# Development and Use of a Dynamic Sequential Sampling Program for Onion Thrips, *Thrips tabaci* (Thysanoptera: Thripidae), on Onions

A. M. SHELTON, J. P. NYROP, R. C. NORTH,
C. PETZOLDT,[1] AND R. FOSTER[2]

Department of Entomology, New York State Agricultural Experiment Station,
Cornell University, Geneva, New York 14456

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**ABSTRACT** Data collected in 1983 from six commercial onion fields in upstate New York indicate that dispersion characteristics of onion thrips (OT), *Thrips tabaci* Lindeman, are precisely described by Taylor's power law ($s^2 = am^b$), with $\ln a = 0.517$, $s_{\ln a} = 0.059$, $b = 1.89$, and $s_b = 0.028$ ($n = 47$; $r^2 = 0.99$; $P \leq 0.0001$). Additionally, during the main period of infestation (late July–late August) OT appear to be randomly distributed within an onion field. Data on OT dispersion were used to develop a sequential sampling procedure linked to a dynamic action threshold of three OT per leaf. This sampling plan was tested in 50 commercial onion fields in 1985. Results indicate that treatment decisions were reached 88% of the time after inspecting only 15 plants. Only 10 of 314 (3%) field inspections required a scout to examine 50 plants to reach a treatment decision. When the sequential sampling plan was compared with a fixed sample size of 50 or 100 plants, 95% of the decisions made were the same, and in the remaining 5% of the cases no sequential decision was made.

**KEY WORDS** *Thrips tabaci*, onions, sampling

EFFICIENT ONION production in upstate New York hinges on the rational management of a weed/pest complex: Botrytis leaf blight, *Botrytis squamosa* Walker; onion maggot, *Delia antigua* (Meigen); and onion thrips (OT), *Thrips tabaci* Lindeman. Onion maggot control relies primarily on proper application of a soil insecticide at planting and good harvesting practices. Control of the other pests should be premised on scouting before treatment decisions are made. In the Cornell onion integrated pest management (IPM) program, scouting procedures focus on Botrytis leaf blight as the primary pest because of its damage potential. Scouting for Botrytis leaf blight involves walking through the field along a V-shaped path and examining five plants at each of 10 sites for leaf lesions. At each site, notes are also taken on the species composition of the weed complex and its severity. Treatment thresholds for Botrytis leaf blight and the weed complex have been developed and implemented in the Cornell onion IPM program. OT is a frequent, but usually less devastating, member of the onion pest complex in upstate New York. Although OT do not usually feed on the onion bulb and cause direct damage, they can reduce photosynthetic capacity of the plant. However, there are conflicting reports (Quartey 1982, Edelson et al. 1986) on the effect of OT populations on onion yields.

In upstate New York, OT overwinter as adults within winter wheat, alfalfa, and weedy vegetation (North & Shelton 1986) and then migrate when these crops become unsuitable because of maturation and senescence or cropping practices (Shelton & North 1986). This temporal and spatial variation in migration from these early season crops influences the time of arrival of OT in a particular onion field so that some fields become infested when plants are young and other fields become infested when plants are older. Hence, a treatment threshold for OT on onions should be a dynamic threshold, which takes into consideration the size of the plant. This variation in the time of infestation may have been one of the major factors in the conflicting reports on the influence of OT on onion yields. Our field experience indicates that high populations (e.g., 20 OT per plant) on seedling onions will cause plants to die, whereas the same populations on mature onions may actually be beneficial, killing the leaves and promoting curing of the onion bulb.

For growers to accept scouting-based OT management, this dynamic action threshold for OT must be linked with an efficient sampling scheme that is compatible with sampling for the more potentially damaging onion pests. In 1983, we began a project to develop sampling schemes for OT. As a first step, we sought to determine the distribution of OT in commercial fields using a single plant as a sample unit. Second, we examined these same fields for any sign of aggregation of OT populations in portions of the field. When this was accom-

[1] Cornell University IPM Programs, Geneva, NY 14456.
[2] Current address: Everglades Research and Education Center, P.O. Drawer A, Belleglade, FL 33430.

**Table 1. Within- and among-cluster (three plants per cluster) variance components for OT sampling on onions in commercial fields in upstate New York, 1983**

| Field | Variance | | | | $\bar{x}$ | $n^a$ |
|---|---|---|---|---|---|---|
| | Within-cluster | % of total | Among-cluster | % of total | | |
| F1 | 442.70 | 89.3 | 53.0 | 10.7 | 19.70 | 240 |
| F2 | 1,585.30 | 95.2 | 80.6 | 4.8 | 33.90 | 570 |
| S1 | 0.56 | 100 | $0^b$ | $0^b$ | 0.51 | 390 |
| S2 | 0.50 | 100 | $0^b$ | $0^b$ | 0.50 | 350 |
| D1 | 1.73 | 90.5 | 0.18 | 9.5 | 1.20 | 609 |
| D2 | 11.33 | 82.6 | 2.39 | 17.4 | 3.92 | 520 |

[a] Total number of plants used in model.
[b] Estimate of variance component was negative.

plished, a sequential sampling program, which takes into account crop stage, was developed and evaluated in commercial fields.

## Materials and Methods

All work was conducted in commercial fields within a three-county area in upstate New York. All common onion agronomic practices, including the use of insecticides, occurred during the course of study.

Six fields, ranging in size from ca. 2 to 4 ha, were systematically sampled during 1983 for OT. The fields were sampled between 22 July and 25 August, the main period for OT infestations. The onion plant stage during the sampling period ranged from the 4- to the 10-leaf stage. Each field was sampled once by dividing it into a grid with ca. 200 cells of equal area. Within each of these cells, three plants, each in a separate row, were severed at the soil surface and placed in individual containers. The plants were washed in 50% alcohol in the laboratory and the solution was examined under a microscope for larvae, pupae, and adult OT. For analysis, all life stages were combined and these data were used to describe the dispersion parameters and within-field pattern of OT, and to construct a sequential sampling scheme.

The dispersion of the sample counts was studied three ways. First, the counts from each field were subjected to analysis of variance to estimate the within-cell and among-cell variance components. In this analysis, a large section of each field (≥80 cells) was used so that we could obtain a balanced design with the same number of rows as columns. Second, Taylor's power law (Taylor 1961) was used to describe the sample variance as a function of the sample mean. The data from each field were subdivided into 47 groups corresponding to sample transects within each field. The number of plants in each transect ranged between 40 and 87. Means and variances were calculated for each transect in each field and were used to estimate the parameters of Taylor's model. Finally, the means from each cell (three plants) were used to generate a three-dimensional plot of the distribution of OT within each field.

A sequential sampling plan was developed by employing the estimated variance/mean relationship in the general confidence-interval method developed by Iwao (1968). The procedure was modified slightly (Nyrop & Simmons 1984) so that a minimum of 15 plants was sampled before counts were compared with the stop lines. In addition, we set the maximum number of plants at 50, because this number corresponded to the fixed number of plants sampled for Botrytis leaf blight. If the maximum sample size was reached, a mean based on the 50-plant sample was calculated and compared with the threshold. We used Taylor's power law to model the variance/mean relationships instead of Iwao's formula. $\alpha$ was set to 0.05; however, this is simply a parameter of the sampling plan and not a probability of error (Nyrop & Simmons 1984). Stop lines, probability of error curves (EC), and average sample number curves (ASN) were calculated for five crop phenologies (i.e., the 2-, 4-, 6-, 8-, and 10-leaf stages). This was done because a threshold of three OT per leaf was used, but the sample unit was a complete plant. The EC and ASN curves were estimated via simulation by generating negative binomially distributed random variates with $k = \mu^2/(\sigma^2-\mu)$. Each simulation (crop stage × mean thrips density) was replicated 2,000 times. The EC depicts the probability of making an incorrect decision given a true population mean, and the ASN depicts the expected number of samples required to make a decision. Our threshold for the sequential sampling plan (three OT per leaf) is based on a synthesis of four hypothetical action thresholds for whole plant counts (Quartey 1982), but modified so that thresholds are based on individual leaf counts.

During 1985, the sequential sampling scheme was used in 50 fields, ranging in size from ca. 2 to 10 ha. Each field was examined weekly, for a total of 314 field inspections. Sampling involved the nondestructive examination of between 15 and 50 plants per field. Five plants were sampled at each of up to 10 sites along a V-shaped transect through the field. In 235 field inspections, scouts counted OT and reached a decision using both the sequential sampling plan and a fixed sample size of either 50 or 100 plants.

## Results and Discussion

The results of the variance partitioning are shown in Table 1. In all fields, the among-cell variance component was small compared with the within-cell component. The variance of a mean estimated by sampling $c$ cells and $p$ plants per cell is given by $s_m^2 = s_p^2 + ns_c^2/(cn)$. As a result, whenever the between-cell component ($s_c^2$) is >0, $n$ should be set to 1 and the number of cells maximized to minimize the variance of the sample mean. However, in onion sampling, it is necessary to sample groups

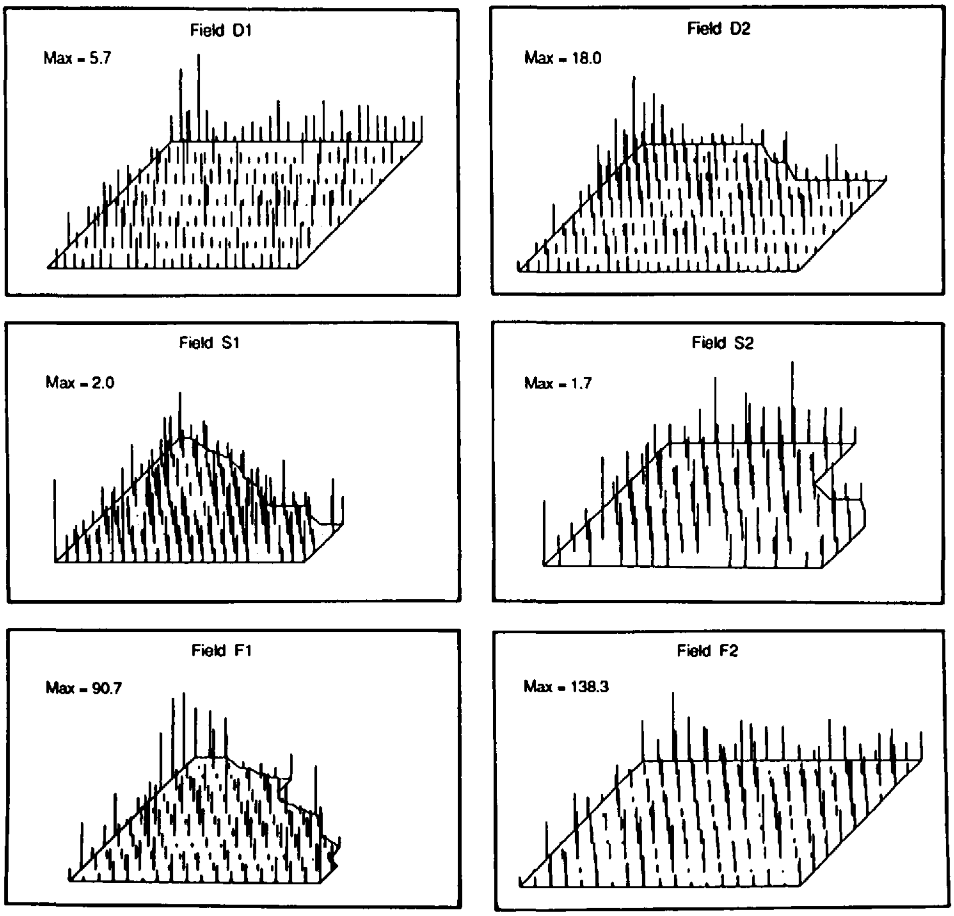


**Fig. 1.** Distribution of OT in commercial onion fields. Each line is the average number of OT per three plants. Max, the highest density per plant.

of plants or clusters because of the sampling protocol for other pests. Fortunately, this results in only minimal decline in sampling efficiency from the standpoint of the variance when estimating OT numbers. Taylor's power law (Taylor 1961) ($s^2 = am^b$) provided a precise description of the variance as a function of the mean ($\ln a = 0.517$; $s_{\ln a} = 0.059$; $b = 1.89$; $s_b = 0.028$; $n = 47$; $r^2 = 0.99$; $P \leq 0.0001$).

The within-field distributions of OT in six commercial onion fields are shown in Fig. 1. Each position on each plot is the average number of OT found on three plants. Visual examination of these plots indicates that neither the interior nor exterior portions of the field consistently harbor greater number of OT. There are, however, two instances when a border portion of the field harbored proportionately greater numbers of OT. In field D2, plants in six sample clusters shown in the upper left-hand corner of the figure had more OT on average ($\bar{x} = 12.6$) than the average number of OT per plant throughout the field ($\bar{x} = 3.9$). However, the average number of OT per plant from some sample clusters located in the center of the field was also relatively high ($\bar{x}$ ranged from 9.9 to 11.3). In field F1, the highest average number of OT was found in six sample clusters shown in the upper left-hand border of the figure ($\bar{x} = 64.4$). Again, some single sample clusters from the center of the field also had high average OT counts (e.g., $\bar{x} = 84.9$).

We conclude from these data that although there may be "hot spots" of OT along borders in some fields, the distribution throughout a field is essentially random. This conclusion seems valid during the main period of OT infestation in onions in our area, although initial infestations may be concentrated in the border areas.

Two potential problems confront the development and use of a sequential sampling procedure for OT. First, sampling protocols for other onion pests dictate use of a cluster sampling procedure. This results in a violation of an assumption of sequential sampling (i.e., that the observations are random and independent). They are not strictly independent because the intracluster correlation coefficient ($\delta$) (Jessen 1975) is positive. This coefficient can be estimated as $\delta = [ms(c) - ms(p)]/[n \cdot ms(T)]$, where $ms(c)$ is mean square between clusters of plants, $ms(p)$ is mean square within clus-

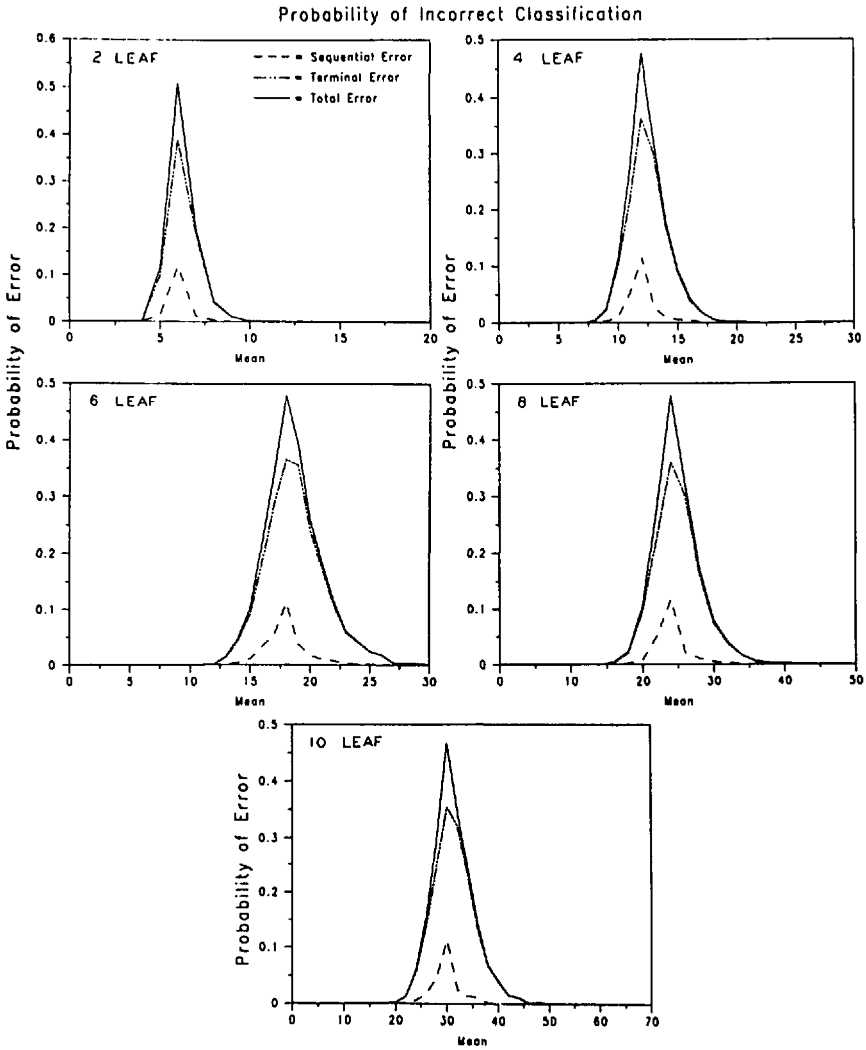


**Fig. 2.** Probability of error curves for an OT sequential sampling plan in onions. Error probabilities are the probabilities that the sampling plan will estimate OT density as less than the threshold (three per leaf) when they are greater and the converse when OT densities are less than the threshold. Mean, average number of OT per plant.

ters of plants, $n$ is number of plants in a cluster, and $ms(T)$ is total mean square. The values of $\delta$ can range from $-(1/n) - 1$ to 1.0. Therefore, in this case, $\delta$ has a potential range of −0.67 to 1.0. When $\delta$ is positive, sample plants within a cell are "more alike" than plants in different cells. For OT, this

**Table 2. Distribution of sample sizes required to make a treatment decision for OT in 50 commercial onion fields (314 total field inspections) in upstate New York, 1985**

| Decision | No. of plants inspected before a decision was made | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 15 | 16–20 | 21–25 | 26–30 | 31–35 | 36–40 | 41–45 | 46–50 |
| No treat | 269 | 8 | 7 | 1 | 2 | 1 | 2 | 2 |
| Treat | 8 | 4 | 2 | 0 | 0 | 0 | 0 | 8 |
| Total | 277 | 12 | 9 | 1 | 2 | 1 | 2 | 10 |

correlation coefficient is small ($\delta$ = 0.11, 0.05, 0, 0, 0.096, 0.165 for the fields sampled). As a result, the effect of this violation should be minimal, in our judgement. The second problem is that when sampling for pest management, a decision is to be reached for an entire field; however, with sequential sampling, only a small portion of a field might be sampled before arriving at a decision. If this portion of the field is not representative of the entire field, an error may be made. With OT, this is not a problem because of the distribution of the thrips throughout the field (Fig. 1).

Stop lines for the sequential sampling plan are given by $3L \pm 0.95\,[a(3L)^b]$, where $L$ is the number of leaves on the onion plants and $a$ and $b$ are the parameters for the variance/mean model. The EC and ASN functions are shown in Fig. 2 and 3, respectively. The EC is divided into a sequential

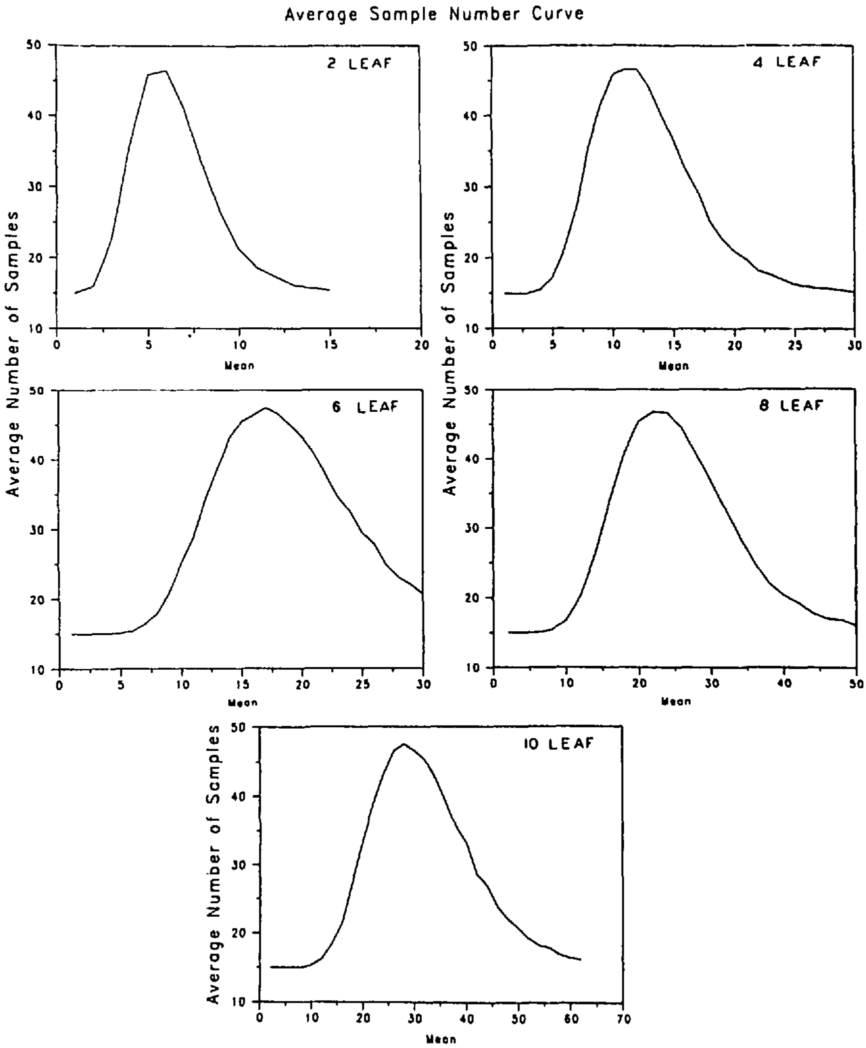


**Fig. 3.** Expected number of samples required to reach a decision for OT control in onions using a sequential sampling plan. Mean, average number of OT per plant.

error component and a terminal error component. The sequential error component arises from incorrect decisions made before reaching the maximum sample size of 50 plants. The terminal error component arises from incorrect decisions made after sampling 50 plants. When summed, these components yield the probability of making an incorrect decision given any true OT density (the abscissa). For the five crop phenology stages, the probability of deciding that a field does not require treatment when the OT exceed the action threshold is <0.05 when a threshold of four OT per leaf is used instead of three per leaf. Because a threshold of three per leaf is conservative, the procedure should rarely, if ever, lead to a decision to not treat when, in fact, control is warranted. The ASN curves (Fig. 3) show that when OT populations are either 1.5-fold greater than the threshold or less than half of the threshold, considerable savings in sampling costs are realized using the sequential procedure rather than a fixed sample size.

The results obtained from using the sequential procedure in the field are provided in Table 2. Treatment decisions were reached after looking at only 15 plants in 277 of 314 field inspections (88%). Only 10 of 314 (3%) field inspections required a scout to inspect 50 plants to reach a treatment decision. Of the 235 field inspections where scouts counted OT and reached a treatment decision based on both the sequential sampling plan and a fixed sample size of 50 or 100 plants, 95% (224) of the decisions made were the same. In the 11 remaining fields, no sequential decision was reached. With sequential sampling, it was never recommended not to spray when use of a fixed sample method recommended spraying. This agreement between the sequential sampling system, which used counts taken at a relatively few, closely spaced sites, also supports the observation that OT are randomly scattered throughout onion fields.

Previous work by Edelson et al. (1986), which analyzed the spatial distribution of OT on onions, indicated that OT populations are overdispersed when density is more than one per plant. Our results from this study also indicate that OT have an aggregated sampling distribution and one that is precisely described by Taylor's power law when a single plant sample unit is used. Our analysis of the sequential sampling plan indicates that it has good error qualities and is parsimonious with respect to sampling resources. In addition, this procedure is flexible with respect to the pattern of sampling required, and changes in OT thresholds or sampling protocols for other onion pests can easily be incorporated.

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