# Seasonal Abundance and Mathematical Distribution of Wireworms and Wireworm Feeding Damage in Sweet Potato[1]

Dakshina R. Seal, Richard B. Chalfant[2], and R. McSorley[3]

Tropical Research and Education Center
University of Florida, 18905 S. W. 280 St.
Homestead, FL 33031 USA

J. Entomol. Sci. 32(3): 311-320 (July 1997)

**ABSTRACT** Seasonal abundance and spatial distribution of wireworm feeding damage were determined for sweet potato by examining storage roots. Spatial distribution of wireworms was determined by sampling corn-wheat seed baits. Wireworm feeding damage (deep, shallow and healed holes) increased as the season progressed. The distribution of wireworms in sweet potato fields was clumped as was feeding damage distribution. The spatial distribution of wireworm damage on sweet potato roots fits the negative binomial distribution. Values for the negative binomial parameter $k$ for two fields indicated a clustered distribution of wireworm feeding damage. Greater $k$-values for healed feeding damage and total feeding damage than for deep and shallow feeding damage indicate that sample size could be adjusted, depending on seasons, to achieve optimal sampling efficiency. As feeding damage can predict wireworm populations, a sampling strategy based on early-season wireworm damage data is particularly timely, efficient and economical for evaluating wireworm damage data.

**KEY WORDS** Sweet potato, wireworms, feeding damage, damage distribution, sampling

Wireworms are major pests of sweet potato, *Ipomoea batatas* (L.) Lam., in the southeastern United States (Chalfant and Seal 1991, Schalk et al. 1986). Loss to the sweet potato industry due to wireworms in Georgia is serious, amounting to as much as $1.6 million on 2400 ha (Douce and McPherson 1988). The species *Conoderus scissus* Schaeffer, *C. rudis* Brown and *C. amplicollis* (Gyllenhal) are the principal pests in Georgia sweet potato fields (Seal 1990).

[1] Received 29 June 1995; Accepted for publication 14 April 1997.
[2] University of Georgia, Coastal Plain Experimental Station, Tifton, GA 31793.
[3] University of Florida, IFAS, Entomology and Nematology Department, Gainesville, FL 32611-0620.

Accurate and efficient sampling is crucial to successful pest management (Borth and Harrison 1984) and cannot be developed until the dispersion patterns of the insects involved are known (Boiteau et al. 1979). Sampling insects in soil is slow and may damage the crop; hence, little information is available on the biology of the wireworm species infesting sweet potato.

Consequently, it is difficult to develop precise control strategies against wireworms (Chalfant et al. 1987). Additionally, sampling wireworms is very difficult because wireworms usually leave the feeding site once they have fed (Seal and Chalfant, unpubl. data). Furthermore, the common wireworm species in Georgia and Florida may not respond well to baiting during certain environmental conditions (Seal and Jansson, unpubl. data).

In addition to difficulties involved in sampling wireworms themselves, their damage is often erratically distributed and difficult to predict (Seal 1990). Accurate sampling of damage can be of critical importance in loss assessment studies, yet little information exists on distribution of damage by wireworms or other pests. We hypothesize that, since wireworms show aggregated spatial distribution in the field (Seal et al. 1992), their damage should also show an aggregated spatial pattern. Therefore, our objectives were to determine seasonal abundance of wireworm damage of different types in sweet potato, and to compare spatial distribution of wireworms and wireworm damage for *C. scissus* and *C. amplicollis* at the Gopher Ridge Farm field and the Ponder Farm field, respectively, in southern Georgia.

## Materials and Methods

**Seasonal abundance of wireworm feeding damage.** The field, a 0.2-ha site of Tifton loamy sand, was planted to 'Jewel' sweet potato from vine cuttings on 29 July 1986. Plant spacing was 46 cm in the row and 1.3 m between rows. The field was divided into 16 equal plots (3 rows by 30.5 m). Samples were collected on 21 August, 16 September, 7 October, 18 October, and 10 November. At each sampling, storage roots of two randomly selected plants per plot were examined for wireworm feeding damage which was characterized as shallow (<1mm deep), deep (>1 mm), or healed (old scars).

Data were transformed (square root [x + 0.25]) (Steel and Torrie 1980) to normalize the variance before use of analysis of variance (ANOVA, Neter and Wasserman 1974). Means among damage types were separated using the Ryan-Einot-Gabriel-Welsch multiple-range F-test (PROC GLM, option REGWF, SAS Institute 1985). The relationship between wireworm feeding damage and time was determined by linear regression analysis (Neter and Wasserman 1974).

**Spatial distribution of wireworms.** The study was conducted in two fields (16 by 120 m) near Tifton, GA, at the Ponder Farm (Tifton loam sand) and the Gopher Ridge Farm (Bonifay soil type) both planted in early July to the sweet potato cultivars 'Jewel' and 'Red Jewel', respectively. *Conoderus amplicollis* was the predominant wireworm in the Ponder Farm, whereas *C. scissus* was the predominant species in the Gopher Ridge field (Seal 1990). Plant, row spacing, and plot size were as described above. Spatial distribution of wireworms was studied by randomly placing five corn-wheat seed baits (1:1 by volume) (Seal 1990) in each of 16 plots (3 rows × 30.5 m) 2 wk before harvest. Baits were placed in a hole (10 cm wide, 10 cm deep) and were covered with soil. On emergence of bait plants (14 d after placement), baits were dug with adjacent soil (10 cm wide, 20 cm deep). Each sample was then checked visually to separate wireworms.

Distribution of wireworms was determined for the whole areas (i. e., across 16 equal plots) of two fields located in the Ponder Farm and the Gopher Ridge Farm. In order to obtain an idea of wireworm distribution in smaller areas, spatial distributions were determined for combinations of individual plots to make a series of smaller units. Distribution of wireworms was determined separately for 0.012, 0.025, 0.050, and 0.100 ha areas corresponding to 2, 4, 8, and 16 plots, respectively. In this way the effect of sampling areas of different sizes can be determined. The mean number of wireworms and the associated variance for each area were calculated. The data were fit to Taylor's power law (Taylor 1961) and Iwao's patchiness regression (Iwao 1968). For both methods, a higher degree of aggregation is exhibited by the population as the slope value increases.

**Spatial distribution of wireworm damage.** This study was also conducted in the two fields described above. Plant, row spacing and plot designs were identical to those in the seasonal abundance study. Like the wireworm distribution study, the distribution of wireworm feeding damage was also determined for the whole and smaller areas of a field as discussed in the wireworm distribution study. Distribution of wireworm feeding damage was determined by randomly collecting 25 roots, one root/plant, from each plot at harvest. The roots were cleaned in water, and the number and depth of damage holes from wireworm feeding were recorded. Feeding damage was characterized as shallow, deep, or healed.

To determine the damage distribution, the total number of wireworm feeding damage occurrences of each category on sweet potatoes for all plots of each field was entered into the program of Gates and Ethridge (1972). The program fits six frequency distributions (Poisson, negative binomial, Thomas double poisson, Neyman's type A, Poisson with zeroes, logarithmic with zeroes) to the observed data and tests each fit by the Chi-square method. Furthermore, spatial distribution of total (shallow+deep+healed) wireworm feeding damage for four plot sizes (0.012, 0.025, 0.050, and 0.100 ha) was determined from Taylor's power law and Iwao's patchiness regression.

The index of dispersion (ID) or mean/variance ratio is another measure of dispersion. This is tested by calculating the index:

$$ID = \frac{s^2\,(n-1)}{x}$$

Where n = the number of samples, $s^2$ = sample variance, and x = sample mean. ID is distributed as a chi-square variable with n-1 degree of freedom (Elliott 1977). The value of ID will approach zero for the regularly distributed wireworms or wireworm feeding damages, while a value of ID > 1 implies an aggregated distribution of sample counts.

## Results and Discussion

**Seasonal abundance of wireworm feeding damage.** Significantly more deep feeding damage than shallow or healed damage occurred on sweet potato roots at each sampling. The feeding damage of each type increased through the season (Table 1).

**Spatial distribution of wireworms.** Wireworm populations were much lower at Gopher Ridge compared with the Ponder Farm. Taylor's power law and Iwao's patchiness regression consistently provided a good fit to wireworm data collected from both fields (Table 2). The $b$ values for all plots, except in few instances, were significantly higher than 1.0 ($P < 0.05$) indicating an aggregated distribution of wireworm at both Ponder Farm and Gopher Ridge. Similar patterns of wireworm distribution were reported by Seal et al. (1992).

**Spatial distribution of wireworm feeding damage.** The observed healed damage at both fields differed significantly from the expected for three discrete mathematical distributions (Poisson, Poisson with zeros, Thomas double Poisson) at both the Gopher Ridge and Ponder Farm fields (Table 3). In both fields, healed damage counts were fit by at least two discrete frequency distributions (negative binomial, Neyman's type A and logarithmic with zeros for Gopher Ridge, and negative binomial and Neyman's type A for Ponder Farm). Chi-square values for deep damage holes were the lowest for the negative binomial distribution and Neyman type A in the Gopher Ridge and Ponder Farm, respectively. Shallow damage counts were fit by the negative binomial distribution at the Gopher Ridge site, and Neyman's type A and Thomas double poisson at the Ponder Farm field. In each field, the goodness-of-fit tests on the observed numbers of total wireworm feeding damage holes (healed + deep + shallow) indicated significant differences in four of the six distributions. Overall, in rating the quality of fit of each expected distribution on the basis of Chi-square statistics, the negative binomial distribution clearly provided the best fit to the counts of all damage types (healed, deep, shallow, and total) at the Gopher Ridge Farm. However, for the Ponder Farm, Neyman's type A fitted most closely the healed damage followed by negative binomial distribution. For other feeding damage types, either negative binomial or Neyman's type A or both fitted closely at both fields. Although these are both generalized distributions (Pielou 1969), both contiguous, and both theoretically related, they are intended to describe different situations. Neyman's type A distribution is intended to describe the spatial distribution found soon after insect larvae hatch from egg masses (Southwood 1975). In view of the biology of wireworm where eggs are laid in clusters in soil and larvae disperse before they reach storage roots, Neyman's type A is probably not the better choice of the two distributions (Borth and Harrison 1984). The negative binomial is more appropriate and has an easily computed measure of aggregation, the parameter $k$ (Waters 1959).

The small $k$ values, particularly at Gopher Ridge indicated a high degree of aggregation (Table 4). Pielou (1969) has shown that $k$ changes when a population decreases in size due to nonrandom deaths (migration). At Gopher Ridge, closely-related $k$ values for the different types of feeding damage suggest that all damage resulted from the same population of wireworms with little change in population distribution. However, a comparatively lower $k$ value for the deep damage type compared with healed damage suggests some change of wireworms damage in the Ponder Farm field. The deep and shallow damage holes were recent implying that they were made prior to downward movement of wireworms for overwintering; whereas healed damage holes were made early in the growing season.

**Table 1. Seasonal abundance of wireworm feeding damages on sweet potato storage roots at Tifton, Ga. in 1986.**

| | Mean ± SD* number of | | | |
|---|---|---|---|---|
| Month | Shallow | Deep | Healed | Total damage |
| August | 0.22 ± 0.04 b | 0.50 ± 0.06 a | 0.09 ± 0.03 b | 0.81 ± 0.05 |
| September | 0.41 ± 0.06 b | 1.03 ± 0.08 a | 0.28 ± 0.05 b | 1.72 ± 0.11 |
| October | 0.44 ± 0.07 b | 1.59 ± 0.09 a | 0.31 ± 0.05 b | 2.34 ± 0.13 |
| November | 1.47 ± 0.09 b | 2.53 ± 0.10 a | 0.59 ± 0.06 b | 4.59 ± 0.16 |

Relationship Between Feeding Damage and Month

| Damages | n | $r^2$ | Regression** | P |
|---|---|---|---|---|
| Shallow | 160 | 0.27 | y = -0.31 + 0.38x | 0.0001 |
| Deep | 160 | 0.45 | y = -0.25 + 0.67x | 0.0001 |
| Healed | 160 | 0.13 | y = -0.06 + 0.15x | 0.0001 |
| Total | 160 | 0.54 | y = -0.63 + 1.19x | 0.0001 |

*Means for feeding damages within rows followed by the same letter are not different ($P < 0.05$), Ryan-Einot-Gabriel-Welsh multiple F-test, SAS Institute 1985).
**y = number of feeding damage; x = date (Aug. = 1, Sept. = 2, Oct. = 3, Nov. = 4).

The index of dispersion, $s^2/x$, is another parameter useful for determining spatial distribution (Borth and Harrison 1984). If, in a set of counts of number of individuals per sample area, this index is greater than unity (>1), then the dispersion is not random. In each of the experiments, the relative variance (RV) was greater than unity for all damage types (Table 4), indicating aggregated distribution of damage throughout the fields.

Taylor's power law and Iwao's regression indicated an aggregated distribution of feeding damage in all plots in the Gopher Ridge field except for Taylor's power law in the 0.050 ha plot (Table 5). Both methods indicated aggregated, random, and regular distribution of wireworm feeding damages in 0.012, 0.025, and 0.100 ha plots at the Ponder Farm field, respectively. The difference in distribution of feeding damage at the two locations may be due to the different wireworm species present as discussed above.

In summary, wireworm distribution at both the Ponder Farm and Gopher Ridge fields was aggregated except in a few instances and without regard to plot size. Both Taylor's power law and Iwao's patchiness regression consistently described wireworms distribution. Wireworm feeding damage was also aggregated at both

**Table 2. Wireworm distribution for different plot areas at the Gopher Ridge and Ponder Farms sweet potato fields near Tifton, GA in 1986.**

| Plot size (ha) | n* | Taylor's power law | | | Iwao's patchiness regression | | |
|---|---|---|---|---|---|---|---|
| | | $r^2$ | a | b | $r^2$ | a | b |
| | | | | Gopher Ridge Farm | | | |
| 0.100 | 2 | 0.99 | 2.04 | 1.70 Agg** | 0.99 | -0.35 | 2.40 Agg |
| 0.050 | 4 | 0.98 | 2.09 | 1.64 Agg | 0.98 | -0.23 | 2.33 Agg |
| 0.025 | 8 | 0.88 | 2.19 | 1.50 Agg | 0.84 | 0.10 | 2.09 Agg |
| 0.012 | 16 | 0.84 | 0.35 | 1.42 Ran | 0.80 | 0.22 | 2.01 Agg |
| | | | | Ponder Farm | | | |
| 0.100 | 2 | 0.98 | 1.62 | 2.04 Agg | 0.99 | -1.06 | 2.70 Agg |
| 0.050 | 4 | 0.94 | 1.62 | 1.74 Ran | 0.95 | -0.90 | 2.51 Agg |
| 0.025 | 8 | 0.82 | 1.60 | 1.63 Agg | 0.82 | 0 69 | 2.41 Agg |
| 0.012 | 16 | 0.78 | 1.55 | 1.58 Agg | 0.72 | 0.62 | 2.27 Agg |

*n = numbers of plots
**Agg = aggregated distribution, *b* significantly > 1 ($P < 0.05$); Ran = random distribution, *b* not significantly > 1 ($P > 0.05$)

fields. The negative binomial gave the best fit to wireworm feeding damage data. Both Taylor's power law and Iwao's patchiness regression indicated aggregation of wireworm damage in most plots at the Gopher Ridge Farm field. Although these two statistics agreed in describing feeding damage distribution at the Ponder Farm plots, damage distribution in most plots was different from wireworm distribution except for shallow holes. It is clear that wireworm damage shows aggregated spatial distribution much like that of the wireworms themselves. Although it would be more appropriate to conduct this study in more than two fields, time and resources did not allow this opportunity. Nevertheless, we consider it worthwhile to present at least these data on wireworms themselves and their damage distribution. However, further studies in additional sites are needed to confirm distribution patterns and to develop optimal sampling plans. This information is useful for timely application of biorational chemicals and pathogens to reduce wireworm damage on sweet potatoes.

**Table 3. Chi-square goodness-of-fit statistics for six discrete frequency distributions fited to data on wireworm feeding damage at two sweet potato fields in Georgia in 1986.**

| Discrete frequency distribution | Chi-square statistics | | | |
|---|---|---|---|---|
| | Shallow | Deep | Healed | Total |
| | Gopher Ridge Field | | | |
| Poisson | 725.05* | 151.47* | 29.48* | 738.09* |
| Poisson with zeros | 160.27* | 18.48* | 8.03* | 327.70* |
| Negative binomial | 15.80 ns | 7.83 ns | 3.69 ns | 19.63 ns† |
| Thomas double poisson | uf** | 88.87* | 15.79* | uf |
| Neyman type A | 77.04* | 10.51* | 5.91 ns | 85.20* |
| Logarithmic with zeros | uf | 8.57 ns | 3.78 ns | uf |
| | Ponder Field | | | |
| Poisson | 855.30* | 683.15* | 195.00* | 800.80* |
| Poisson with zeros | 92.47* | 31.44* | 38.27* | 812.30* |
| Negative binomial | 40.96* | 18.33* | 10.27 ns | 46.19* |
| Thomas double poisson | 16.08 ns | 32.61* | 15.79* | uf |
| Neyman type A | 9.08 ns | 11.43 ns | 8.94 ns | 93.37* |
| Logarithmic with zeros | uf | 30.10* | 37.24* | uf |

*data differ from fitted distribution ($P < 0.05$),
**uf = unable to fit.
† ns = data do not differ from fitted distribution.

**Table 4. Negative binomial distribution fit to data on wireworm feeding damage at two sweet potato fields in Georgia in 1986.**

| Damage Type<br>Shallow | n* | ID | P | k | ID | P | k |
|---|---|---|---|---|---|---|---|
| | | Gopher Ridge Field | | | Ponder Field | | |
| Deep | 400 | 7.01 | 0.60 | 0.15 | 3.35 | 0.01 | 0.80 |
| Healed | 400 | 3.70 | 0.44 | 0.13 | 3.11 | 0.02 | 0.33 |
| Total | 400 | 2.08 | 0.29 | 0.24 | 2.20 | 0.21 | 1.14 |
| | 400 | 5.84 | 0.41 | 0.34 | 3.52 | 0.01 | 2.29 |

*n = number of observations, ID = variance : mean, p = probability of chi-squared goodness of fit, k = measure of aggregation.

**Table 5. Distribution of wireworm feeding damage (shallow+deep+healed) on sweet potato storage roots in plots at the Gopher Ridge and Ponder Farm sweet potato fields near Tifton, GA in 1986.**

| Plot size (ha) | n* | Taylor's power law | | | Iwao's patchiness regression | | |
|---|---|---|---|---|---|---|---|
| | | $r^2$ | a | b | $r^2$ | a | b |
| | | | Gopher Ridge Farm | | | | |
| 0.100 | 2 | 0.99 | 4.07 | 1.52 Agg** | 0.99 | -1.62 | 2.59 Agg |
| 0.050 | 4 | 0.84 | 4.57 | 1.29 Ran | 0.50 | -2.84 | 1.92 Agg |
| 0.025 | 8 | 0.95 | 3.39 | 1.67 Agg | 0.90 | 0.54 | 2.96 Agg |
| 0.012 | 16 | 0.83 | 2.88 | 1.65 Agg | 0.74 | 0.23 | 2.80 Agg |
| | | | Ponder Farm | | | | |
| 0.100 | 2 | 0.99 | 25.11 | -0.23 Reg | 0.99 | 6.89 | 0.12 Agg |
| 0.050 | 4 | 0.39 | 0.79 | 1.91 Ran | 0.46 | -0.72 | 1.65 Agg |
| 0.025 | 8 | 0.63 | 1.32 | 1.52 Ran | 0.82 | 0.28 | 1.37 Agg |
| 0.012 | 16 | 0.78 | 0.68 | 1.88 Agg | 0.89 | -0.51 | 1.48 Agg |

*n = numbers of plots
**Agg = aggregated distribution, *b* significantly > 1 ($P < 0.05$); Ran = random distribution, *b* not significantly > 1 ($P > 0.05$); Reg = regular distribution, *b* significantly < 1 ($P < 0.05$).

## Acknowledgments

We thank M. R. Hall (University of Georgia, Department of Horticulture, Coastal Plain Experiment Station, Tifton, GA) and R. J. Zimmerman (Rogers Messa Research Center, 3060 Highway 92, Hotchkiss, Colo. 81419) for critical review of the manuscript. We also thank S. K. Seal for typing the manuscript and her cooperation during this research. This article is Florida Agricultural Experiment Station Journal Series No. R- 05327.

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