Does Pesticide-Induced Activity of Twospotted Spider Mite (Acari: Tetranychidae) Really Contribute to Population Increases in Orchards?

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ABSTRACT The effect of pesticides on the population density, dispersion, and activity of the twospotted spider mite, Tetranynchus urticae (Koch) (Acari: Tetranychidae) was investigated under field and laboratory conditions on tart cherry, Prunus cerasus L. In the laboratory, the pesticides permethrin, phosmet, and phosalone significantly increased the time spider mites were active, whereas the pesticide azinphosmethyl did not significantly affect activity. In the field, by 12 d after pesticide application, mite populations on all pesticide-treated trees were significantly higher than those on the water-sprayed control trees. Analysis of these populations showed that no significant differences in dispersion occurred on any treatment between the evaluation 2 d before application and the evaluation 2 d after application. These facts, combined with the very low numbers of predators observed in this test, suggest that pest resurgence is probably not a result of increased mite activity, but is instead related to a pesticide’s ability to stimulate mite physiology, either directly or indirectly, through changes in host plant nutritional value.

KEY WORDS Arachnida, Tetranynchus urticae, dispersion, pest resurgence


Recently, several researchers (Penman et al. 1981, 1986; Penman & Chapman 1983; Iftner & Hall 1983; Iftner et al. 1986) have revived an old hypothesis (Davis 1952a) that spider mite resurgence may also occur because some pesticides increase locomotor activity. The increased locomotor activity is thought to result in dispersal from dense colonies that may increase the reproductive potential of the population as a whole because of reduced intraspecific competition (Davis 1952a,b; Iftner & Hall 1983). However, the strength of this hypothesis is reduced considerably because these same studies also demonstrated that feeding inhibition and reduced egg laying occur concurrently with the increased activity patterns (Davis 1952a, Penman et al. 1981, Iftner & Hall 1983, Iftner et al. 1986).

Close examination of the above hypothesis suggests that even if feeding inhibition and reduced egg laying do not occur, at least three conditions must be met simultaneously for pest resurgence to take place from this mechanism alone: (1) the pesticide affects behavior, (2) before pesticide application, intraspecific competition is significantly depressing the population’s reproductive capacity, and (3) in response to the pesticide, mite populations change their interleaf distribution (=dispersion) in a manner that reduces intraspecific resource exploitation. Although direct testing of condition 2 in the field is somewhat difficult, condition 3 can be tested relatively easily.

When the population is increasing to higher levels, the only way that intraspecific competition can be reduced is to decrease the degree of population clumping (i.e., dispersion). Therefore, a test of condition 3 can be performed by measuring the dispersion of the population before and after the application of a pesticide that is known to affect behavior. This test has the advantage that the proposed mechanism of dispersal does not need to be observed directly; only the result (a more uniform dispersion and increased population levels) is necessary to decide the validity of condition 3.

I began these studies to determine if condition 3 occurs for populations of the twospotted spider mite, Tetranynchus urticae (Koch) (Acari: Tetranychidae), treated with pesticides that affect behavior on tart cherry (Prunus cerasus L.) in Utah.
used laboratory studies to evaluate pesticide effects on behavior and field studies to ascertain changes in mite dispersion and population density caused by pesticide application.

**Materials and Methods**

**Spider Mite Activity.** A twospotted spider mite colony was maintained in the laboratory on 'Fordhook' lima beans (*Phaseolus lunatus* L.) at 25°C and 14:10 (L:D) photoperiod. The parental colony was collected from tart cherry trees in Box Elder County, Utah, in summer 1988.

Tart cherry leaves were dipped in a pesticide suspension (azinphosmethyl as Guthion 50 wettable powder [WP] [Dow Chemical Company, Midland, Mich.], phosalone in Zolone 25 WP [Rhone-Poulenc Ag Company, Research Triangle Park, N.C.J], phosmet as Imidan 50 WP [ICI Americas, Wilmington, Del.], or permethrin as Pounce S.2 emulsifiable concentrate [FMC Corporation, Philadelphia]) or in a distilled water control and allowed to air dry. Pesticides were applied at a single rate of 0.65, 1.64, 1.64 g, and 1.9 mg (AI) per liter of water for azinphosmethyl, phosmet, phosalone, and permethrin, respectively. Pesticides were mixed no more than 5 d before use and were kept refrigerated at 3°C until used. Leaves were placed abaxial side up (i.e., lower surface up) on water-saturated paper toweling in a Petri dish. Strips of toweling were used to form an arena on the leaf of 2.5 by 2.5 cm. A single mature female mite was selected randomly from the colony and placed in the arena for a 1-h acclimation period. The activity of the mite was video-taped during the second hour at ½ normal speed using a time-lapse video recorder (TLC 1550, Gyyr Products, Anaheim, Calif.) connected to a video camera (model GX-N4, JVC Company of America, Elmwood Park, N.J.). A 50-mm macro lens (Canon USA, Lake Success, N.Y.) was substituted for the normal JVC lens to provide sufficient resolution and light sensitivity. At the end of the second hour, each mite was prodded with a fine camel’s-hair brush to be sure it was still alive. Only mites that were active and did not show any signs of distress when prodded were used in the analysis. All experiments were conducted inside a temperature cabinet at 25°C and approximately 15% RH.

When 30 mites had been video-taped for each treatment (using different leaves and mites for each replicate), the film was reviewed at normal speed and the time mites spent being active was determined using a stopwatch. Times reported and analyzed were multiplied by 6 to determine the actual time spent being active. If the mite was immobile it was assumed to be feeding, ovipositing, or resting. Mean differences among treatments were evaluated using analysis of variance and a protected least significant differences (LSD) test at P = 0.05 (Little & Hills 1978). A log(x + 1) transform was used before analysis; back-transformed means are presented.

**Laboratory Toxicity Tests.** To determine if pesticide toxicity had any effect upon field populations, pesticide toxicities at the above rates were assessed. Tart cherry leaves were dipped into either a pesticide suspension (as described above) or distilled water and allowed to air dry. Twenty adult females were added per leaf, placed in a temperature cabinet at 25°C with a photoperiod of 14:10 (L:D), and mortality was assessed 24 h later. Each treatment was replicated five times for a total of 100 adult females evaluated per treatment. Differences among treatments were evaluated using analysis of variance and a protected LSD test performed on sin⁻¹√% Mortality (Little & Hills 1978). Back-transformed means are presented.

**Effect on Field Populations and Dispersion.** A plot of approximately 2 ha of tart cherries planted on a 7.7-m square grid was located in the Willard area of Box Elder County. The experiment was set up as a randomized block design with five replicants. Trees were approximately 12 yr old and 4 m high. Five mites per tree per sampling date were mounted in Hoyer’s medium (Krantz 1978) for later identification to species.

Pesticides were applied by handgun at 2.1 kg/cm² until runoff on 10 August 1988 at the same rates used in the laboratory tests. Control trees were sprayed with water only. Mite densities and dispersion were evaluated 2 d before treatment, and at 2, 12, 19, and 26 d following treatment. The trees were sampled for spider mites and the Western orchard predatory mite, *Typhlodromus occidentalis* Nesbitt (Acari: Phytoseiidae), by randomly selecting 25 leaves from the periphery of each tree between 1 and 2 m off the ground (Jones 1990). Samples were bagged, placed in an ice chest, and returned to the laboratory. Population levels were assessed by examining and recording the number of mites on each leaf separately.

Analysis of field data considered mean populations as well as mite dispersion within the trees. Differences in population densities were analyzed with a randomized block design ANOVA (Wilkinson 1986) performed on log(x + 1) transformed data for each sampling day. A protected LSD test at P = 0.05 was used for separation of treatment means (Little & Hills 1978). A repeated-measures ANOVA (Wilkinson 1986) was used to determine if significant differences in the population levels of *T. occidentalis* were found between treatments for the entire duration of the test.

Dispersion analysis was performed using bootstrap estimates of Green’s index (1966) (Cₘ = (s²/m − 1) / (ΣX − 1)), where s² is the sample variance, m is the sample mean and ΣX is the total number of individuals per sample), and Morisita’s index (1959) (Iₘ = N / [ΣX² − ΣX] · (ΣX³ − ΣX)⁻¹), where N is the number of samples taken). Green’s index ranges from −1/(N − 1) (uniform) to 1 (clumped), whereas Morisita’s index varies from
Table 1. Effect of selected pesticides on the activity of twospotted spider mite in laboratory bioassays

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Min active/h (±SEM)</th>
<th>% Increased activity from control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>15.6 (2.0)a</td>
<td>—</td>
</tr>
<tr>
<td>Azinphosmethyl</td>
<td>16.2 (2.4)a</td>
<td>4</td>
</tr>
<tr>
<td>Phosalone</td>
<td>24.1 (2.1)b</td>
<td>54</td>
</tr>
<tr>
<td>Phosmet</td>
<td>23.3 (2.5)bc</td>
<td>88</td>
</tr>
<tr>
<td>Permethrin</td>
<td>35.1 (3.3)c</td>
<td>125</td>
</tr>
</tbody>
</table>

Means within the same column followed by the same letter are not significantly different at P = 0.05 according to ANOVA and protected LSD test performed on log(x + 1) data.

1 − [(N − 1)/2ΣX − 1] (uniform) to N (clumped). These two indices were chosen because of their theoretical independence from changes in m and ΣX (Green 1966). Bootstrap techniques (Efron & Tibshirani 1986) were used to resample the data randomly for each treatment 100 times per sampling day; this provided estimates of the mean dispersion and SEM for each estimate. Comparisons of dispersion indices within a treatment were performed using a z test assuming unpaired observations and unequal variances using the bootstrap estimates of the mean and SEM for each index (Little & Hills 1978). Two comparisons of dispersion were made to determine the effects of pesticides: (1) preapplication (−2 d) versus +2-d sample and (2) preapplication versus +26-d sample.

Results

Spider Mite Activity. Mite activity varied significantly among pesticide treatments (F = 11.02; df = 4, 135; P < 0.0001) (Table 1). Mites on permethrin residues spent 125% more time moving than mites on the control leaves. Increased activity also was observed with mites on leaves treated with phosalone (54% increase) or phosmet (88% increase). Only mites on the leaves treated with azinphosmethyl exhibited no significant increases in activity (3.6% increase) compared with mites on the control leaves.

Laboratory Toxicity Tests. There were significant differences in mite mortality among those placed on different residues (F = 22.04; df = 4, 20; P > 0.001). There were no significant differences in mortality between the control leaves (3.8%) and the leaves treated with permethrin (0.9%) (P = 0.05, LSD test); however, mites placed on leaves treated with phosalone and phosmet exhibited a significant increase in mortality (P = 0.05, LSD test) over the control (28 and 35%, respectively). Mites on azinphosmethyl residues experienced a significantly higher mortality (56.7%) than those on any other treatment (P = 0.05, LSD test).

Effect on Field Populations and Dispersion. Microscopic examination of mites collected from each tree in the plot each day mites were sampled showed that 98.6% (517/524) of the mites mounted were T. urticae, and 1.4% (7/524) were the McDaniel spider mite, Tetranychus medanieli McGregor.

Except on the sampling date 2 d after application, all pesticides evaluated had significant effects on T. urticae population levels (Table 2). Populations on control and treated trees were reduced between the sample 2 d before application and the evaluation 2 d after application, probably as a result of the physical removal of mites by pesticide application. By 12 d after spray and continuing until the last sample, all treated trees had significantly higher populations of T. urticae than the control trees (Table 2). By the evaluations at 19 and 26 d, populations on trees treated with permethrin were significantly higher than on all other treatments. However, pest resurgence per se occurred only on the trees treated with permethrin, where populations increased significantly over preapplication levels (ANOVA, F = 38.5; df = 1, 3; P = 0.008).

Predator populations were low on all trees (106 T. occidentalis collected on 3,125 leaves over the entire test). The repeated-measures ANOVA showed that predator populations on the phosalone treatments were significantly lower than populations on all the other treatments (F = 3.83; df = 4, 20; P = 0.02, only one predator collected over entire test), with no significant differences occurring between the other treatments.

No significant differences (P = 0.05) in dispersion of T. urticae were evident between the samples 2 d before and 2 d after according to either Green’s or Morisita’s index (Table 3). This shows that increased locomotor activity observed in the laboratory studies does not translate into a more uniformly distributed population. Comparisons of

Table 2. Mean number of the twospotted spider mites per leaf (±SEM) at different times following pesticide application on tart cherry during summer 1988 at Willard, Utah

<table>
<thead>
<tr>
<th>Treatment</th>
<th>−2</th>
<th>2</th>
<th>12</th>
<th>19</th>
<th>26</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permthrin</td>
<td>5.56 (1.25)a</td>
<td>2.23 (1.13)a</td>
<td>5.96 (1.26)a</td>
<td>17.14 (1.30)a</td>
<td>18.30 (1.35)a</td>
</tr>
<tr>
<td>Phosmet</td>
<td>10.32 (1.49)a</td>
<td>3.19 (1.33)a</td>
<td>4.43 (1.17)b</td>
<td>4.37 (1.42)b</td>
<td>4.57 (1.40)b</td>
</tr>
<tr>
<td>Phosalone</td>
<td>8.86 (1.55)a</td>
<td>2.11 (1.21)a</td>
<td>3.27 (1.23)b</td>
<td>3.57 (1.30)b</td>
<td>7.14 (1.23)b</td>
</tr>
<tr>
<td>Azinphosmethyl</td>
<td>6.08 (1.35)a</td>
<td>2.26 (1.26)a</td>
<td>3.49 (1.29)b</td>
<td>2.95 (1.32)b</td>
<td>3.27 (1.19)b</td>
</tr>
<tr>
<td>Control</td>
<td>5.90 (1.30)a</td>
<td>1.29 (1.14)a</td>
<td>0.54 (1.11)c</td>
<td>0.64 (1.23)c</td>
<td>0.29 (1.11)c</td>
</tr>
</tbody>
</table>

Means within a column followed by the same letter are not significantly different at P = 0.05 according to ANOVA and protected LSD test. Analysis performed on log(x + 1) data, back-transformed means presented with standard errors (in parentheses).
Table 3. Effect of pesticides on dispersion of twospotted spider mite on tart cherry in Willard, Utah, at various times following pesticide applications

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Index</th>
<th>Days after treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>-3</td>
</tr>
<tr>
<td>Control</td>
<td>I&lt;sup&gt;c&lt;/sup&gt;</td>
<td>3.572 (0.515)</td>
</tr>
<tr>
<td></td>
<td>C&lt;sub&gt;s&lt;/sub&gt;</td>
<td>0.024 (0.004)</td>
</tr>
<tr>
<td>Azinphosmethyl</td>
<td>I&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.757 (0.902)</td>
</tr>
<tr>
<td></td>
<td>C&lt;sub&gt;a&lt;/sub&gt;</td>
<td>0.023 (0.007)</td>
</tr>
<tr>
<td>Phosmet</td>
<td>I&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.059 (1.164)</td>
</tr>
<tr>
<td></td>
<td>C&lt;sub&gt;b&lt;/sub&gt;</td>
<td>0.025 (0.010)</td>
</tr>
<tr>
<td>Permethrin</td>
<td>I&lt;sup&gt;d&lt;/sup&gt;</td>
<td>3.031 (0.421)</td>
</tr>
<tr>
<td></td>
<td>C&lt;sub&gt;d&lt;/sub&gt;</td>
<td>0.017 (0.003)</td>
</tr>
<tr>
<td>Phosalone</td>
<td>I&lt;sup&gt;e&lt;/sup&gt;</td>
<td>5.053 (1.126)</td>
</tr>
<tr>
<td></td>
<td>C&lt;sub&gt;e&lt;/sub&gt;</td>
<td>0.031 (0.009)</td>
</tr>
</tbody>
</table>

Bootstrap mean with SEM in parentheses.
<sup>a</sup>Morisita's index.
<sup>c</sup>Green's index.

the samples before application and 26 d after revealed that although there was a slight tendency towards a more uniform distribution, only in the case of the trees treated with phosalone (using Morisita's index) were the differences significant (z = 2.35, P = 0.05). However, because the increased locomotor activity observed in the laboratory was much greater on the leaves treated with permethrin and phosmet and no change in dispersion was detected on those trees, it is unlikely that the change in dispersion on trees treated with phosalone was the result of increased locomotor activity.

**Discussion**

These results show that *T. urticae* populations on tart cherry do not fulfill all the conditions necessary for resurgence to be induced by increased activity. Although the laboratory results further document pesticide-induced activity (condition 1 fulfilled for some pesticides), the field results do not support the contention that mite populations on treated surfaces distributed themselves more uniformly (condition 3 not fulfilled). Instead, results from the field studies showed that pesticide applications resulted in population levels that were independent of any changes in activity patterns noticed in laboratory studies.

Mite populations on trees treated with permethrin were the only ones that exhibited pest resurgence (i.e., levels were significantly higher after application than before application). However, the lack of concomitant changes in population dispersion suggested that pesticide-induced activity was not responsible for pest resurgence. This is supported, in part, by studies in other systems which show that when resurgence occurs, the rate of aerial dispersal by *T. urticae* does not increase above that observed at comparable population levels in a non-resurgence episode (Boykin & Campbell 1984). In addition, other factors such as the direct stimulation of reproduction have been observed with permethrin on *Panonychus citri* McGregor (Acari: Tetranychidae) (Jones & Parrella 1984) and a similar effect on *T. urticae* reproduction has been reported for certain carbamates (Boykin & Campbell 1982) and organo-phosphate materials (Maggi & Leigh 1983).

There are several reasons why the increased locomotor activity detected under laboratory conditions does not necessarily translate into higher population levels in field situations. First, more time spent moving can translate into less time spent feeding. Davis (1952a) found that the egg production of *T. urticae* was depressed for the first 4 d after treatment and Iftner et al. (1986) showed this effect can continue for at least 3 d with permethrin. Given the relatively short oviposition period and high nutritional requirements of ovipositing females, this suggests that reproduction should actually decrease unless egg production is stimulated by other mechanisms. In addition, even if oviposition is only delayed or reduced for 3 d, it will significantly lower the population's intrinsic rate of increase (r<sub>m</sub>) (Carey 1982). Second, increased dispersal need not result in the population being significantly more uniformly distributed and better able to exploit available leaf resources (i.e., condition 3 is not necessarily met simply because increased activity occurs).

Significant intraspecific competition (condition 2) occurring before pesticide application may also be quite rare in commercial situations. Attia & Boudreaux (1964) working with *T. urticae* populations on lima beans found that the egg production of 20 adult females on a 2.54-cm-diameter leaf disk was depressed about 30% compared with the same size leaf disk with only 3 females present. Although there is a general conception that dense spider mite colonies (>20 individuals on a leaf) are fairly common, extensive studies of spider mite dispersion on tart cherry and apple in Utah during 1985–1988 reveal that these large colonies of *T. urticae* occur on only about 3.6% of the leaves sampled when the mean population level is 5 mites per leaf, 21.9% of the leaves at a mean of 10 mites per leaf and on
28% of the leaves at a mean of 15 mites per leaf (unpublished data). Even if pesticides influence dispersion, at mite densities that growers typically tolerate in Utah (mean <5–7 mites per leaf), they will likely have a minor effect on the population, because most of the reproductive females in the population are not experiencing significant intraspecific competition (i.e., condition 2 is not normally met in commercial situations). Even if condition 2 is met, Ifnner & Hall (1983) and Penman & Chapman (1983) show that mites tend to congregate on the nontreated portions of the plant, which would result in condition 3 not being fulfilled. For example, if poor pesticide coverage leaves a significant number of pesticide-free refugia, then population levels in those refugia may increase and intraspecific competition would actually decrease effective resource exploitation. Increased clumping could also happen if coverage is poor, no dispersal-inducing activity occurs, and the pesticide induces significant mortality. If coverage is fairly uniform, refugia would be rare and the net change in population dispersion would probably be minimal.

Although this study suggests that pesticide-induced activity does not contribute significantly to population increases following pesticide application in tart cherry orchards, pesticide-induced behavioral changes may be important in creating foci for outbreaks in agroecosystems where higher levels of spider mites are tolerated and the plant canopies are contiguous (see Wilson et al. 1987). The results of my study should not be construed to imply that natural spider mite dispersal (as opposed to pesticide-induced activity) is not an important component of spider mite population dynamics. Indeed, Boykin & Campbell (1984), Hoy et al. (1985), and others clearly document the dispersal potential of all active stages (particularly the adult females) of tetranychid mites and its effect on population dynamics.

Studies on pest resurgence have shown that it is an extremely complex phenomenon. Although a single factor may be dominant in some situations, I suggest that each case of pest resurgence is the result of a unique blend of reduced predation, dispersal (both natural and pesticide-induced), changes in host plant nutritional value, and/or sublethal effects on natural enemies and their prey. In the Utah tart cherry ecosystem, when populations of the Western orchard predatory mite are low to nonexistent, pest resurgence is probably caused by improved host plant nutrition or direct stimulation of spider mite reproduction, or both.

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References Cited


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