A PROPORTION METHOD FOR SAMPLING SPITTLEBUG POPULATIONS

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THE PROBLEM

Insect control is usually evaluated by comparisons of "treated" and "check" counts of (1) number of insects per unit or (2) proportion of infested units. Insects per unit is an actual measure of insect population while proportion of infested units may be more a measure of crop loss than it is of insect population. (*e.g.*, the presence of a single worm in a fruit renders the fruit as valueless as several worms in a fruit. In this example a measure of crop loss, proportion of infested, is more important than a measure of insect population.) There are many examples, however, where proportions of infested units are used as estimates of insect population. Both methods have been employed by research workers to estimate infestations of the meadow spittlebug, *Philaenus leucophthalmus* (L.). In one method a set number of stems are randomly selected and the number of nymphs on each stem is counted and recorded. The counts are then expressed as nymphs per stem. In the other method a set number of stems are randomly selected and the number having one or more spittlebugs present is recorded. The counts are expressed as a proportion or percentage of stems infested.

The nymphs per stem method, which is an actual population measure, has the disadvantage of being laborious since every stem must be examined carefully and each nymph discovered and counted. The proportion infested stems method is more rapid since as soon as one nymph is found the stem is recorded as infested. The disadvantage lies in the fact that the stem with many nymphs has no more weight in the final proportion value than does a stem with only one nymph. The method is therefore less precise in estimating actual insect population.

In spittlebug control the aim is to compare insect populations since the presence of a single nymph on a stem does not constitute complete loss of the crop. The question at hand is therefore, "How good an estimator of insect populations is the proportion of infested stems?" There should be some relationship between the two methods. If this relationship could be expressed mathematically, the counts obtained by one method could be converted into the values obtained by the other. It is this mathematical relationship that will be described in the present work.

METHODS

During the 1952–53 seasons sufficient data were collected to provide an empirical test of the relationship of the nymphs per stem (N/S) counts of proportion infested (PI). Records of nymphs on individual stems were kept so that the N/S counts also provided a PI count. In the various experimental trials that were conducted the treatments were usually replicated four times. The practice was to count nymphs on each of 25 stems in each plot of the experiment. Therefore the data used were in sets of 25 from which both a N/S and a PI count could be obtained. During the two seasons, 457 sets of 25 stems each of alfalfa and 247 of red clover were obtained. The counts from red clover were treated separately from those of alfalfa since it is conceivable that the characteristic counts might be different.

Among the sets obtained, there were PI counts that fell in every category from 1 infested in 25 counted to 25 infested in 25 counted. The PI value for each of these categories was therefore .04, .08, .12, . . . , 1.00. All of the N/S

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counts that corresponded to a particular PI category were combined and a mean N/S count determined. The first three columns of Tables 1 and 1A show the PI determination, the number of observed sets, and the corresponding mean N/S.

The corresponding N/S and PI counts can be plotted using PI values as the abscissas and the N/S values as the ordinates. A line fitted through these points should represent the relationship between the two variables. Since the proportions were evenly spaced the method of Orthogonal Polynomials, Anderson and Houseman (1942), could be used to fit the regression line. This method was utilized and the formula obtained for the predicted value of the mean N/S was

$m = 0.40p + 12.53p^2 - 32.63p^3 + 29.38p^4$ for red clover

$m = 1.09p + 3.95p^2 - 8.00p^3 + 10.39p^4$ for alfalfa

where p equals the proportion of stems infested.

The formula computed from the empirical data enables us to predict the N/S count from the PI count. Column 4 of Tables 1 and 1A shows the mean N/S predicted by the regression formula.

Bowen (1945) and Wadley (1954) discuss the limitations of using counts of the proportion of noninfested (or infested) plants to estimate insect populations. Bowen was able to use proportion noninfested to estimate mean leafhopper counts from mathematical theory because the counts conformed to the Poisson distribution. As both Bowen and Wadley point out the most severe limitation of

TABLE 1

Red Clover

IS/25	No. Sets	Obs. m	m	Obs. s	s
1	37	.04	.03	.23	.22
2	31	.09	.10	.34	.41
3	13	.16	.18	.49	.58
4	15	.23	.27	.61	.73
5	12	.40	.37	1.18	.86
6	7	.43	.46	.92	.98
7	7	.43	.56	.94	1.09
8	4	.75	.65	1.96	1.21
9	4	.80	.74	1.62	1.32
10	7	.85	.83	1.70	1.45
11	4	.99	.92	1.60	1.59
12	3	.91	1.08	1.21	1.74
13	9	1.33	1.15	2.11	1.92
14	6	1.16	1.31	0.59	2.14
15	5	1.38	1.51	1.89	2.38
16	7	1.86	1.76	2.30	2.65
17	6	2.30	2.09	3.15	3.00
18	4	2.26	2.50	2.54	3.33
19	10	3.34	3.02	3.59	3.74
20	11	3.71	3.66	4.64	4.24
21	11	4.43	4.46	4.02	4.73
22	8	5.17	5.43	5.19	5.43
23	12	6.58	6.60	5.58	6.02
24	11	7.27	8.01	6.14	6.83
25	3	10.41	9.67	7.30	7.64

IS/25 = Infested stems in 25 total
No. Sets = Number of observed sets
Obs. m = Observed mean number of nymphs per stem
m = Means number of nymphs per stem predicted by regression
Obs. s = Observed standard deviation of individual counts
s = Standard deviation of individual counts predicted by regression

the method comes about under high infestations where the variability becomes so large that the noninfested counts are poor estimators of the mean. In the present study the distribution of the counts needed to be determined and the variances over the entire range of proportions estimated.

The distributions of the N/S counts under any given proportion infested were fitted to the Poisson and the negative binomial. In general, the Poisson did not provide a good fit, while at most levels the negative binomial seemed satisfactory. Because of its complexity, estimation of the variance from theory using the negative binomial did not seem as feasible as the following empirical procedure which was used.

Column 3 of tables 1 and 1A contains the observed mean N/S for all of the counts under a particular PI. Using these same data, an estimate of variance was obtained from the counts under each PI. The observed standard deviation (square root of variance) is tabulated in column 5 of tables 1 and 1A. A regression line was fitted to these points using the method of Orthogonal Polynomials with the resulting formulas.

$s = 5.95p - 10.81p^2 + 12.50p^3$ for red clover

$s = 7.422p - 14.40p^2 + 14.75p^3$ for alfalfa

where p equals the proportion of stems infested.

TABLE 1A

Alfalfa

IS/25	No. Sets	Obs. m	m	Obs. s	s
1	44	.05	.05	.25	.26
2	26	.12	.11	.60	.51
3	26	.19	.18	.68	.61
4	18	.25	.25	.70	.88
5	24	.33	.33	.84	1.03
6	19	.37	.42	.80	1.16
7	18	.52	.50	1.14	1.27
8	12	.52	.60	.99	1.38
9	13	.66	.71	1.12	1.49
10	13	.92	.82	1.77	1.61
11	21	1.01	.95	1.75	1.73
12	17	1.02	1.10	1.58	1.87
13	13	1.25	1.27	1.73	2.03
14	19	1.62	1.47	2.28	2.23
15	17	1.50	1.70	1.91	2.46
16	9	2.16	1.96	3.06	2.71
17	25	2.50	2.28	3.22	3.06
18	21	2.66	2.64	2.74	3.36
19	16	3.17	3.07	3.66	3.76
20	22	3.49	3.56	4.00	4.27
21	18	3.66	4.13	3.59	4.75
22	17	4.50	4.80	4.89	5.50
23	12	5.99	5.56	6.67	6.07
24	9	6.09	6.43	5.59	6.93
25	8	7.76	7.42	7.50	7.77

IS/25 = Infested stems in 25 total
No. Sets = Number of observed sets
Obs. m = Observed mean number of nymphs per stem
m = Mean number of nymphs per stem predicted by regression
Obs. s = Observed standard deviation of individual counts
s = Standard deviation of individual counts predicted by regression

In addition to the predicted mean N/S there is now available a corresponding predicted standard deviation of the N/S. The values for this predicted standard deviation are tabulated in column 6 of tables 1 and 1A.

After the estimation of a mean N/S and the standard deviation, the next step is to compute the confidence limits of a mean determined from counts of twenty-five or some other logical number of stems. Since 25 and 100 stems have been used as units in the experimental work at the Ohio Agricultural Experiment Station the standard deviation of sample means of 25 and 100 was computed for each proportion of infested stems. The standard deviation of sample means (standard error) was computed by dividing standard deviation, predicted by the regression line, by the square root of the number of observations constituting the sample mean. These values are tabulated in columns 3 and 6 of tables 2 and 2A.

The standard error term was multiplied by 1.96 and the result subtracted from and added to the predicted mean. The lower value was taken as the lower limit of the mean and the upper value the upper limit of the mean at the 95 percent confidence level. The determination of the 95 percent confidence limits by this method depends upon the counts being normally distributed. The counts are not so distributed as has been shown. From the standpoint of practical procedure,

TABLE 2

Red Clover

			95% limits-25			95% limits-100	
p	m	$S\bar{x}_{25}$	lower	upper	$S\bar{x}_{100}$	lower	upper
.04	.03	.04	0	.11	.02	0	.07
.08	.10	.08	0	.26	.04	0	.18
.12	.18	.12	0	.42	.06	.06	.30
.16	.27	.14	0	.54	.07	.13	.41
.20	.37	.17	.04	.70	.09	.19	.55
.24	.46	.20	.07	.85	.10	.26	.66
.28	.56	.22	.13	.99	.11	.34	.78
.32	.65	.24	.18	1.12	.12	.41	.89
.36	.74	.26	.23	1.25	.13	.49	.99
.40	.83	.29	.26	1.40	.15	.54	1.12
.44	.92	.32	.29	1.55	.16	.61	1.23
.48	1.08	.35	.39	1.77	.17	.75	1.41
.52	1.15	.38	.44	1.89	.19	.76	1.52
.56	1.31	.43	.47	2.15	.21	.90	1.72
.60	1.51	.48	.57	2.45	.24	1.04	1.98
.64	1.76	.53	.72	2.80	.27	1.23	2.29
.68	2.09	.60	.91	3.27	.30	1.50	2.68
.72	2.50	.66	1.21	3.79	.33	1.85	3.15
.76	3.02	.75	1.55	4.49	.37	2.29	3.75
.80	3.66	.85	1.99	5.33	.42	2.93	4.39
.84	4.46	.91	2.68	6.24	.46	3.56	5.36
.88	5.43	1.09	3.29	7.57	.54	4.37	6.49
.92	6.60	1.20	4.25	8.95	.60	5.42	7.78
.96	8.01	1.37	5.66	10.36	.68	6.68	9.34
1.00	9.67	1.53	6.67	12.67	.76	8.18	11.16

p = Proportion infested stems
m = Predicted mean nymphs per stem
$S\bar{x}_{25}$ = Standard deviation of mean of 25 stems
95% limits-25 = 95% confidence limits of prediction of nymphs per stem by counts of 25 stems
$S\bar{x}_{100}$= =Standard deviation of mean of 100 stems
95% limits-100 = 95% confidence limits of prediction of nymphs per stem by counts of 100 stems

however, it did not seem worthwhile to try to estimate a negative binomial distribution for each proportion of infested stems and determine the 95 percent point of each individual distribution. In the absence of this latter group of determinations the $\pm 1.96 \cdot s_{\bar{x}}$ value was used. Columns 4, 5, 7, and 8 of tables 2 and 2A contain these limits. The following discussion will show that this approximation was apparently close enough for acceptable results.

TEST OF ACCURACY

The basic equations for the mean and the standard deviation were computed from data obtained in Ohio during the 1952–53 seasons. If the formulas were to be useful, they should apply universally. Data obtained during other seasons and in other locations were tested. In Ohio in 1954–55, 283 sets of 25 stems each of red clover and 166 sets of 25 alfalfa stems were evaluated for nymphs per stem and proportion of infested stems. The actual number of nymphs per stem was compared with the number predicted by the regression formula. Two hundred and sixty-five of the nymphs per stem values for red clover and 165 of the values for alfalfa fell between the limits of the predicted mean plus or minus 1.96 standard

TABLE 2A

Alfalfa

p	m	$S\bar{x}_{25}$	95% limits-25 lower	95% limits-25 upper	$S\bar{x}_{100}$	95% limits-100 lower	95% limits-100 upper
.04	.05	.05	0	.15	.03	0	.11
.08	.11	.10	0	.31	.05	.01	.21
.12	.18	.12	0	.42	.06	.06	.30
.16	.25	.18	0	.60	.09	.07	.43
.20	.33	.21	0	.74	.10	.13	.53
.24	.42	.23	0	.87	.12	.18	.66
.28	.50	.25	.01	.99	.13	.25	.75
.32	.60	.28	.05	1.15	.14	.33	.87
.36	.71	.30	.12	1.30	.15	.42	1.00
.40	.82	.32	.19	1.45	.16	.51	1.13
.44	.95	.35	.26	1.64	.17	.62	1.28
.48	1.10	.37	.37	1.83	.19	.73	1.47
.52	1.27	.41	.47	2.07	.20	.88	1.66
.56	1.47	.45	.59	2.35	.22	1.04	1.90
.60	1.70	.49	.74	2.66	.25	1.21	2.19
.64	1.96	.54	.90	3.02	.27	1.43	2.49
.68	2.28	.61	1.08	3.48	.31	1.67	2.89
.72	2.64	.67	1.33	3.95	.34	1.97	3.31
.76	3.07	.75	1.60	4.54	.38	2.33	3.81
.80	3.56	.85	1.89	5.23	.43	2.72	4.40
.84	4.13	.95	2.27	5.99	.48	3.19	5.07
.88	4.80	1.10	2.64	6.96	.55	3.72	5.88
.92	5.56	1.21	3.19	7.93	.61	4.36	6.76
.96	6.43	1.39	3.71	9.15	.69	5.08	7.78
1.00	7.42	1.55	4.38	10.46	.78	5.89	8.95

p = Proportion infested stems
m = Predicted mean nymphs per stem
$S\bar{x}_{25}$ = Standard deviation of mean of 25 stems
95% limits-25 = 95% confidence limits of prediction of nymphs per stem by counts of 25 stems
$S\bar{x}_{100}$ = Standard deviation of mean of 100 stems
95% limits-100 = 95% confidence limits of prediction of nymphs per stem by counts of 100 stems

errors. Therefore, 95.32 percent of the 449 samples fell within the computed 95 percent confidence limits.

Mr. Clarence White of the Illinois Natural History Survey provided the authors with data from 43 sets of 100 alfalfa and red clover stems taken in Illinois in 1952–53. Thirty-nine (90.7%) of the nymphs per stem values fell within the limits of the predicted mean plus or minus 1.96 standard errors.

Apparently data gathered at different locations and in different seasons fit the predicted means and standard deviations computed by the described method.

USE

The immediate practical use of this study to anyone interested in evaluating spittlebug populations is obviously that of estimating nymphs per stem from a proportion of infested stems count. After the proportion of infested stems is determined, the regression formula may be solved for an estimate of the mean nymphs per stem. This has been done and tabulated for proportions which are divisible by .04. Tables 2 and 2A may be entered under column 1 (proportion of infested stems) and the predicted number of nymphs per stem found from column 2. If the proportion infested in a total of 25 or 100 is obtained, the upper and lower limits of the mean may be obtained from columns 4 and 5 or 7 and 8.

Tables 3 and 3A tabulate the differences that can be discovered using 25 and 100 stem samples. These differences are computed on the basis of the estimated

TABLE 3

Red Clover

	At 95% confidence level a 25 stem sample is		At 95% confidence level a 100 stem sample is	
p	greater than	less than	greater than	less than
.04	—	.28	—	.16
.08	—	≤ .40	—	.20
.12	—	.52	—	.28
.16	—	.60	.04	≤ .32
.20	—	.64	.08	.44
.24	—	.68	.08	.48
.28	.04	.72	.12	.56
.32	.04	.72	≥ .16	.56
.36	.04	.76	.16	.60
.40	≥ .08	.76	.16	.64
.44	.08	≤ .76	.20	≤ .64
.48	.08	.80	.24	.64
.52	.12	.80	.24	.72
.56	.12	.84	.32	.72
.60	.16	.84	.36	.76
.64	.20	.88	≥ .44	≤ .76
.68	.24	.88	.48	.80
.72	.32	.92	.56	.84
.76	≥ .44	.96	≥ .64	.88
.80	.52	.96	.68	.92
.84	.60	1.00	.72	.92
.88	.68	—	.76	.96
.92	.72	—	.84	1.00
.96	.80	—	.88	—
1.00	.84	—	.92	—

p = Proportion infested stems

nymphs per stem rather than on the variance of the proportion of infested stems. An example of the use of the tables follows.

Suppose that 100 red clover stems are examined and 56 are found to be infested with one or more nymphs. The proportion of infested stems is then 0.56. Enter table 2 in column 1 at 0.56. Read the predicted nymphs per stem in column 2, 1.31. One point three one nymphs is therefore the best prediction of the nymphs per stem in the plot from which the stems were taken. From Table 2, column 6, find the standard error, 0.21. The 95 percent confidence limits may be found in columns 7 and 8, 0.90 to 1.72. From this 100 stem sample we may conclude that the true mean lies somewhere between 0.90 and 1.72. Looking at table 3, column 1, opposite 0.56 we find in columns 4 and 5 the values 0.32 and 0.72. These figures represent the proportions of infested stems which are different from our sample of 0.56. Therefore, if another field or another treatment has a true proportion of infested stems of less than 0.32 or more than 0.72, we could conclude that the population in the sample field was different.

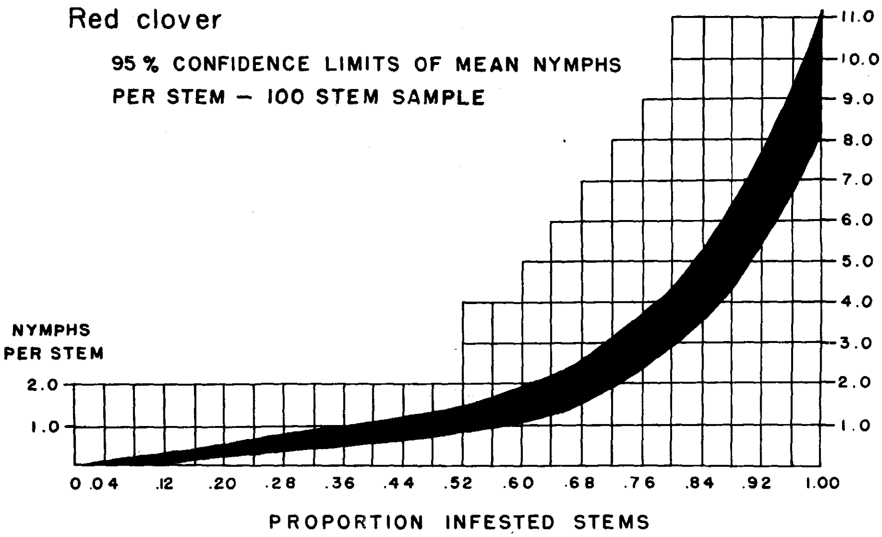
For graphic estimates of the nymphs per stem from counts of the proportion infested, figures 1 and 1A have been prepared. Enter the graph along the bottom at the appropriate proportion. Follow upward to the point of interception of the black area. Follow across to the scale at the side to find the lower limit of the mean nymphs per stem of a 100 stem sample. The point of interception of the top of the black area indicates the upper limit of the mean of a 100 stem sample.

TABLE 3A

Alfalfa

	At 95% confidence level a 25 stem sample is		At 95% confidence level a 100 stem sample is	
p	greater than	less than	greater than	less than
.04	——	.40	——	.20
.08	——	.48	——	.28
.12	——	.52	——	.32
.16	——	≤ .60	——	.40
.20	——	.60	.04	.44
.24	——	.64	.04	.48
.28	——	.68	.08	.52
.32	——	.72	.12	.52
.36	——	.72	.12	.56
.40	.04	.76	.16	.60
.44	.04	.80	.20	.64
.48	.08	.80	.24	.68
.52	.12	.84	.32	.68
.56	.12	.88	.36	.72
.60	≥ .20	.92	.40	.76
.64	.24	.92	.44	.80
.68	.28	.96	.52	.84
.72	.36	1.00	.56	.88
.76	.40	——	.60	.92
.80	.48	——	.64	.96
.84	.52	——	.68	.96
.88	.56	——	.72	1.00
.92	.64	——	.76	——
.96	.68	——	.84	——
1.00	.72	——	.88	——

p = Proportion infested stems



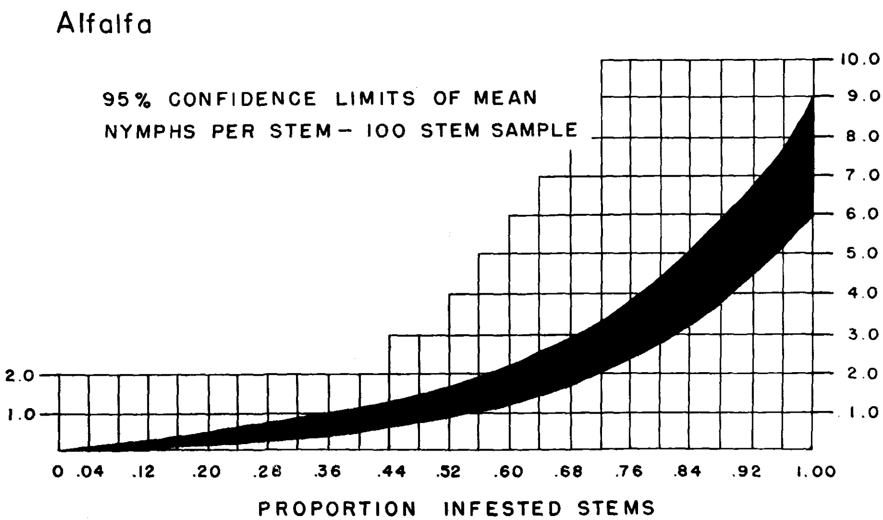


FIGURE 1 (above) and FIGURE 1A (below)

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