be lower than absolute weevil counts because weevils tend to hide between florets on the sunflower heads. Field counts must be converted to absolute counts before the sampling plans can be applied. The relationship between field counts and absolute counts varies with the sampling methods that bring the weevils to the surface of the sunflower heads. McBride et al. (1992) recommended two methods: brush the face of the heads vigorously or spray a commercial preparation of mosquito repellent containing diethyl toluamide on the head. Both methods will cause the weevils to move out of hiding spots. Weiss & Brewer (1988) determined the relationship between field counts and absolute counts if the mosquito repellent method is used for sampling, which can be used to estimate absolute weevil counts from field counts. In field sampling, the total estimated absolute weevil counts are compared with lower and upper critical values of corresponding sampling plans after each sunflower head is sampled, and decisions are made accordingly. The sequential sampling plans are more efficient at low or high

Table 1. Analysis of variance on the number of red sunflower seed weevils per head, showing the variations among quadrats and within quadrats.

Sampling date	Source of variation	df	MS	F	P
Field 1					
4 August	Among quadrats	8	13.37	0.61	0.7666
	Within quadrats (among heads)	99	21.88		
10 August	Among quadrats	8	364.42	2.12	0.0403
	Within quadrats (among heads)	99	171.57		
13 August	Among quadrats	8	94.76	0.94	0.4863
	Within quadrats (among heads)	99	100.64		
Field 2					
13 August	Among quadrats	19	4.27	1.02	0.4390
	Within quadrats (among heads)	220	4.18		
17 August	Among quadrats	19	40.82	1.06	0.3984
	Within quadrats (among heads)	220	38.65		
20 August	Among quadrats	19	8.36	0.94	0.5314
	Within quadrats (among heads)	220	8.88		
24 August	Among quadrats	19	9.33	2.33	0.0019
	Within quadrats (among heads)	220	4.01		
Field 3					
13 August	Among quadrats	8	323.13	0.92	0.5018
	Within quadrats (among heads)	99	350.43		
19 August	Among quadrats	8	436.86	0.75	0.6442
	Within quadrats (among heads)	99	579.72		
22 August	Among quadrats	8	56.19	0.54	0.8218
	Within quadrats (among heads)	99	103.59		
Field 4					
13 August	Among quadrats	8	0.23	1.77	0.0924
	Within quadrats (among heads)	99	0.13		
17 August	Among quadrats	8	5.47	0.51	0.8489
	Within quadrats (among heads)	99	10.81		
20 August	Among quadrats	8	3.61	1.03	0.4219
	Within quadrats (among heads)	99	3.52		
24 August	Among quadrats	8	1.13	0.67	0.7192
	Within quadrats (among heads)	99	1.70		
Field 5					
10 August	Among quadrats	8	0.38	0.83	0.5795
	Within quadrats (among heads)	99	0.46		
16 August	Among quadrats	8	1.94	2.42	0.0200
	Within quadrats (among heads)	99	0.80		
19 August	Among quadrats	8	16.52	4.86	0.0001
	Within quadrats (among heads)	99	3.40		

weevil densities than the fixed-size sampling plan and more reliable at the densities near the thresholds.

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