

IMPLICATIONS OF CHANGES IN ARTHROPOD DISTRIBUTION FOLLOWING CHEMICAL APPLICATION

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INTRODUCTION

The basis for modern integrated pest management programs in agriculture is an efficient yet statistically adequate sampling plan (RUESINK, 1980; SHEPARD, 1980). Most of the sampling procedures currently in use have been developed for crops of high cash value or vast acreage whose producers financially support the intensive research necessary to provide the required background information. Not surprisingly, such economically important commodities also receive extensive pesticide input to counter the damaging effects of arthropod infestations. Paradoxically, many available sampling plans have originated from data collected from untreated fields (LATHEEF and HARCOURT, 1973; SHEPARD and CARNER, 1976; FINCH et al., 1978; WALKER et al., 1984) in order to: 1) allow development of large populations needed to produce a wide range in mean density, which statistically aids in producing a better fit to many regression-based indices, 2) eliminate pesticide toxicity or reentry concerns, or 3) avoid the difficulty and costs associated with pesticide application. In the study reported here, the impact of chemical treatment on the spatial distribution of arthropods, and hence on the genesis of biologically and statistically accurate sampling plans, was evaluated.

MATERIALS AND METHODS

The influence of pesticide application on the within-field dispersion of arthropods was investigated for *Tetranychus urticae* KOCH (Acari: Tetranychidae), the twospotted spider mite, on *Fragaria ananassa* (L.), commercial variety 'Tufts', strawberries. *T. urticae*, a major pest of California's one-half billion dollar strawberry industry, has a relatively short life cycle (CARY and BRADLEY, 1982) with a series of easily identified life stages. *F. ananassa* is densely planted as an annual in southern California, lasting approximately 7-8 months. This system produces an initially mite-free planting, which allows examination of *T. urticae* populations from the initial colonization phase through an exponential increase phase. Experimental plantings of 15 double row beds \times 82 m were maintained in Orange County, CA using standard commercial practices with the exception of pesticide applications, which were used as experimental treatments.

In both 1983 and 1984, the plantings were stratified into nine equal sections of 27.3 m by 5 beds, from which four plants per section were randomly sampled each week for

15 weeks. All trifoliates on each plant were treated using a wax-immersion technique which effectively killed all stages of *T. urticae* and thereby prevented migration between leaflets or continued development prior to examination (TRUMBLE et al., 1984). Plants were then transported to the laboratory and examined with a dissecting microscope for numbers of eggs (pretreatment only), immatures plus adult males, and adult females. Separate counts were made for the youngest, highest (i.e.: uppermost mature) and oldest trifoliates of each plant as these had differing levels of nitrogen, an indicator of amino acid content to which spidermites respond positively (HUFFACKER et al., 1969). The micro-Kjeldahl technique (McKENZIE and WALLACE, 1954) was used to determine that %N was significantly different between the oldest (2.86%) and the youngest (3.23%) or highest (3.24%) trifoliates ($n=20$ samples/group, $P \geq 0.05$).

Cyhexatin (Tricyclohexyltin hydroxide), was applied once each season at 0.855 kg/ha following five weeks of sampling. Although both crops were transplanted during the first week of November, sampling was not initiated until January, when *T. urticae* were first found in the field. Weekly sampling was continued through April of both years for at least 10 post-treatment counts.

Since each strawberry field was a continuum, *T. urticae* dispersion analyses were based on single plant counts, which corresponded to the "natural habitat unit" for sampling described by PATIL and STITELER (1974). GREEN's coefficient C_x (GREEN, 1966), selected for a proven lack of dependence on density (MYERS, 1978), was calculated for each weeks data using the formula:

$$C_x = (s^2/m - 1) / \sum x - 1,$$

where s^2 =variance, m =mean number of *T. urticae* per plant, and $\sum x$ =total number observed each week. Widely used index of spatial dispersions calculated by the regression method proposed by IWAO (1970) and IWAO and KUNO (1971) was then included. Values for IWAO's index were generated by solving the formula:

$$\hat{m} = a + \beta m,$$

where a =the intercept on the ordinate, β =the slope of the regression line when $\hat{m} = m + (s^2/m - 1)$. The parameters a and b of TAYLOR's power law (TAYLOR, 1965) $s^2 = am^b$, were estimated from the regression equation:

$$\log (s^2) = \log (a) + (b) \log (m),$$

where a and b =the intercept and regression coefficient, respectively. TAYLOR's power law was included in this study due to a proven effectiveness in many theoretical and empirical situations in a variety of disciplines and because of the many sampling procedures and applications which have been based on this index. Students t -tests were used to test the hypotheses that $a=0$ and $b=1$, as well as for documenting if values of a and b were significantly different between analyses.

RESULTS AND DISCUSSION

All indices were in agreement: *T. urticae* populations were more aggregated prior to pesticide application. GREEN's index, where a value of one is considered highly aggregated and a value of 0 is random, averaged above 0.34 in both years during this period for all stages examined (overall C_x range: 0.72 in week one to 0.06 in week 5, $\bar{x}=0.34$, $SD=0.26$). In the week immediately following chemical treatment, C_x was 0.19 and 0.24 in 1983 and 1984, respectively (overall C_x post-treatment range: 0.24 to 0.01, $\bar{x}=0.09$, $SD=0.06$). Similar results were evident with both IWAO's and TAYLOR's regression techniques which generated significantly greater slopes ($P \geq 0.01$) prior to treatment, indicating these populations were more aggregated (Table 1). Biologically, these results were descriptive since migrating females reproduced rapidly, creating a situation where a few plants had large numbers of spidermites and most had none. As densities increased, intra-field dispersal accelerated and the population distribution became less aggregated as the available niches were utilized. However, following the density-independent mortality factor of pesticide application, the density of survivors remaining to initiate the population (female density 1983=0.43/plant; 1984=1.09/plant) was inherently more uniform than that of the original migrating adults (1983=1.57/plant; 1984=2.31/plant). Removal of organisms in a density-independent fashion left the survivors with a density reduction of 99.96% for all life stages excepting eggs in 1983

Table 1. Pre and post-treatment *T. urticae* dispersion on *P. ananassa* as measured by TAYLOR's power law, $s^2=am^b$, and IWAO's regression, $m=a & \beta$.

Year	Stage of Development	Pre-Treatment			Post-Treatment		
		<i>a</i>	<i>b</i>	r^2	<i>a</i>	<i>b</i>	r^2
TAYLOR's power law							
1983	Eggs	3.56	1.91	0.987	—	—	—
	Immatures & adult males	2.95	1.91	0.982	3.09	1.60	0.948
	Adult females	2.64	1.84	0.949	1.93	1.47	0.925
	Active stages	2.80	1.92	0.976	2.61	1.60	0.917
1984	Eggs	2.71	1.90	0.967	—	—	—
	Immatures & adult males	3.95	1.85	0.980	2.72	1.78	0.940
	Adult females	1.70	1.88	0.930	2.04	1.67	0.920
	Active stages	2.27	1.95	0.979	2.20	1.82	0.957
IWAO's regression							
1983	Eggs	30.06	3.02	0.923	—	—	—
	Immatures & adult males	14.12	2.57	0.892	25.05	1.21	0.949
	Adult females	4.05	2.42	0.736	2.35	1.19	0.989
	Active stages	15.98	2.50	0.873	25.87	1.17	0.959
1984	Eggs	-2.39	2.79	0.887	—	—	—
	Immatures & adult males	30.99	2.50	0.875	15.03	1.99	0.906
	Adult females	3.29	2.58	0.866	5.39	1.66	0.888
	Active stages	25.56	2.46	0.882	40.49	1.72	0.883

and 99.97% in 1984, and with a distribution only slightly more aggregated than that found immediately prior to the treatment. Although favored niches on the plant could cause mortality to be less than entirely density dependant, the mortality for both years was quite similar, in spite of different densities at the time of treatment (adult females 1983=19.86/plant; 1984=50.26/plant. The slight and transient increase in aggregation following chemical treatment was expected, since some colonies were eliminated and coverage could not be entirely uniform.

Less aggregated distributions occurring after pesticide application had considerable influence on sampling procedures. Statistically, far less effort was necessary to estimate mean density per plant when *T. urticae* populations approached randomness. For example, GREEN's formula (GREEN, 1970) for estimating mean density at a precision level (D_o) of 0.25 was calculated by solving:

$$\log T_n = \frac{\log(D_o^2/a)}{b-2} + \frac{b-1}{b-2} \log n$$

where T_n =the cumulative number of *T. urticae* counted, a and b were the intercept and slope parameters of TAYLOR's power law, and n =the number of samples collected. In 1983, a 0.25 precision level required counts of 1,380,364,265 mites (excluding eggs) prior to treatment, and 47,672 following treatment for 10 whole plant samples. Cumulative *T. urticae* counts from 20 plants required 356 pretreatment and 126 post-treatment.

IWAO's technique for developing sequential sampling plans based on a critical density (Iwao, 1975) was similarly affected by changes in dispersion (Fig. 1). For an arbitrarily selected density of 60 mites per plant, the upper and lower limits were calculated with 75% confidence with the following formulas:

$$\text{upper limit} = nm_o + t\sqrt{n[(\alpha+1)m_o + (\beta-1)m_o^2]}$$

$$\text{lower limit} = nm_o - t\sqrt{n[(\alpha+1)m_o + (\beta-1)m_o^2]}$$

with n =the number of plants sampled, m_o =critical density, t =the t value for 75% confidence, and α and β =the intercepts and slopes produced by IWAO's regression of \bar{m} on the mean. In application, randomly chosen plants are sampled in sequence, and sampling stops when the cumulative number of *T. urticae* falls outside of the area between the upper and lower limits. Since the area of "no decision" is smaller for post-treatment counts, decisions may be reached more rapidly.

There was an additional reason for separating pre and post-treatment sampling plans. Although the pretreatment data from 1983 and 1984 could be analyzed together since neither the α or β values differed significantly at the $P \geq 0.05$ level, the same was not true for post-treatment counts. Variability in pesticide effectiveness due to differences in coverage, residue deposits and weather combined to influence the pattern of survivors, leading to dissimilarity in distribution. Such similarity in dispersion for pretreatment populations and dissimilarity in post-treatment populations were observed for all stages (excluding eggs) using both IWAO's and TAYLOR's regression methods. Thus, inequality in aggregation patterns following chemical application, and hence effectiveness and

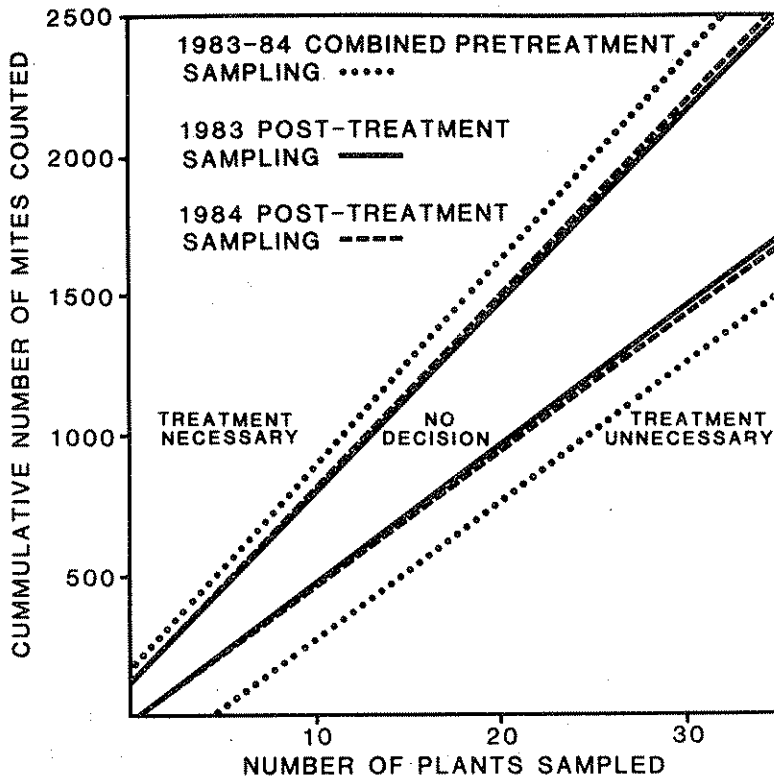


Fig. 1. Sequential sampling based on Iwao's regression parameters and a critical density of 60 active stages of *T. urticae* per plant. In operation, plants are sequentially sampled until the cumulative no. of mites falls above or below the region between the lines. Note that the area requiring additional samples is much larger prior to pesticide application.

statistical reliability of sampling, is a problem which must be addressed when new sampling plans are developed.

A solution to this problem which proved applicable to the *T. urticae*-*F. ananassa* system was to use a binomial (presence-absence) sampling program which permits large numbers of samples to be rapidly collected in the field. Based on a technique originally developed for monitoring *Heliothis* species in Australian cotton (WILSON and ROOM, 1983), this sampling plan was generated for pre and post-treatment populations using the following equation:

$$P(I) = 1 - e^{-x} [\ln(ax^{b-1})(ax^{b-1}) - 1]$$

where $P(I)$ = the proportion of infested plants and the values of a and b are the parameters of TAYLOR's power law. A density treatment level of 20 active stages of *T. urticae* per mature leaflet, which is currently used by growers in California (Dr. R. NELSON, Driscoll Associates, Personal Communication, 1984), was extrapolated to 15 for the trifoliolate samples used in the present study. Since the dispersion parameters for TAYLOR's power law were not significantly different (t -test, $P \geq 0.05$) between the highest trifoliolate and the entire plant for either pre or post-treatment counts, the binomial sampling plan

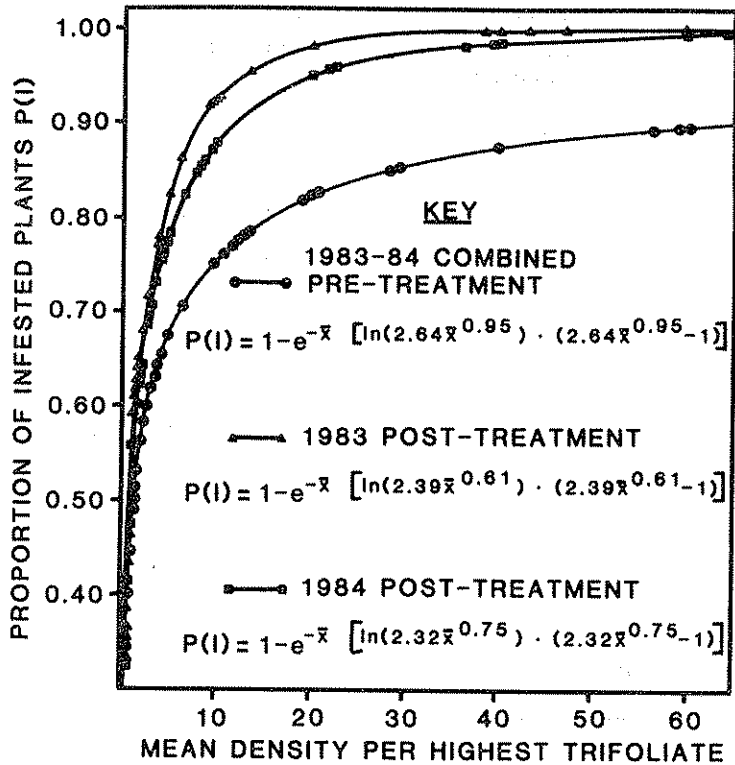


Fig. 2. Binomial sampling scheme for *T. urticae*. At the critical density of 60 active stages per trifoliolate, the $P(I)$ for post-treatment samples are nearly in agreement. The much lower $P(I)$ for pretreatment samples was due to greater aggregation. Sample points on lines refer to observed mean densities, showing that the data adequately represented the range of densities presented.

presented in Fig. 2 was based on the presence or absence of active stages on the highest trifoliolate. This greatly simplified sampling procedures in the field. If the critical value of 60 mites per trifoliolate were used as suggested by OATMAN et al. (1981), the variability between 1983 and 1984 post-treatment dispersions were reduced, but the slopes of the lines were not significantly different from zero. Thus this technique is less useful at the higher levels of density since small changes in the vertical axis relate to large movements along the horizontal axis.

If differences in distribution caused by pesticide use were ignored, and the data analyzed over the entire season, dispersions were skewed artificially toward randomness (ex: active stages 1983: $s^2=2.61 m^{1.60}$, $r^2=0.919$; $\bar{m}=38.55+1.21 m$, $r^2=0.896$; 1984: $s^2=2.30 m^{1.86}$, $r^2=0.955$; $\bar{m}=63.33+1.75 m$, $r^2=0.873$). Therefore, even though these analyses produced robust coefficients of determination, sampling plans developed from the regression parameters were inaccurate and biologically unrealistic.

Although these results are not applicable to all agricultural or biological systems, the implications of changing distributions following the application of pesticides have far reaching significance. Those researchers involved in sampling must now consider

not only the modification of sampling plans to account for changes in distribution following chemical use, but must also consider the possibility that the population distributions of organisms may not be equivalent between years with, or even occurrences of, mortality factors such as pesticide application.

Further, those sampling plans developed for use in agriculture which are based on data from treated fields may actually lead to economic losses if used with crops which have not had pesticide applications. For example, Fig. 2 demonstrates that treatments at a critical density of 15 mites/trifoliolate should correspond with an infestation level of approximately 50% in treated fields. However, if the proportion of infested plants reaches 90% for pre-treatment populations, the crop would be destroyed.

SUMMARY

The influence of pesticide application on the within-field distribution of arthropods was investigated for *Tetranychus urticae*, the twospotted spider mite, on strawberries. Analyses of dispersions based on GREEN's coefficient, IWAO's regression of mean crowding on the mean, and TAYLOR's power law all indicated that mite populations were highly aggregated initially. As densities increased, more of the available niches were filled, leading to a less clumped dispersion. However, pesticide applications causing greater than 99.9% mortality acted in a nearly density independent fashion and, although the originating populations were similar in number, did not produce dispersions equivalent to the initial migrants. As a result, ignoring these changes by developing sampling plans based on dispersion indices which generated a single slope for an entire data set, led to statistical errors that invalidated the sampling programs. In order to accurately reflect the field biology of the spidermites, sampling plans for pre and post-treatment populations were substantially different.

The impact of such changes in dispersion were graphically demonstrated using both sequential and binomial sampling techniques. Both methods showed that fewer samples were necessary to estimate densities at a given precision level for post-treatment populations. Also, these techniques indicated that post-treatment populations had similar, but significantly different, dispersions. The implications of changes in pre and post-treatment dispersions, as well as problems associated with inconsistent dispersions following pesticide use, are discussed.

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農業施用に伴う節足動物の空間分布の変化に対する考察

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節足動物の圃場内分布に対する農業施用の影響を、イチゴに寄生するナミハダニ *Tetranychus urticae* について調べた。GREEN の係数、歳による平均に対する平均こみあい度の回帰法、及び TAYLOR の power law に基づく解析の結果、これらすべての解析法は、ハダニの個体群が初期には強い集中分布をしていたことを示した。そして密度が高まるにつれて利用できる空間が満たされて、分布の集中度が低くなった。しかし、農業施用の結果、ほぼ密度独立的にハダニの99.9%以上の死亡率が生じ、残された個体群は、初期の移入個体群と比べて個体数は同じ位であったが、分布の型は異なっていた。その結果、このような変化を無視して、すべてのデータセットに1本の直線を当てはめることによって得られた分布示数に基づく標本抽出計画を開発しても、標本抽出設計を無意味にするような統計的誤差が生じることになる。従って、ハダニの野外生態を正確に反映させるためには、農業施用前と施用後の個体群に対して異なった標本抽出計画を立てる必要がある。そのような分布様式の変化が逐次抽出法及び binomial sampling technique (存在頻度法) の計画に対してどのような影響をもたらすかを図によって示した。どちらの方法においても所定の精度で密度を推定するための必要標本数は、一般に農業施用後の個体群の密度を推定する場合の方がより少なくて済むことは明らかであったが、この場合個々の個体群の分布特性にはある程度の変異がみられた。