Distribution of *Trialeurodes vaporariorum* and *Bemisia tabaci* (Homoptera: Aleyrodidae) on Some Greenhouse-grown Ornamental Plants[1]

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ABSTRACT The within-plant and between-plant distributions of all stages of both greenhouse whitefly (GHWF), *Trialeurodes vaporariorum* (Westwood) on poinsettia, chrysanthemum and gerbera daisy, and sweetpotato whitefly (SPWF), *Bemisia tabaci* (Gennadius) on poinsettia, were examined using Taylor's power law ($s^2 = am^b$) and Iwao's patchiness ($\overset{*}{m}$-m) methods. We found that all developmental stages of the two whitefly species on all plants examined were aggregated within and between plants. The vertical distribution of whitefly stages is stratified among leaves within the plant with respect to leaf age rather than relative height of the leaves on the plants. Most of the adults, eggs and the first-instar nymphs occurred on young leaves. The second- and third-instar nymphs occurred on middle-aged leaves, and most of the pupae and empty pupal cases occurred on middle-aged and older leaves. Comparison of whitefly counts from the different combinations of top, middle, and bottom leaves with the whole-plant counts on poinsettia was correlated and these leaves can be sampled as an indication of population levels within a greenhouse population.

KEY WORDS Insecta, greenhouse whitefly, sweetpotato whitefly, distribution, poinsettia, *Trialeurodes vaporariorum, Bemisia tabaci.*

In the past decade, the sweetpotato whitefly (SPWF), *Bemisia tabaci* (Gennadius), has invaded greenhouses causing heavy damage to poinsettias and other important ornamental plants in several southern states (Price et al. 1986). The greenhouse whitefly (GHWF), *Trialeurodes vaporariorum* (Westwood), has long been an important pest in greenhouse-grown vegetables and ornamental plants worldwide. The marketability of plants is reduced markedly when the plant foliage is contaminated with whitefly 'scales' (nymphal stages) and honeydew.

Reliable methods for estimating insect population densities are essential for basic as well for applied population dynamical studies (Southwood 1978). An understanding of the spatial distribution patterns of the insects is important for the development of reliable sampling programs. The spatial distribution patterns of GHWF have been studied on vegetables (e.g. tomato, cucumber and green beans) in Europe and Asia, and several sampling programs have been developed (Ekbom 1981, Xu 1985, Xu et al. 1980, 1981, Yano 1983, Noldus et al. 1986a, 1986b). The within-plant distributions of SPWF on cotton plants in the field have been investigated in Africa and Mideast (Ohnesorge et al. 1980, Ohnesorge and Rapp 1986), and the spatial distribution pattern of pupae (red-eye nymphs) within the

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cotton plant has been studied in Sudan (von Arx et al. 1984). However, the dispersion patterns of these two whitefly species have not been qualitatively investigated on greenhouse-grown ornamental plants.

The objectives of this study were to quantify the within-plant and between-plant distributions of each developmental stage of GHWF on poinsettia, gerbera daisy and chrysanthemum in the greenhouse, and to assess if the within-plant distribution of the whiteflies is defined by the negative geotaxic feeding behavior of the adults (i.e. the relative height of leaves on the plant) or the developmental ages of the leaves. Dispersion patterns of SPWF on poinsettia also were examined.

Materials and Methods

Plant Growing Conditions. Studies with the GHWF were conducted in greenhouses at Georgia Experiment Station, Griffin, GA. Poinsettia (*Euphorbia pulcherrima* Willd.), gerbera daisy (or transvaal daisy, *Gerbera jamesonii* H. Bolus) and chrysanthemum (*Dendranthema grandifolium* Tevyel) were potted one each in 15-cm plastic azalea pots. Plants were watered and fertilized using standard cultural practices. All plants were placed about 30 cm apart on benches and infested with adult whiteflies. Examinations began about 4 weeks later when all developmental stages of whiteflies were found on all plants. The four lowest leaves were removed soon after rooted cuttings were received. These leaves are removed by growers to reduce introductions of whiteflies from propagators. In addition, lateral branches, discolored or damaged, and dead and old leaves were removed three days prior to the beginning of examination. Distribution of SPWF was studied on poinsettia at a commercial greenhouse located near Griffin, Ga. Plants were grown individually in pots. When plants were about five weeks old, leaves were inspected for SPWF.

Within-plant Distribution. Distributions of GHWF adults on poinsettias and chrysanthemums were examined by inspecting the lower surface of 10 leaves of 20 plants in descending order from the upper or youngest expanded leaf. To avoid disturbing the adults, the leaves were not touched and the number on each leaf was counted when the adults were not active. Immature stages were counted on seven leaves of 20 poinsettia and 20 gerbra daisy plants. Because of a heavy infestation of GHWF on chrysanthemums in our greenhouse, only the upper 13-14 pairs of leaves in the descending order from the top were marked, and every other leaf beginning with the uppermost leaf of 20 plants were randomly selected, i.e. 7 leaves from each plant, so that the number of leaves examined were identical from all three host plants. Numbers of each immature stage in a 2-cm^2 area were counted. For temporary preservation, the leaves were placed inside transparent plastic bags, tightly closed, and stored at 3-5°C. The number of whiteflies of each stage was counted in the laboratory. Distribution of SPWF on poinsettia was examined by randomly selecting one leaf from the top, between top and middle, middle, between middle and bottom, and bottom of the plants. A total of 100 leaves from 20 randomly selected plants were counted. Number of adults on whole leaves, and number of immatures in a 2-cm^2 area of each leaf were counted in the laboratory. Because GHWF adults from 10 leaves were counted, comparison

of within-plant distribution of GHWF adults with SPWF adults was made by averaging the numbers of two leaves from top, between top and middle, middle, between middle and bottom, and bottom of the plants.

Within-plant counts of each leaf level were subjected to analysis of variance (ANOVA), and were separated using least significant difference test (LSD) at $P = 0.05$ (SAS Institute 1985). In addition, correlation analysis was completed to determine the relationship between the counts of whitefly nymphs, pupae, and adults from the top leaf, middle leaf, bottom leaf, and combinations of these leaves with the whole-plant counts of whiteflies on poinsettia in greenhouses.

Between-plant Distribution. The between-plant distribution patterns of egg, nymphal stage, pupae and adults of GHWF were examined on poinsettia and chrysanthemum. A total of 50 plants for each host were randomly arranged into 10 blocks with each block containing 5 plants on the benches in the greenhouse for nymphal, pupal and adult stages, and 60 plants in 15 blocks with 4 plants per block for egg stage. Numbers of eggs, nymphal stages (including first-, second- and third-instar nymphs), pupae on the entire plant were counted in the laboratory by using a stereomicroscope. Number of adults on the entire plant was counted from leaves in the greenhouses by carefully turning over the leaves when the adults were not active.

The spatial distribution of egg, nymphal, pupal and adults of SPWF were examined on 200 poinsettias, and 40 plants were selected at random and divided into 10 blocks (4 plants per block). All leaves of each plant were bagged separately, and all developmental stages were examined in the laboratory using a stereomicroscope.

Spatial Distribution Pattern Analysis. Taylor's power law method (Taylor 1961) and Iwao's patchiness regression method (Iwao 1968, 1977) were used to examine the spatial distribution patterns of the two whiteflies. Taylor's power law ($s^2 = am^b$) was calculated as the regression of log-transformed variance ($\log_{10} s^2$) on log-transformed mean ($\log_{10} m$) in a linear model such that

$$\log_{10}(s^2) = \log_{10} a + b \log_{10}(m)$$

in which b is a measure of aggregation, and a is largely a sampling factor related to sample unit size. Iwao's patchiness regression method has shown that mean crowding ($\overset{*}{m}$) is related to the mean (m) over a series of densities:

$$\overset{*}{m} = \alpha + \beta m$$

in which $\overset{*}{m}$ is defined by Lloyd (1967) as:

$$\overset{*}{m} = m + (s^2/m - 1)$$

where s^2 = sample variance, m = sample mean. The intercept α is the index of basic contagion and β is the density contagiousness coefficient among sample units (Iwao 1968). The indices of aggregation or slopes coefficients (b and β) in the Taylor's and Iwao's methods indicate a uniform, random, and aggregated distribution pattern when slope < 1, slope = 1, and slope > 1, respectively. The

simple linear regression procedure (SAS Institute 1985) was used to compute the all parameters for both Taylor's and Iwao's methods. Indices were calculated to quantify aggregation at all stages of both species within plants and between plants. Aggregation coefficients were compared with b or $\beta = 1.0$ using Student's *t*-test procedure (SAS Institute 1985).

Results

Within-plant Distribution. The numbers, and percentages of each stage of GHWF on each leaf position of poinsettia, chrysanthemum and gerbera daisy are summarized in Tables 1 and 2.

On chrysanthemum and poinsettia, a majority of adults, eggs and first-instar nymphs were found on the top young leaves and less on middle-aged leaves. A large number of the second- and third-instar nymphs occurred on the middle-aged leaves, and most pupae and empty pupal cases on the middle-aged and older leaves. The percentage of each stage varied depending on the number of leaves on the plant. The vertical distribution patterns of all stages generally were similar in both plant species.

Gerbera daisy has a different plant architecture than poinsettia or chrysanthemum. The youngest leaves are located in the center rather than on the top terminal of the plant. The distribution of each GHWF stage showed that the eggs and first-instars occurred mostly on the youngest leaves, second- and third-instars occurred on middle-aged leaves and most pupae occurred on the oldest leaves. The proportions of each stage of GHWF generally were similar by leaf age in gerbera daisy and the erect plants.

Correlation coefficients between the counts of whitefly nymphs, pupae, and adults from the top leaf, middle leaf, bottom leaf and combinations of these leaves with the whole-plant counts on poinsettia are in Table 3. The results indicated that the sampling units can be reduced by only sampling the top and middle leaves in both whitefly species. Sampling top-middle, top-bottom, or top-middle-bottom leaves for adults of GHWF and SPWF can be used to determine the whole-plant population with the correlation coefficients as great as 0.81-0.90, while counts of nymphs and pupae from top-middle, top-middle-bottom leaves for both species were well correlated with those from whole-plant (r-values ranged from 0.85-0.92).

The vertical distribution of SPWF adults was affected by the extremely high population infestation on the plants (Table 1). Under this condition, the adults tend to locate on lower leaves for feeding and oviposition because of competition for space on upper young leaves. As a result, the numbers of adults among the five strata were significantly divided into two groups, the top two levels of leaves and the lower three levels (Table 1). The populations of the eggs and other immature stages were relatively low, therefore, the stratification was more defined for these stages than for adults. The vertical distributions of SPWF and GHWF were similar on poinsettia.

The indices of aggregation (slope coefficients, b and β) of Taylor's and Iwao's methods and the linear coefficients of determination (r^2) of the regressions for the within-plant distribution for both whitefly species are summarized in Table 4. In Taylor's power law method, the slopes or indices of aggregation (b) for both

Table 1. Distribution of greenhouse whitefly and sweetpotato whitefly adults on some selected greenhouse-grown ornamental plant.

Leaf position	Greenhouse whitefly				Sweetpotato whitefly	
	Poinsettia		Chrysanthemum		Poinsettia	
	mean*	%	mean	%	mean	%
Top	59.0 a	35.9	60.1 a	50.6	456.1 a	31.7
Top-middle	43.3 a	26.3	34.2 b	28.8	348.5 a	24.3
Middle	28.7 b	17.5	9.0 c	7.6	196.2 b	13.7
Middle-bottom	22.2 b	13.5	7.8 c	6.6	230.4 b	16.0
Bottom	11.2 c	6.8	7.6 c	6.4	205.1 b	14.3

* The means within a column followed by the same letter are not significantly different (P = 0.05, LSD).

GHWF and SPWF ranged from 1.50-2.50, which were significantly greater than 1 (P = 0.05 or P = 0.01, t-test at Ho: b = 1) for most of stages of both whiteflies on the various host plants. Iwao's patchiness regression method also well described the relationship of $\overset{*}{m}$ to m in both GHWF and SPWF in all but a few instances. The β-values (1.26-6.29) are significantly greater than 1 in all cases (P = 0.05 or P = 0.01, t-test at Ho: β = 1). Meanwhile, the majority of α terms in Iwao's method were not significantly different from zero ($P > 0.05$, t-test at Ho: α = 0). These results demonstrate that the distribution patterns between leaves of all whitefly stages are highly aggregated within the plant canopy.

Yano (1983) reported that the β values ranged from 1.47 to 2.29 for the within-plant distributions of GHWF eggs, young and mature nymphs and adults on tomato. Von Arx et al. (1984) reported that the SPWF pupae (red-eye nymphs) distinctly aggregated on and around a main stem leaf on cotton plant (β values: 1.535-2.711), and their location varied depending on plant growth and cotton variety. We observed a similar range of β values for both species on greenhouse ornamental plants.

Between-plant Distribution. The aggregation indices for between-plant distributions of egg, nymphal, pupal stages and adults GHWF and SPWF are listed in Table 5. The linear coefficients of determination (r^2) for all whitefly stages on both poinsettia and chrysanthemum were relatively high, ranging from 0.92-0.98 (Taylor's method) and from 0.82-0.99 (Iwao's method) for GHWF, and from 0.90-0.97 (Taylor's method) and from 0.76-0.91 (Iwao's method) for SPWF. In both Taylor's power law and Iwao's methods, the indices of aggregation (b values and β values) for GHWF on poinsettia and chrysanthemum and for SPWF on poinsettia were significantly greater than 1.0 ($P < 0.05$, t-test) for all stages. This indicates that all stages of both species were aggregated between plants. However, the b and β values of GHWF on poinsettia and chrysanthemum were highest for adults and lowest for pupae, whereas those of SPWF on poinsettia were highest in adult stage and lowest in nymphal stages.

Table 2. Distribution of immature stages of greenhouse whitefly and sweetpotato whitefly on three greenhouse-grown ornamental plants.

Leaf level*	Egg		1st instar		2nd instar		3rd instar		Pupa	
	mean†	%	mean	%	mean	%	mean	%	mean	%
Greenhouse whitefly on poinsettia										
1	56.6 a	54.9	43.3 ab	19.9	1.5 c	1.7	0.0 c	0.0	0.0 c	0.0
2	22.5 b	21.8	73.0 a	33.6	20.1 a	22.9	14.3 a	23.7	2.4 c	4.2
3	11.4 c	11.1	55.7 ab	25.6	23.2 a	26.5	19.3 a	32.0	12.2 b	21.1
4	9.7 c	9.4	32.6 b	15.0	27.9 a	31.8	18.9 a	30.0	22.2 a	38.3
5	2.8 c	2.7	12.6 c	5.9	15.0 b	17.1	8.6 b	14.3	21.1 a	36.4
Greenhouse whitefly on chrysanthemum										
1	230.6 a	56.6	17.3 c	5.2	0.0 c	0.0	0.0 c	0.0	0.0 b	0.0
2	97.9 b	24.0	127.7 a	38.4	11.0 bc	9.9	0.0 c	0.0	0.0 b	0.0
3	33.6 c	8.2	85.6 b	25.7	27.2 a	24.4	13.9 b	17.0	2.0 b	3.4
4	22.4 c	5.5	58.2 b	17.5	24.6 a	22.1	23.1 a	28.2	14.0 a	20.2
5	14.1 c	3.5	22.8 c	6.9	23.6 a	21.1	23.1 a	28.2	14.0 a	23.9
6	7.1 c	1.7	13.0 c	3.9	14.1 ab	12.6	17.1 ab	20.8	15.0 a	25.6
7	1.7 c	0.4	8.0 c	2.4	11.1 bc	9.9	10.8 b	13.2	15.7 a	26.9
Greenhouse whitefly on gerbera daisy										
1	304.3 a	46.8	9.2 b	3.9	0.5 c	1.3	0.0 b	0.0	0.0 c	0.0
2	185.2 b	28.5	88.3 a	37.6	6.0 bc	16.0	0.0 b	0.0	0.0 c	0.0
3	132.6 b	20.4	79.4 a	33.8	9.5 a	25.3	2.7 b	19.1	2.6 b	13.8
4	9.7 c	1.5	36.3 b	15.4	10.2 a	27.2	5.9 a	41.8	6.9 a	36.5
5	16.5 c	2.5	18.5 b	7.9	4.6 bc	12.3	2.6 ab	18.4	6.3 a	33.3
6	1.0 c	0.2	2.3 b	1.0	1.7 c	4.5	2.8 ab	19.9	2.9 b	15.3
7	1.0 c	0.2	1.0 b	0.4	0.5 c	1.3	0.1 b	0.7	0.2 c	1.1
Sweetpotato whitefly on poinsettia										
1‡	385.9 a	37.5	17.7 ab	24.4	4.8 b	11.3	1.6 b	6.0	0.9 c	1.7
2	279.1 b	29.2	19.0 a	26.3	10.1 ab	23.9	5.0 ab	18.5	5.5 b	10.3
3	166.9 c	17.5	17.6 ab	24.3	11.5 a	27.4	7.2 a	26.9	8.5 b	15.9
4	89.2 d	9.3	12.7 ab	17.5	8.6 ab	20.4	7.9 a	29.3	20.8 b	38.9
5	62.2 d	6.5	5.5 b	7.6	7.2 ab	17.0	5.2 ab	19.4	17.8 a	33.2

* The leaves are in descending order from the youngest to the oldest;

† The means within a sub-column followed by the same letter are not significantly different ($P = 0.05$, LSD);

‡ The leaf levels of 1-5 are in descending order from the top, top-middle, middle, middle-bottom, and bottom of the plant, respectively.

Table 3. Correlation coefficients (r-values) between leaves at selected levels of the plant with whole plant whitefly populations on poinsettia in greenhouse.

Leaf position	Greenhouse whitefly		Sweetpotato whitefly	
	Adult	Nymph & pupa	Adult	Nymph & pupa
top	0.65	0.65	0.79	0.69
middle	0.62	0.92	0.56	0.84
bottom	0.77	0.62	0.82	0.58
top-middle	0.86	0.91	0.87	0.86
top-bottom	0.81	0.68	0.87	0.65
top-middle-bottom	0.88	0.92	0.90	0.85
middle-bottom	0.68	0.91	0.78	0.83

Discussion

The whiteflies were not uniformly distributed on the leaves in the three plant species. Among the whitefly stages, the percentages of the adults, eggs, first-instar nymphs occurred mostly on young leaves although all leaves regardless of their ages contained eggs or first-instar nymphs of the two whitefly species on all host plants examined. Ohnesorge et al. (1980) also reported that some eggs of SPWF were even laid on the old leaves in cotton. In our study, second- and third-instar nymphs of both species were more generally distributed but were most prevalent on middle-aged leaves, whereas pupae were concentrated on older leaves. Combining all developmental stages together, the numbers of both whitefly species were largest on the young or upper leaves and smallest on the old or bottom leaves. A likely reason for reduced numbers of older nymphs and pupae on the older leaves is high mortality of the young mobile nymphs.

The stratification of vertical distribution by developmental stages on different aged leaves most likely was a result of a preference for young leaves for feeding and oviposition by adult whiteflies. With the growth of the host plant, more new leaves developed, and the relative position of leaves changed continually. Thereby, the stratification of whitefly developmental stage with leaf age was formed. A similar vertical distribution stratification was reported for GHWF on several upright vegetables by Hargreaves (1915), Lloyd (1922) and Ekbom and Xu (1990), and for SPWF on cotton by Ohnesorge and Rapp (1986). Consequently, the position of a particular developmental stage of whiteflies can be expected and predicted by using the phenology of the plant growth. Furthermore, we found that the distribution of GHWF was similar by leaf age in gerbera daisy and the erect plants, poinsettia and chrysanthemum. The pattern on gerbera daisy indicates that the vertical distribution of whitefly

Table 4. The estimated values of indices of within-plant aggregation of Taylor's power law and Iwao's regression for all developmental stages of greenhouse whitefly and sweetpotato whitefly on some selected greenhouse-grown ornamental plants.

Stage	No. of data sets	Taylor's power law		Iwao's regression	
		b	r^2	β	r^2
Greenhouse whitefly on gerbera daisy					
Egg	22	1.71*	0.76	2.21*	0.50
First instar	22	1.52*	0.66	2.34*	0.35
Second instar	22	1.99*	0.86	2.93*	0.41
Third instar	22	1.85*	0.95	2.83*	0.69
All nymphs	22	1.57**	0.66	5.16*	0.29
Pupa	22	1.84*	0.97	2.56*	0.72
Greenhouse whitefly on chrysanthemum					
Egg	15	1.97*	0.86	2.85*	0.86
First instar	15	2.18*	0.53	3.07*	0.62
Second instar	15	2.17*	0.93	1.77*	0.90
Third instar	15	1.75*	0.93	2.08*	0.90
All nymphs	15	2.72*	0.63	5.15*	0.48
Pupa	15	1.63*	0.69	1.86*	0.75
Adult	20	2.50*	0.86	2.38*	0.88
Greenhouse whitefly on poinsettia					
Egg	24	1.71*	0.87	1.68*	0.54
First instar	24	1.85*	0.92	1.24**	0.98
Second instar	24	1.95*	0.87	2.27*	0.98
Third instar	24	1.86*	0.87	2.51*	0.91
All nymphs	24	2.25*	0.97	3.55*	0.99
Pupa	24	2.01*	0.95	2.22*	0.96
Adult	20	2.20*	0.92	1.71*	0.97
Sweetpotato whitefly on poinsettia					
Egg	20	1.81*	0.81	1.28**	0.90
First instar	20	1.75*	0.96	1.82*	0.97
Second instar	20	1.50*	0.96	1.32**	0.95
Third instar	20	1.56*	0.82	1.40**	0.81
All nymphs	20	1.61*	0.91	2.07*	0.89
Pupa	20	1.61*	0.91	1.56*	0.75
Adult	20	1.89*	0.63	1.26**	0.76

* Significant at $P = 0.05$; ** Significant at $P = 0.01$ (*Ho*: b or $\beta = 1$, *t*-test).

Table 5. The estimated values of indices of between-plant aggregation of Taylor's power law and Iwao's regression for all developmental stages of greenhouse whitefly and sweetpotato whitefly on some selected greenhouse-grown ornamental plants.

Stage	No. of data sets	Taylor's power law		Iwao's regression	
		b	r^2	β	r^2
Greenhouse whitefly on poinsettia					
Egg	15	1.94*	0.96	1.98*	0.98
Nymph	10	2.01*	0.97	1.70*	0.98
Pupa	10	2.02*	0.97	1.25**	0.98
Adult	10	2.06*	0.97	2.30*	0.95
Greenhouse whitefly on chrysanthemum					
Egg	10	1.88*	0.91	1.84*	0.93
Nymph	10	2.04*	0.90	1.62*	0.92
Pupa	10	1.98*	0.99	1.51*	0.97
Adult	10	1.94*	0.94	2.00*	0.96
Sweetpotato whitefly on poinsettia					
Egg	10	1.96*	0.80	1.61*	0.90
Nymph	10	2.03*	0.91	1.37**	0.97
Pupa	10	1.96*	0.76	1.44**	0.91
Adult	20	1.99*	0.91	1.83*	0.95

* Significant at $P = 0.05$; ** Significant at $P = 0.01$ (*Ho*: b or β = 1, *t*-test).

stages within plant was stratified on the plants in relation to leaf age rather than the relative leaf height on the plant and not related to the negative geotaxic feeding behavior of adult whiteflies.

Because only the first-instar nymphs of the whiteflies are mobile, and leaf to leaf movement by nymphs usually is limited, between-plant aggregation patterns of adults directly influence aggregation patterns of immature stages. It was not surprising to expect that the adult and egg stages are more aggregated than nymphal and pupal stages. Xu (1985) reported that the aggregation was greater for the adult stage and was relatively low for nymphal stages. He suggested that this was due to the tendency of adults to feed near the major veins of the leaves, and the relative high mortality of early nymphal stages (18.6 to 22.8%). Yamada et al. (1979) found that the GHWF nymphs on cucumber were less aggregated than adults. It was difficult to compare the distribution patterns as described on vegetables by several workers, however, it was still worthwhile to mention some of those results here. The between-plant aggregation indices, β values for GHWF adults were 4.1- 17.9 and for nymphs were 2.1 - 22.7 on tomato and cucumber (Ekbom, 1981), and β value for GHWF adults on cucumber was 4.6 (Xu et al., 1980). These values were somewhat larger than the range of values we observed for GHWF.

In the greenhouses, we found that the plants near the ventilation fans or near doors may harbor much higher number of whiteflies than plants located elsewhere. This extreme aggregation of whiteflies on those plants was called patches or "pockets" by Ekbom (1977). The formation of these patches may be the effect of uneven ventilation or air flow in the greenhouse because the movement of the adult whiteflies were easily affected by the air or wind movement in the greenhouse. These factors should be considered when interpreting the aggregation data and developing sampling plans.

In conclusion, the within-plant and between-plant spatial distributions of those two whiteflies were significantly aggregated. Both species were more highly aggregated within plants than between plants. The between-plant aggregation was greatest for adult and egg stages for both species, lowest for pupal stage of GHWF and nymphal stages of SPWF. The degree of aggregation may be affected by population density in that the distribution patterns were highly aggregated under low or moderate population density, while aggregation may be reduced at extremely high and low population densities. For an accurate sampling plan, it was important that the counts were done over a variety of population densities, plant ages, environmental conditions, and locations in the greenhouse in order to obtain an accurate and general description of the spatial distribution patterns. However, counting whiteflies on entire plants and hundreds of entire leaves was time-consuming and is not practical for managing a large scale of greenhouses. Our results indicate that a young and old leaf may provide a representative sample unit for all growth stages in a survey. Information is needed on the number of samples needed within a greenhouse for decisions on management practices.

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References Cited

Ekbom, B. S. 1977. Development of a biological control program for greenhouse whiteflies (*Trialeurodes vaporariorum* Westwood) using *Encarsia formosa* (Gahan) in Sweden. Z. Ang. Entomol. 84: 145-154.

1981. Spatial distribution of in a host (*Trialeurodes vaporariorum*)-parasitoid (*Encarsia formosa*) interaction. Plant Protection Reports, Swedish Univ. Agri. Sci. 1-13.

Ekbom, B. S. and Rumei Xu. 1990. Sampling and spatial patterns of whiteflies. pp. 107-121. *In* Dan Gerling [ed.]: Whiteflies: their bionomics, pest status and management. Intercept, Andover, UK, 348 pp.

Hargreaves, E. 1915. The life history and habits of the greenhouse whitefly (*Aleyrodes vaporariorum* Westwood). Ann. Appl. Biol. 1: 303-334.

Iwao, S. 1968. A new regression method for analyzing the aggregation pattern of animal populations. Res. Popul. Ecol. 10: 1-20.

1977. The $\overset{*}{m}$-m statistics as a comprehensive method for analyzing spatial patterns of biological population and its application to sampling problems. pp. 21-46. *In* M. Morisita (ed.): Studies of methods of estimating population density, biomass and productivity in terrestrial animals. Univ. of Tokyo Press, Tokyo, Japan.

Lloyd, D. 1922. The control of the greenhouse whitefly (*Asterochion vaporariorum*), with notes on its biology. Ann. Appl. Biol. 9: 1-32.

Lloyd, M. 1967. 'Mean crowding'. J. Anim. Ecol. 36: 1-30.

Noldus, L. P. J. J., Rumei Xu, M. H. Eggenkamp-Rotteveel Mansveld and J. C. van Lenteren. 1986a. The parasite-host relationship between *Encarsia formosa* Gahan (Hymenoptera: Aphelinidae) and *Trialeurodes vaporariorum* (Westwood) (Homoptera: Aleyrodidae). XX. Analysis of the spatial distribution of greenhouse whiteflies in a large glasshouse. J. Appl. Entomol. 102: 484-498.

Noldus, L. P. J. J., Rumei Xu, and J. C. van Lenteren. 1986b. The parasite-host relationship between *Encarsia formosa* Gahan (Hymenoptera: Aphelinidae) and *Trialeurodes vaporariorum* (Westwood) (Homoptera: Aleyrodidae). XIX. Feeding-site selection by the greenhouse whitefly. J. Appl. Entomol. 101: 492-507.

Ohnesorge, B. and G. Rapp. 1986. Methods for estimating the density of whitefly nymphs (*Bemisia tabaci* Gennadius) in cotton. Trop. Pest Management 32: 207-211.

Ohnesorge, B., N. Sharaf and T. Allani. 1980. Population studies on the tobacco whitefly, *Bemisia tabaci* (Gennadius) (Homoptera: Aleyrodidae) during the winter season. I. The spatial distribution on some host plants. Z. Ang. Entomol. 90: 226-232.

Price, J. F., D. Schuster and D. Short. 1986. Managing sweetpotato whitefly. Greenhouse Grower. December: 55-57.

SAS Institute. 1985. SAS procedure guide for personal computers, vers. 6th ed. SAS Institute, Cary, NC, USA.

Southwood, T. R. E. 1978. Ecological methods, with particular reference to the study of insect populations. Chapman and Hill, London, UK. 524 pp.

Taylor, L. R. 1961. Aggregation, variance and the mean. Nature (London) 189: 732-735.

Von Arx, R., J. Baumgartner and V. Delucchi. 1984. Sampling of *Bemisia tabaci* (Genn.) (Sternorrhyncha: Aleyrodidae) in Sudanese cotton fields. J. Econ. Entomol. 77: 1130-1136.

Xu, Rumei. 1985. Dynamics of within-leaf spatial distribution patterns of greenhouse whiteflies and the biological interpretation. J. Appl. Entomol. 22: 63-72.

Xu, Rumei, Z. H. Li, T. Y. Li and L. F. Liu. 1980. Spatial patterns of adults of greenhouse whiteflies *Trialeurodes vaporariorum* Westw. in greenhouse. Acta Entomol. Sinica 23: 265-275.

1981. Research on sampling techniques of adults of greenhouse whiteflies (*Trialeurodes vaporariorum* Westw.). J. Beijing Normal Univ. 4: 95-102.

Yamada, H., T. Koshihara and K. Tanaka. 1979. Population growth of the greenhouse whitefly, *Trialeurodes vaporariorum* Westwood, on greenhouse cucumber. Bull. Veg. and Ornam. Crops Res. Stn. A. 5: 1191-1199.

Yano, E. 1983. Spatial distribution of greenhouse whitefly (*Trialeurodes vaporariorum* Westwood) and a suggested sampling plan for estimating its density in greenhouses. Res. Popul. Ecol. 25: 309-320.