Research Article

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Spatial dispersion and binomial sequential sampling for the potato psyllid (Hemiptera: Triozidae) on potato

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Abstract

BACKGROUND: The potato psyllid is a serious pest of potatoes. Sampling plans on potatoes for the potato psyllid have yet to be developed, thus the authors' objectives were (1) to determine the most efficient within-plant sampling unit, (2) to determine the spatial dispersion of potato psyllids in potato fields and (3) to develop a binomial sequential sampling plan for this pest.

RESULTS: Significantly more potato plants were infested with potato psyllids on the edges of the field, and significantly more plants were infested with psyllids on the 'top' and 'middle' of the potato plant. Significantly more psyllids were also found on the undersides of leaves. The potato psyllid has an aggregated distribution in potato fields. Binomial sequential sampling plans were developed for three action thresholds representing 0.5, 1 and 5 psyllids per plant. The average sample numbers for these action thresholds were between 12 and 16 samples, depending on the action thresholds. However, based on the shape of the operating characteristic curve, the 0.5 and 1 sampling plans were more reliable than the 5 psyllids per plant plan.

CONCLUSION: The binomial sequential sampling plans are useful for detecting potato psyllids at low levels of infestation, which will be useful for pest management purposes.

Keywords: *Bactericera cockerelli*; potato; binomial sequential sampling program; resampling software

1 INTRODUCTION

The potato psyllid, *Bactericera cockerelli* (Sulc) (Hemiptera: Triozidae), is a serious pest of potatoes (*Solanum tuberosum* L.) in Central and North America and in New Zealand.[1–4] The potato psyllid causes damage on potato plants by direct feeding, which can result in significant reductions in crop quality and longevity.[5] More importantly, the potato psyllid can transmit a bacterial pathogen *Candidatus* Liberibacter psyllaurous (aka *Ca.* L. solanacearum) to potatoes, which is associated with 'zebra chip' (ZC) disease.[4,6,7] Complete yield losses in potatoes can occur when plants are exposed to psyllids carrying the pathogen.[6,7] ZC is a relatively new disease of potato that was first documented near Saltillo, Mexico, in 1994.[6] ZC causes the decline of the potato plants to the point of plant death and production of unacceptable tubers for commercial purposes.[6] Consequently, the potato psyllid and ZC have caused economic losses running to millions of dollars to both potato producers and processors.[6]

The development of a sampling program to monitor insect populations is a fundamental tool for integrated pest management (IPM).[8] As IPM is an ecology-based approach to pest management that relies on current information about the status of the pest and the crop, a sampling program is critical for decision-making tactics.[9] No studies to date have developed a sampling program for the potato psyllid. Information so far has been largely anecdotal regarding the dispersion and location of potato psyllids in agricultural fields. Thus, the objectives of the present study were to describe the spatial dispersion of the potato psyllid in agricultural fields, to determine the most efficient sampling unit and develop and validate a binomial sequential sampling plan for the potato psyllid. These data will be a necessary first step in the development of an IPM program against the potato psyllid where there is a need quickly to estimate the population density of this pest.

2 MATERIALS AND METHODS

2.1 Field locations and sampling

Biweekly sampling of potato psyllids began on 7 May 2009 and ended on 3 December 2010. Commercial potato fields ranging from 26 to 59 ha and planted with the varieties 'Cal White', 'Red LaSoda' and 'Satina' in Riverside County (Lakeview, CA) were subjected to proprietary commercial pesticide applications. Insecticide-free potato plantings with the varieties 'Atlantic' and 'Cal White' were carried out in 2009 and 2010, respectively, at the University of California's South Coast Research and Extension Center in Orange County (Irvine, CA), each 0.002 ha in size. By sampling in both insecticide-treated and untreated fields, the sampling plan is not subject to the common problem caused by change in arthropod distribution following pesticide application.[10] In the insecticide-treated fields in Lakeview, visual counts were conducted using a systematic sampling design where samples

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were taken at fixed spatial intervals in order to determine the pattern of infestation in the fields.[8] A total of 15–25 plants from 3–5 transects were sampled within a field every 20 m for up to 80 m on each sample date. These transects started at the edge (defined as the outermost boundaries of the field) and then went into the field. In the untreated fields in Irvine, visual counts were conducted using a stratified random sampling design where the plantings were divided into four plots and two potato plants were sampled per strata per sample date. For the purposes of finding the most efficient sampling unit: (1) the numbers of plants from the Lakeview fields infested with potato psyllids on the field margins and within the field were compared to determine whether there were 'edge effects' and analyzed with a chi-square test (PROC FREQ); (2) the within-plant distribution of potato psyllids was determined by dividing the plant into 'top', 'middle' and 'bottom' sections and was also analyzed with a chi-square test (PROC FREQ); (3) the numbers of potato psyllids found on the 'top' and 'bottom' of leaves were recorded and compared using *t*-tests (PROC TTEST).[11]

2.2 Potato psyllid distributions

The number of potato psyllids per plant was counted on potato plants in Riverside County in 2009 and 2010 using the sampling design described above. Three commonly used indices for classifying dispersion patterns were calculated, including Green's index (C_x), Iwao's patchiness or mean crowding regression and Taylor's power law.[12–14] Three such indices were chosen in an attempt to obtain a consensus on dispersion, because the use of a single index can be misleading.[15,16]

Green's index (C_x) was calculated using the equation

$$C_x = (s^2/m) - 1/(n-1)$$

where s^2 is the variance of the mean, m is the mean number of potato psyllids in i sampling units and n is the total number of potato psyllids sampled in i sampling units.

Iwao's mean crowding regression was determined by solving the equation

$$m' = \alpha + \beta m$$

where α (estimated by a) is the intercept of the ordinate and β (estimated by b) is the slope of the regression line when m is regressed on the mean. Mean crowding, m', was derived from the equation

$$m' = m + (s^2/m) - 1$$

and replaced the mean and variance from the count data.[17] Regressions and parameters were generated using SAS (PROC REG).[11]

For Taylor's power law the relationship between the mean and variance, $s^2 = am^b$, was used to solve for the coefficients a and b with linear regression when a log transformation was used:

$$\log(s^2) = \log(a) + (b)\log(m)$$

where a is the intercept and b is the slope.[18] Regressions and parameters were generated using SAS (PROC REG).[11]

2.3 Development and validation of binomial sequential sampling plans

Nineteen field datasets were used to develop and validate binomial sequential sampling plans for the potato psyllid. Steps used to

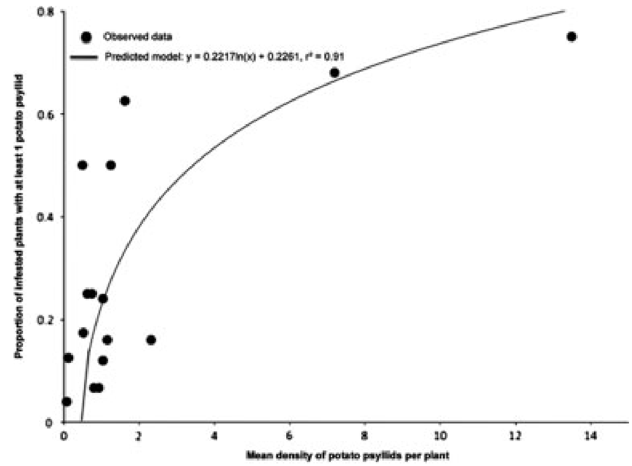

Figure 1. Empirical relationship between the proportion of potato plants infested with at least one potato psyllid and the mean number of potato psyllids per plant.

develop the binomial sampling plan followed those listed in Galvan *et al*.[19]

Firstly, the empirical relationship between the proportion of potato plants infested with at least one potato psyllid (P_T) and the mean density of potato psyllids per plant (m) was derived using the equation

$$\ln(m) = \alpha + \beta \ln[-\ln(1 - P_T)]$$

where α and β are parameters estimated from the data, and ln signifies the natural logarithm.[20,21] Because the potato industry does not have an economic action threshold for the potato psyllid, action thresholds of 7, 23 and 58% of the infestation rate were used to represent mean densities of 0.5, 1 and 5 potato psyllids per plant respectively (Fig. 1). Munyaneza[22] noted that as few as one infective psyllid per potato plant can infect a potato plant with *Ca.* L. psyllaurous. However, not all psyllid populations from different geographic areas are equally infective.[23] Thus, the action thresholds represent the range of densities that growers are likely to encounter in the field.

Secondly, the stop lines were created for each action threshold by means of Wald's sequential probability ratio test (SPRT) using RVSP (Resampling for Validation of Sample Plans) software.[24,25] Parameters in SPRT include θ_1 (the lower boundary for the decision action threshold), θ_2 (the upper boundary for the decision action threshold), α (the type I error or treat when the actual pest density was below the action threshold) and β (the type II error or not treat when the actual pest density was above the action threshold).[19,21] The lower and upper boundaries of the action threshold were both held at 0.10 above and below the action threshold, and the type I and II error rates were held constant at 0.10.[19,21,25] The tally threshold was held constant at one potato psyllid per plant, which means that potato plants with ≥ 1 potato psyllid per plant were considered to be infested.

Thirdly, to validate the precision and efficiency of the sequential binomial sampling plans, operating characteristic (OC) functions were calculated for each threshold, and the average sample number functions were determined.[26]

3 RESULTS

3.1 Determination of the sampling unit

For within-field sampling of the potato psyllid, significantly more plants were infested with potato psyllids on the edge of the fields compared with plants within the fields ($\chi^2 = 15.56$, df = 1, $P < 0.0001$). Out of 203 plants examined in Riverside County during the dates when psyllids were present in 2009 and 2010, 40 plants were infested with potato psyllids. Thirty-three (82.5%) of the potato-psyllid-infested plants were located on the edge of the field, and only seven (17.5%) of them were located within the field.

For the within-plant distribution of the potato psyllid, significantly more plants had potato psyllids located on the top ($\chi^2 = 15.64$, df = 1, $P < 0.0001$) and middle ($\chi^2 = 11.93$, df = 1, $P = 0.0006$) of potato plants compared with the bottom of the plant. There was no significant difference between the numbers of plants that were infested with potato psyllids on the top and middle of potato plants ($\chi^2 = 0.28$, df = 1, $P = 0.5979$). Out of 283 potato plants examined in Orange and Riverside counties during the sampling dates in 2009 and 2010, 43 plants (15.2%) were infested with psyllids on the top of the plant, 40 plants (14.1%) were infested with psyllids on the middle of the plant and 20 plants (7.1%) were infested with psyllids on the bottom of the plant.

Potato psyllids preferred the leaves to any other plant structure. More than 99% of the potato psyllids found were on the leaves of the potato plants in Riverside and Orange counties in 2009 and 2010. Out of 131 leaves examined with potato psyllids present, significantly more potato psyllids were found on the abaxial surface of leaves (4.1 ± 0.50, 109) (mean $\pm$ SE, N) versus the adaxial surface of leaves (1.8 ± 0.5, 22) ($t = 3.48$, df = 80.39, $P = 0.0008$).

3.2 Potato psyllid distributions

Mean potato psyllid densities ranged from 0.08 to 7.20 per plant (Table 1). All of the indices were in agreement that the potato psyllid populations were aggregated in Riverside County in 2009 and 2010 (Table 1). Green's coefficient was greater than 0, indicating that psyllid populations were aggregated in Riverside County in 2009 and 2010. The slopes of the regression lines for Iwao's mean crowding regression were significantly greater than 1, indicating aggregated psyllid populations for Riverside County in 2010 ($t = 10.50$, df = 1, $P = 0.0413$). While the slope was numerically greater than 1 for Iwao's regression for psyllid populations in Riverside county in 2009, it was not significantly different from 1 ($t = 2.72$, df = 1, $P = 0.1125$).

Taylor's power law provided a better fit of the regression models (Table 1). All of the slopes of the regression lines for Taylor's power law were quite similar, and all were significantly greater than 1, indicating that psyllid populations were aggregated (Riverside County, 2009: $t = 11.86$, df = 1, $P = 0.0070$; Riverside County, 2010: $t = 3.89$, df = 1, $P = 0.0301$).

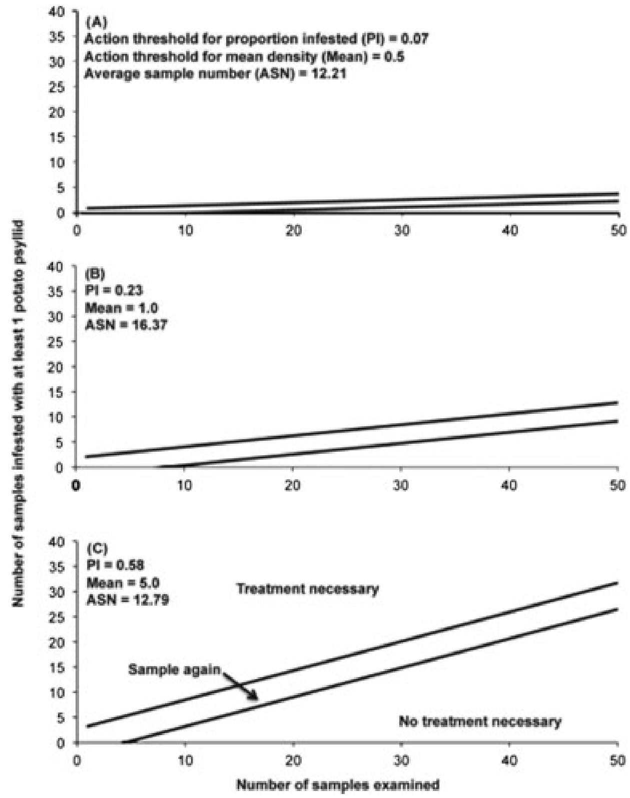

Figure 2. Decision stop lines for the binomial sequential sampling plans of (A) 0.07, (B) 0.23 and (C) 0.58 proportion infested with at least one potato psyllid, obtained from the resampling software.

3.3 Binomial sequential sampling plans

Three sequential binomial sampling plans with different action thresholds using the presence/absence of the potato psyllid are presented in Fig. 2. As sampling proceeds, if the cumulative number of infested plants is less than the lower decision threshold line, then sampling can be stopped and no treatment is required. If the cumulative number of infested plants is above the upper decision threshold line, then management action is required. If the cumulative number of infested plants falls between the lower and upper thresholds, additional plants need to be sampled, but it is recommended that no more than 50 plants be sampled. If, after 50 plants, a decision is not made, the potato field must be resampled at a later date. The average sample number based on these action thresholds is between 12 and 16 samples and represents the average number of samples needed to reach a treatment decision (Fig. 2). The OC curves with the three different action thresholds are shown in Fig. 3. Generally, the steeper the slope around the OC value of 0.5, the better is the quality control.[27] Based on the shape

Table 1. Dispersion indices for the potato psyllid in Riverside County in 2009 and 2010

			Iwao's mean crowding regression			Taylor's power law		
Year	Range of means[a]	Green's index	*a*	*b*	r^2	*a*	*b*	r^2
2009	0.08–7.20	1.16	4.83	2.35	0.79	0.89	1.46	0.99
2010	0.80–2.32	0.84	1.11	10.50	0.80	1.06	1.80	0.83

[a] Mean number of potato psyllids per plant for the year and location.

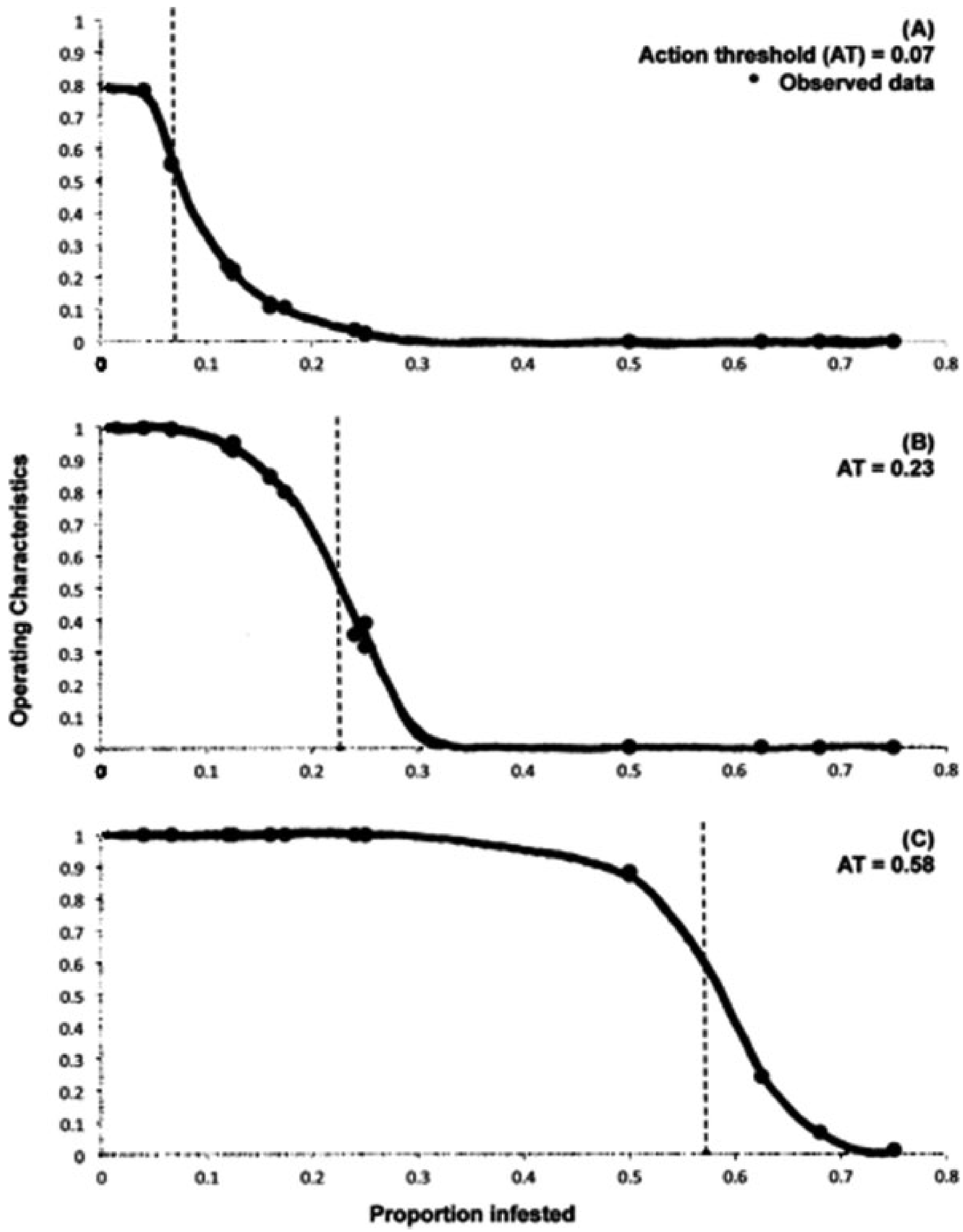

Figure 3. Operating characteristic curves for the binomial sequential sampling plans for the potato psyllid on potatoes based on the action thresholds of (A) 0.07, (B) 0.23 and (C) 0.58 proportion infested with at least one potato psyllid.

of the OC curves, the sampling plans using the action thresholds of 0.07 and 0.23 had steeper slopes around the OC value of 0.5 and may represent better, more reliable plans than the plan proposed for the 0.58 action threshold.

4 DISCUSSION

For the development of a sampling plan, choosing an appropriate sample unit is important.[8] In this study, the most efficient sampling unit for the potato psyllid in potatoes involved examining the edges of the fields and sampling the underside of leaves in the middle or top of the plant. Previous studies have noted that potato psyllids can be captured more frequently on the edges of fields and the preference of potato psyllids for the lower surfaces of leaves.[1,28] However, the data presented here are the first to document the within-plant distribution of the potato psyllid. Additionally, the dispersion indices generally agree that the potato psyllid has an aggregated distribution in potatoes. Dispersion data allow a better understanding of the relationship between an insect and its environment and provide basic knowledge for interpreting spatial dynamics and designing efficient sampling programs.[29,30] Other psyllid species such as *Diaphorina citri* Kuwayama and *Trioza erytreae* (Del Guercio) also exhibit aggregated spatial patterns.[30,31] Collectively, the present data can aid in the pest management of the potato psyllid by maximizing efficiency and thereby reducing the costs of sampling.

The motivation for the development of binomial sampling plans has arisen from the need quickly to estimate or classify a pest's population density.[21] While binomial sampling is usually less precise than complete enumerative sampling, the binomial approach can be completed with minimal cost and time.[21,26] In this study, binomial sequential sampling plans for the potato psyllid were developed at three action thresholds representing 0.5, 1 and 5 potato psyllids per plant. There is a critical research need to determine the economic threshold of the potato for the potato psyllid, as this will impact upon the action threshold and the subsequent decision as to whether to spray an insecticide or not. Also critical is an assay rapidly to determine the level of infection of potato psyllid populations for *Ca.* L. psyllaurous. As stated earlier, Munyaneza[22] noted that as few as one infective psyllid per potato plant can infect a potato plant with the ZC pathogen. Levels of infection in potato psyllid populations, combined with an economic threshold, can help determine whether populations of the potato psyllid warrant control or not. These sampling plans are the first for the potato psyllid and should contribute to the continued development of an integrated pest management program for this pest.

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