NUMERICAL AND BINOMIAL SEQUENTIAL SAMPLING PLANS FOR ADULT *BEMISIA TABACI* IN COTTON

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Abstract

Fixed-precision numerical and binomial sequential sampling plans are reported for adults of Bemisia tabaci *(Strain B) on cotton. Both plans are based on whole leaf sample units from the fifth mainstem node (counted from the terminal). Numerical sampling plans allow for the efficient estimation of adult population density. Numerical sampling stop lines are presented relating the cumulative number of adults counted to the number of leaves examined for two levels of statistical precision. Binomial plans were developed to allow classification of adult population density for pest management decision-making application. These plans were devised for three action threshold levels; 5, 10 or 15 adults per leaf. Binomial sampling stop lines are presented relating the cumulative number of infested leaves to the number of leaves examined as an aid for determining the need for population suppression.*

Introduction

The sweetpotato whitefly, *Bemisia tabaci* (Gennadius) Strain B, continues to be a devastating pest of cotton in Arizona and southern California. A critical component in the formulation of effective integrated pest management strategies is the development of efficient sampling methods for assessing population densities. Factors such as small size, highly aggregated distributions, and high reproductive capacity contribute to the difficulty of developing sampling plans for *B. tabaci*. We recently developed and tested fixed-precision, sequential sampling plans for immature *B. tabaci* based on counts from fifth mainstem node leaf disks (Naranjo and Flint 1994). Here we focus on developing efficient sampling plans for adult *B. tabaci*.

Several methods have been developed and used for sampling the non-sedentary adult stage of *B. tabaci* (Butler et al. 1986, Ekbom and Rumei 1990). Based on comparative study we concluded that counts of adults on leaves (leaf turn counts) was the most cost-efficient method for estimating adult population densities over most of the cotton-growing season (unpublished data). Here we develop and present two sampling plans for adults. Numerical sequential sampling plans were developed for the efficient estimtation of adult population density with fixed levels of statistical precision. We also develop and present binomial sampling methods that attempt to estimate mean population density from the proportion of sample units (leaves) infested by at least a predetermined number (tally threshold) of adults. This approach has been successfully applied to a number of arthropod pests (Binns and Nyrop 1992) and can greatly reduce the effort needed to classify population densities for making decisions regarding pest control. One of the major advantages of using a presence-absence approach is that sampling for adults on leaves would not need to be restricted to the early morning when adult activity is minimal.

Material and Methods

Sampling data were collected weekly to bi-weekly from 8 June through 30 September 1993 from upland and Pima cotton fields at the University of Arizona, Maricopa Agricultural Center, and Phoenix, Arizona. All counts were completed before 10:00 AM. A total of 64 field/date observations based on a minimum of 90 leaves each were available for developing numerical and binomial count models. Based on within-plant distributions (Naranjo et al. 1994) we used counts from the fifth leaf for sample plan development. For numerical sampling we used Taylor's power law (Taylor 1961) to describe the mean-variance relationship and Green's (1970) algorithm to calculate sequential sampling stop lines. For binomial sampling we used the empirical model of Nachman (1984), $\ln(m) = a + b\ln(-\ln(1-P_T))$, where m is mean density per leaf, P_T is the proportion of leaves with at least T adults, and a and b are regression coefficients. This model was fitted to our data for values of T = 1 and 3. A tally threshold of 3 was found to have the best operating characteristics and require the fewest samples to make a decision (Naranjo et al. 1994). Plans based on a tally threshold of 1 (presence-absence) were also devised because this is the most common application of the binomial model and is the easiest approach to implement. Wald's (1947) method was then used to develop sequential sampling stop lines based on action threshold densities of 5, 10 or 15 adults per leaf. In each case upper and lower bounds were set at $\pm$ 2 and α and β errors were set at 0.10. These action threshold levels bracket those reported by Ellsworth and Meade (1994).

Results and Discussion

Numerical Sequential Plans. Taylor's power law ($r^2 = 0.97$) appeared to be an adequate descriptor of the relationship between the mean and variance of adult counts on 5th mainstem node leaves. Critical cumulative counts, or stop lines, are presented in Table 1 for precision (SEM/mean) values of 0.1 and 0.25. The number of leaves that need to be examined drops considerably as the density of adult *B. tabaci* increases. For instance, at densities of 1 and 10 adults per leaf 50 and 15 leaves would need to be sampled, respectively, to achieve a precision of 0.25. At densities over 25 adults per leaf 10 or fewer samples would be needed. If a higher level of precision is desired many more samples would be required. For example, 320 leaves would need to be examined at a density of 1 adult per leaf and 45 samples would be needed at a density of 50 adults per leaf.

Binomial Sequential Plans. The fits of the empirical model relating the mean density of adults per leaf to the proportion of infested leaves, P_T, yielded high coefficients of determination for tally thresholds of 1 and 3 adults per leaf ($r^2 = 0.96$ for both). Regardless of the tally threshold used, binomial models, in general, have limits in terms of the densities that can be predicted from proportional infestation. For instance, using a tally threshold (T) of 1, 95% of the leaves would have at least 1 adult whitefly when the average density is 8 adults per leaf. In contrast, with T=3, 95% infestation is associated with an average density of 16 adults per leaf. Thus, a binomial model with T=1 cannot be used to develop sequential stop lines for an action threshold of 15 adults per leaf and it is of limited value for an action threshold of 10 adults per leaf. The selection of T is determined partly by the desired action threshold, but also by considerations of bias in the estimation of mean density and decision error rates associated with the sequential plan (Binns and Bostanian 1990, Nyrop and Binns 1991). Both of these factors played a role in our selection of T=3 (Naranjo et al. 1994).

Binomial sequential stop lines were tabulated for tally thresholds of 1 and 3 and action thresholds of 5, 10 and 15 adults per leaf (Tables 2-4). Operationally, a minimum of 10 leaves should be examined. Additional leaves are examined until the cumulative number of infested leaves is either below or above the no action or action stop lines, respectively. For an action threshold of 10 using T=1, a minimum of 50 leaves would need to be examined to determine the necessity for action. This arises because of the saturation effect of the binomial model discussed above and because binomial variance is comparatively greater at infestation levels < or > 0.5. Also, because of saturation stop lines for an action threshold of 15 adults per leaf cannot be determined for a binomial model with T=1 (Table 4).

At present our numerical and binomial sequential plans should be considered tentative guidelines. Further work is needed to validate these plans against independent field data and to more accurately determine the economic threshold value at which management action should be initiated. Finally, it should be noted that adults may not be the best stage to monitor for management purposes. We are currently developing binomial sampling models for eggs and nymphs based on leaf disk counts.

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Table 1. Numerical sequential sampling stop lines for estimating population density of adult *B. tabaci* for two levels of precision (SEM/mean). The sample unit is a whole 5th mainstem node leaf (terminal = node 1).

Number of Leaves Examined	Cumulative Number of Adults Counted	
	Precision = 0.25	Precision = 0.10
5	534	21289
10	265	10564
15	176	7011
20	132	5242
25	105	4183
30	87	3479
35	75	2977
40	65	2601
45	58	2309
50	52	2076
60	43	1726
70	37	1477
80	32	1291
90	29	1146
100	26	1030

Table 2. Sequential decision table for tally thresholds (T) of 1 and 3 based on an action threshold of 5 adults per leaf. The sample unit is a whole 5th mainstem node leaf (terminal = node 1).

Number of Leaves Examined	Cumulative Number of Leaves Infested			
	T=1		T=3	
	No Action	Action	No Action	Action
10	7	10	4	7
15	11	14	6	10
20	15	18	9	13
25	20	23	12	15
30	24	27	15	18
35	28	31	17	21
40	32	35	20	24
50	41	44	26	29
60	49	52	31	35
70	58	61	37	40
80	66	69	42	45
90	75	78	48	51
100	83	86	53	56

Table 3. Sequential decision table for tally thresholds (T) of 1 and 3 based on an action threshold of 10 adults per leaf. The sample unit is a whole 5th mainstem node leaf (terminal = node 1).

	Cumulative Number of Leaves Infested			
	T=1		T=3	
Number of Leaves Examined	No Action	Action[a]	No Action	Action[b]
10	8	-	6	-
15	12	-	10	15
20	17	-	14	19
25	22	-	18	23
30	27	-	22	27
35	32	-	26	31
40	37	-	30	35
50	46	50	38	43
60	56	60	47	52
70	66	70	55	60
80	75	79	63	68
90	85	89	71	76
100	94	99	79	84

[a] Minimum sample size of 50 leaves required.
[b] Minimum sample size of 15 leaves required.

Table 4. Sequential decision table for tally thresholds (T) of 3 based on an action threshold of 15 adults per leaf. The sample unit is a whole 5th mainstem node leaf (terminal = node 1).

	Cumulative Number of Leaves Infested[a]	
	T=3	
Number of Leaves Examined	No Action	Action[b]
10	7	-
15	11	-
20	16	-
25	20	-
30	25	
35	30	35
40	34	40
50	44	49
60	53	58
70	62	68
80	71	77
90	81	86
100	90	96

[a] T=1 not feasible
[b] Minimum sample size of 35 leaves required.