

AN ABSTRACT OF THE THESIS OF

John E. Dunley for the degree of Master of Science in Entomology presented on November 20, 1989.

Title: Comparative Emigration, Immigration, and Colonization of Apple by *Metaseiulus occidentalis* Nesbitt and *Typhlodromus pyri* Scheuten (Acarina: Phytoseiidae)

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Dispersal and colonization of young potted apple trees by the spider-mite predators *Metaseiulus occidentalis* Nesbitt and *Typhlodromus pyri* Scheuten were studied in the Hood River Valley of Oregon. Experimental mini-orchards of 10 four-year old potted apple trees were established at distances of 0, 10, and 100 m downwind from commercial apple orchards. Mini-orchards were inoculated with *Panonychus ulmi* and

Tetranychus urticae to provide a prey resource for predatory mites. The commercial orchards harbored either *M. occidentalis* or *T. pyri*, or both.

Emigration from the source orchards was estimated by the number of adult females found in mini-orchards located 0 m downwind. Immigration was measured by the initial presence of adult females in mini-orchards at 10 and 100 m. Colonization was interpreted as the presence of predatory mite eggs or nymphal stages in samples from the 10 and 100 m mini-orchards. Leaf samples were taken either biweekly (1987) or weekly (1988).

Metaseiulus occidentalis and *T. pyri* both emigrated from the source orchard trees to the experimental mini-orchards 0 m downwind. *Typhlodromus pyri* rarely immigrated to the mini-orchards 10 m downwind, while *M. occidentalis* reached the potted trees at 10 m soon after the mini-orchards were established. *Metaseiulus occidentalis* also immigrated to the experimental mini-orchards 100 m downwind, whereas *T. pyri* did not. In all cases, immigration of *M. occidentalis* to the experimental mini-orchards was more frequent than for *T. pyri*. Also at all sites, *M. occidentalis* colonized the young apple trees at a faster rate than did *T. pyri*.

**Comparative Emigration, Immigration, and Colonization
of Apple by *Metaseiulus occidentalis* Nesbitt and
Typhlodromus pyri Scheuten (Acarina: Phytoseiidae)**

by

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**Comparative Emigration, Immigration, and Colonization
of Apple by Metaseiulus occidentalis Nesbitt and
Typhlodromus pyri Scheuten (Acarina: Phytoseiidae)**

INTRODUCTION

Since the introduction of synthetic organic pesticides into horticultural practices in the 1940's, deciduous tree fruits throughout the world have been plagued by spider mite pests (Cranham & Solomon 1981). To limit pesticide-induced outbreaks of tetranychids, fruit-growers often choose short-term solutions such as chemical controls. Integrated pest management (IPM) seeks longer-range solutions based on biological controls, selective pesticides, and cultural methods which reduce pest populations yet preserve pest and predator mite ecology (Hoyt 1969; Croft & McGroarty 1975).

IPM programs for spider mites have been implemented worldwide, primarily using predaceous phytoseiid mites (Helle & Sabelis 1985). Two predaceous mite species which have been effectively employed are *Metaseiulus occidentalis* Nesbitt and *Typhlodromus pyri* Scheuten (Croft & Hoyt 1983; Helle

& Sabelis 1985). Both predators occur in the Pacific Northwestern United States, where their management has provided monetary savings for fruit growers (Hoyt 1969; Hoyt 1982; Croft & Hoyt 1983). In Washington state for example, \$5 million in savings per year over 14 years was attributed to control of spider mites in apple orchards by *M. occidentalis* (Hoyt 1982); similar benefits have been noted for *T. pyri* (Croft & Hoyt 1983).

Researchers have postulated that the use of *M. occidentalis* and *T. pyri* together would provide more effective control of spider mites than using either species alone (Wearing et al. 1978; Croft et al. 1990). However, *M. occidentalis* and *T. pyri* have dissimilar climatic preferences. *Metaseiulus occidentalis* occurs primarily in hot, arid regions and is often associated with *Tetranychus* spp. (Hoyt 1974; Hoy 1975); *T. pyri* occurs in more cool and humid environments, and its primary spider mite prey is the European red mite, *Panonychus ulmi* (Koch) (Van de Vrie et al. 1972; Helle & Sabelis 1985). Where the distributions of *M. occidentalis* and *T. pyri* do overlap, their predation attributes may be

complimentary: *M. occidentalis* increases rapidly in response to mite outbreaks, whereas *T. pyri* tends to regulate pest mites at low levels, but may be less able to rapidly respond to spider mite outbreaks (Hoyt 1969; McMurtry 1982; Helle & Sabelis 1985; Croft *et al.* 1990). These population dynamics are related to their predation behaviors: *M. occidentalis* is an obligate predator, requiring substantial mite densities to sustain populations (Pruszyński & Cone 1973; Helle & Sabelis 1985); *T. pyri* survives and reproduces while feeding on pollen, fungi, and plant juices, in addition to spider mites (Chant 1965; Dicke & DeJong 1988).

Both *M. occidentalis* and *T. pyri* occur in the Hood River Valley (HRV) of Oregon, a major apple and pear production area (Jorgenson 1964; Zwick 1972; Croft *et al.* 1990). This area is in a transition zone of climatic favorability for both species, having an annual rainfall of 65-100 cm. The HRV lies between the Eastern Cascades where rainfall averages 28-35 cm, and the Willamette Valley which has 100-150 cm. In their survey, Croft *et al.* (1990) found that *M. occidentalis* and *T. pyri* occurred together in some

orchards in the HRV. In general, however, *T. pyri* was present in older, more established orchards, whereas *M. occidentalis* was present in younger orchards. They suggested that different temperature and humidity preferences, and their colonization abilities may explain their local distribution patterns.

Immigration and colonization of orchards by predatory mites are affected by the species pool environment, or the wild plant and orchard habitat surrounding orchards (Liss et al. 1987). While predator species pools may be influenced by pesticides and prey levels, dispersal traits, such as the ability to emigrate, immigrate and colonize, also determine how phytoseiids will initially populate an orchard. These attributes are particularly important in explaining colonization of new plantings and orchards from which phytoseiids have been temporarily eradicated by chemical use. While much is known about the population dynamics of *M. occidentalis* and *T. pyri* (see Helle & Sabelis 1985), little research has been done on their dispersal and colonization in the field.

The objective of this study was to determine the comparative abilities of *M. occidentalis* and *T. pyri* to reach and colonize apple orchards. More specifically, to study: 1) their relative rates of emigration from different orchard species pools; 2) their abilities to immigrate to small mini-orchards placed at various distances from a source orchard; and 3) their abilities to colonize small mini-orchard apple trees after immigration.

MATERIALS AND METHODS

General Study Methods

This study was conducted in the lower Hood River Valley from May to October 1987 and 1988. To compare the dispersal and colonization of predaceous mites side-by-side, an equal ratio of *M. occidentalis* to *T. pyri* was sought in species pool orchard sites. Croft *et al.* (1990), in their survey of Phytoseiidae in the HRV, identified several sites where populations of both species occurred. Using their data as leads, several sites were initially surveyed in 1987. However, no sites with equal ratios were found, and the best sites available were those with a species ratio of 80:20 or less.

The Von Lubkin, Tallman, McCurdy, and Benton orchards studied in 1987 are located near the center of the HRV, within three miles of each other. Von Lubkin, McCurdy, and Benton were orchards of 6 ha or more each, while Tallman was a small organic orchard of approximately 80 trees. Red Delicious and/or Newtown apple varieties were grown at each site. IPM methods were used in the three commercial orchards,

and the number of pesticide applications used in each orchard for control of non-mite pests was similar. All orchards had a history of biological control of mites, with no miticides having been used for four or more years previous to 1987.

Rates of emigration, immigration and colonization of the two predatory mites were measured by placing mini-orchards of ten young potted apple trees at three different distances from the source orchards (see Figure 1). Mini-orchard trees were four-year old Red Delicious trees, pruned to a height of about six feet, and placed in 25 gallon plastic containers filled with a mixture of soil and barkdust.

Mini-orchards were established by June 1 on the predominantly downwind side of each source species pool orchard. At the orchards, one mini-orchard was placed within the orchard beneath the canopy (0m), but not touching source trees. A second mini-orchard was placed 10 m from the source pool orchard in an open field or pasture. The third was located across an open field or pasture, 100 m from the source pool orchard. The 100 m mini-orchards were at least 500 m

Figure 1. Schematic diagram of the typical experimental setup.

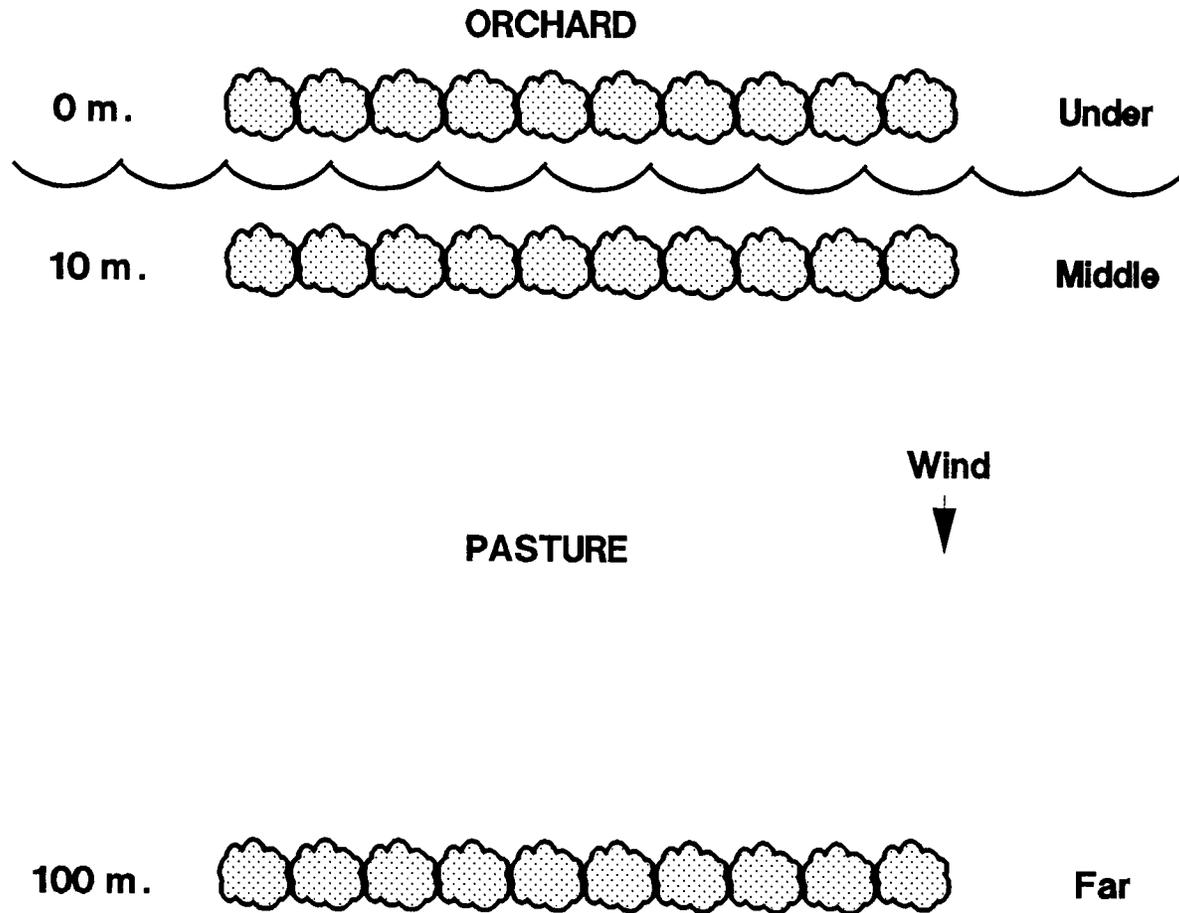


Figure 1.

from any orchard other than the source pool orchard. At the Tallman orchard it was not possible to have a 100 m treatment, as a commercial pear orchard was 300 m to the east.

Standard horticultural practices were used in the mini-orchards, including regular watering, pruning, and applications of fertilizer, with all trees receiving identical care. Trees were randomly assigned to mini-orchards. Before placing mini-orchard trees in the field they were sprayed with formetanate (Carzol, Nor-Am Ag. Products Inc.) and fenvalerate (Pydrin, Shell Chemical Co.). Both pesticides are highly toxic to predatory mites (Roush & Hoyt 1981, Hoyt *et al.* 1978; Babcock & Tanigoshi 1988). Samples were taken four to six times over a six-week period before May 15 to insure that no predatory mites inhabited the trees before they were exposed to experimental conditions. Also, because immigrating phytoseiids required food to colonize the small trees, prey mites were either placed in the trees (1987) or allowed to naturally colonize (1988) each mini-orchard (see further discussion below).

Samples were taken weekly, with 100 apple leaves collected at random from each mini-orchard. A corresponding 100 leaf sample was taken at each source pool orchard, bi-weekly in 1987 and weekly in 1988. Leaves were placed in paper bags, then put inside a plastic bag for storage at 4 C^o. Each leaf was examined in the laboratory using a 30X binocular microscope. Predator and prey mites were initially counted, then all predators removed and mounted on slides in Hoyer's solution. The slides were then cleared in a drying oven at 45 C^o and the phytoseiids identified to species and life stage (Chant 1965).

Groundcover and other vegetation surrounding the mini-orchards were sampled periodically to insure that they did not harbor significant populations of predatory mites which could serve as sources of immigrants and thus confound test results. These samples were inspected using a binocular microscope, then placed in Tullgren funnels with a 40-watt light bulb as a heat source (Schuster and Pritchard 1963). Lima bean leaves infested with *Tetranychus urticae* Koch were placed in a jar of water tightly sealed to the bottom of the funnel. Samples remained in the

funnels for two to seven days, until the vegetation was desiccated. Any predatory mites present in samples were collected from bean leaves and mounted in Hoyer's solution for identification (Chant 1965).

Emigration from the source orchards was estimated by the number of adult females found in the 0m mini-orchards. Immigration was measured by the initial presence of adult females in mini-orchards at 10 and 100 m. Colonization was interpreted as the presence of predatory mite eggs or nymphal stages at the two more distant sites. Once a tree was colonized, immigration could only be inferred by the ratio of adult females to immature stages.

Statistical interpretation of data was made using a two-way analysis of variance (ANOVA). A $\log(x+1)$ transformation of data was used to achieve a normal distribution and satisfy the requirements for the analysis of variance. Differences between means for treatments were tested using Fisher's Protected LSD (Petersen 1985).

1987 Studies

Mini-orchards were established at all four species pool orchards in 1987. Two orchards, Von Lubkin and Tallman, initially contained only *T. pyri*, while *M. occidentalis* was the only species at Benton. McCurdy had predominantly *M. occidentalis*, with low levels of *T. pyri*. *Panonychus ulmi* was the dominant prey at all four orchards. *Aculus schlechtendali* (Nalepa) was also present at all sites.

Because of the limited number of mini-orchard trees available (120), no replications were made in 1987. The establishment of one set of mini-orchards at each site allowed for the surveys to be made of dispersal and colonization by each predatory mite, but direct side-by-side comparison was not possible.

In 1987, prey presence was evaluated for its influence on the colonization of mini-orchards by predators. For each mini-orchard site, five of ten trees were randomly inoculated with *T. urticae* and the other five with *P. ulmi*. *Aculus schlechtendali* could not be eliminated from mini-orchards. Prey levels in mini-orchard trees were monitored

throughout the season, as were the number of immigrating and colonizing predators.

Statistical analysis of 1987 data was performed on data for each mini-orchard distance treatment and species pool orchard. Mean densities of mites were compared using Fisher's Protected LSD (Petersen 1985).

1988 Studies

In 1988, study was limited to the Von Lubkin and McCurdy species pool orchards because *M. occidentalis* and *T. pyri* were both present to some degree. At Von Lubkin, a design using four replications of mini-orchards at each treatment of 0, 10, and 100 m was employed. Multiple replications were not used at McCurdy, but the site provided a mixed population of both predator species. Within each orchard, differences between mean densities for each species for each treatment were compared using Fisher's Protected LSD (Petersen 1985).

RESULTS AND DISCUSSION

Seasonal Mite Species Trends in Study Orchards and Mini-Orchards

The relative densities of predatory and prey mites present over the 1987 and 1988 seasons in each orchard species pool are summarized in Table 1. Prey mite data for mini-orchards are also included. Predator mite data for the mini-orchards were dependent upon experimental treatments; these data are presented later.

In 1987, two of the four source species pool orchards contained *M. occidentalis* as the dominant phytoseiid, while in the other two *T. pyri* dominated (Table 1). The Von Lubkin and McCurdy species pool orchards contained both predatory mite species in 1988.

Panonychus ulmi was the dominant prey species in the species pool orchards in both 1987 and 1988 (Table 1). Researchers have shown that *T. pyri* prefers *P. ulmi* over *T. urticae* (Van de vrie et al. 1972; Dicke & DeJong 1988), while *M. occidentalis* favors *T. urticae* (Hoyt & Caltagirone 1971; Hoyt et

Table 1. General trends of predatory and prey mite densities in species pool orchards and mini-orchards sampled in 1987 and 1988.

1987	Prey			Predators	
	<i>P. ulmi</i>	<i>T. urt.</i>	<i>A. sch.</i>	<i>M. occ.</i>	<i>T. pyri</i>
<u>Species Pool Orchard</u>					
Von Lubkin	*** ¹	*(L)	+ ²	*(L)	**
Tallman	*	T	++	T	*
McCurdy	***	T	++	**	*
Benton	**	0	+	**	0
<u>Mini-orchards</u> ³	**	**	+	--	--
<u>1988</u>					
<u>Species Pool Orchard</u>					
Von Lubkin	**	**	+	*	**
McCurdy	**	*	++	**	*
<u>Mini-orchards</u> ³	**	*	+	--	--

¹ * = low seasonal densities (0.1-1.0/leaf), ** = moderate seasonal densities (1.0-10.0/leaf), *** = high seasonal densities (>10.0/leaf), T = trace (<0.1/leaf), (L) = late season only

² + = 1-50/leaf, ++ = 50-100/leaf

³ This represents the amount of prey in the mini-orchards when they were initially placed in the field. For predatory mite densities, see discussion of immigration and colonization of the mini-orchards.

al. 1979; Sabelis & Van de Baan 1983). The abundance of *P. ulmi* would seemingly favor *T. pyri*; however, the dominance of *P. ulmi* was not the only factor determining the presence of predatory mites at species pool or the mini-orchard sites. Since both predators feed and reproduce on apple rust mite (Chant 1965; Helle & Sabelis 1985), the presence of *A. schlechtendali* in orchard trees may have allowed for development of either *M. occidentalis* or *T. pyri*, irrespective of the spider mites present. Croft et al. (1990) found little correlation between prey species and the distribution of *M. occidentalis* and *T. pyri* in commercial orchards at HRV.

In Table 2, densities of predatory mites in mini-orchard trees inoculated with *P. ulmi* versus *T. urticae* are presented. There was no significant difference in densities of predators in trees infested with either prey species. However, as in the species pool orchard trees, both phytoseiids may have had adequate apple rust mite to reproduce. The actual extent of feeding by predators on individual prey mites was unknown. Thus, while the analysis of prey as a factor did not eliminate the influence of

Table 2. Mean number of adult predatory mite females/leaf collected from mini-orchard trees inoculated with different prey species at four sites in 1987. No significant differences were observed between prey treatments at each orchard.

Species/Orchard	Prey		SE ¹
	<i>P. ulmi</i>	<i>T. urticae</i>	
<i>T. pyri</i>			
Von Lubkin	0.819	0.631	0.100
Tallman	0.407	0.375	0.055
<i>M. occidentalis</i>			
McCurdy	0.979	0.893	0.123
Benton	1.014	1.312	0.148

¹ SE = Standard error for prey treatment means from within each experimental orchard

A. schlechtendali, it did establish that both predatory mite species were able to colonize the mini-orchard trees regardless of which spider mite was present.

Table 3 presents the overall seasonal trends of predatory and prey mite densities in species pool orchards. In some cases, a significant increase in predators was seen seasonally, along with a reduction in pest mites. At Benton (1987), prey populations were almost eliminated by predatory mites. At Von Lubkin, however, in both 1987 and 1988 *T. urticae* increased seasonally to moderate levels, despite appreciable *T. pyri* and some *M. occidentalis*.

Biweekly Predatory Mite Trends in Study Orchards and Mini-Orchards in 1987

Von Lubkin

Croft et al. (1990) reported a predatory mite ratio of 26:74 *M. occidentalis*:*T. pyri*, with densities of .40-1.04 per leaf at Von Lubkin in 1985-1986. In 1987, 1.11 phytoseiids per leaf were found, with a species ratio of 6:94 *M. occidentalis* to *T.*

Table 3. Seasonal trends in predator and prey mite densities at the experimental species pool orchards, 1987-1988. Data is expressed in mites per leaf per five sample dates.

Year/Orchard	<u>Early Season</u>					<u>Mid-Season</u>					<u>Late Season</u>				
	<u>Pest Mites</u> ¹			<u>Preds</u> ²		<u>Pest Mites</u>			<u>Preds</u>		<u>Pest Mites</u>			<u>Preds</u>	
	<u>ERM</u>	<u>2SSM</u>	<u>ARM</u>	<u>Mo</u>	<u>Tp</u>	<u>ERM</u>	<u>2SSM</u>	<u>ARM</u>	<u>Mo</u>	<u>Tp</u>	<u>ERM</u>	<u>2SSM</u>	<u>ARM</u>	<u>Mo</u>	<u>Tp</u>
<u>1987</u>															
Von Lubkin	.53	.03	+ ³	0	.16	2.9	.29	+	.01	.51	7.0	4.2	+	.16	1.4
Tallman	.85	0	++	0	.65	.66	.01	++	.01	.48	.45	0	0	.01	.57
McCurdy	4.8	.15	++	.15	.08	3.6	0	++	1.2	.08	2.7	0	+	1.5	.07
Benton	1.1	0	++	.85	0	2.1	0	+	1.5	0	.07	0	+	1.8	0
<u>1988</u>															
Von Lubkin	2.0	.33	+	.02	.75	3.1	2.8	+	.19	2.2	2.5	5.6	0	.21	2.8
McCurdy	1.0	0	++	.66	.44	2.2	.16	++	1.2	.56	1.3	.06	0	.79	.57

¹ Pest mite species: ERM = *P. ulmi*; 2SSM = *T. urticae*; ARM = *A. schlechtendali*

² Predatory mite species: Mo = *M. occidentalis*; Tp = *T. pyri*

³ Apple rust mite presence indicated by + for < 50/leaf and ++ for > 50/leaf

pyri. *Metaseiulus occidentalis* remained at low densities until August, when *T. urticae* increased in the orchard (Table 3, Fig. 2).

At Von Lubkin, immigrant *T. pyri* adult females occurred in the 0m mini-orchard three weeks after potted trees were placed in the field (Fig. 2). Counts showed that colonization occurred by mid-July as eggs and immatures were readily found.

Typhlodromus pyri was only found at Von Lubkin once in the 10m trees after June 1 until mid-August (Fig. 2). Later samples included immatures as well as increasing adults, so *T. pyri* eventually colonized these trees, but only much later than at the 0m site.

The 100m mini-orchard at Von Lubkin was colonized early by *T. pyri*, on the same date predators were found at 0m (Fig 2). This was puzzling, as *T. pyri* had not yet been found in 10m trees. Close inspection of surrounding vegetation indicated that immigrant predators were coming from a source other than the species pool orchard. An ornamental Hawthorne tree 12 m to the east of the mini-orchard was discovered to contain a large population of *T. pyri* and few prey mites. Thus, the

Figure 2. *Metaseiulus occidentalis* and *T. pyri* (all developmental stages) sampled from mini-orchards surrounding the Von Lubkin source species pool orchard in 1987. Results of the distance treatments (0, 10 and 100 m) are shown for each sample date.

VON LUBKIN ORCHARD SITE

1987

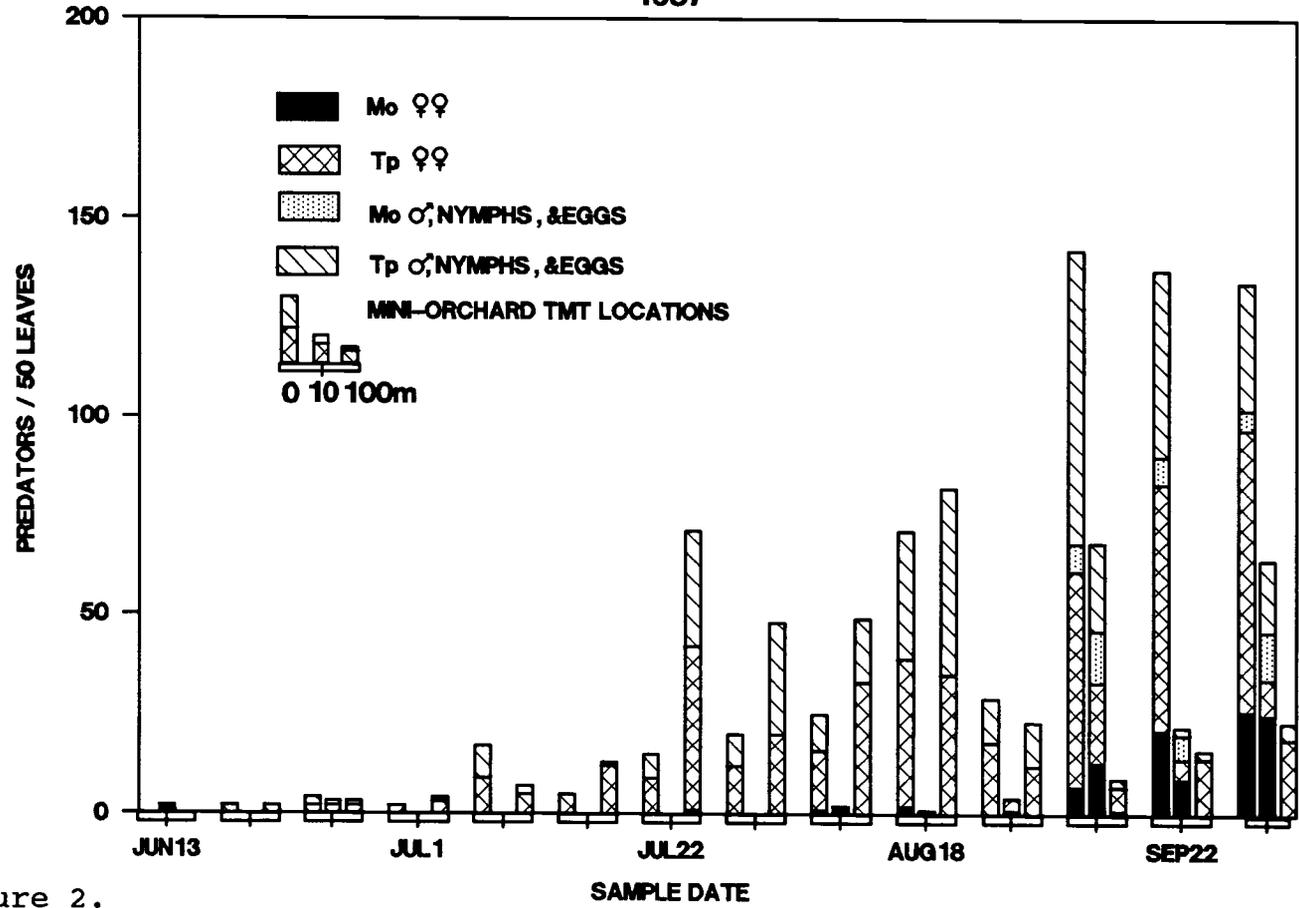


Figure 2.

100m orchard was behaving like a 10m site, with the Hawthorne tree serving as the source. Predators at 100m quickly colonized the mini-orchard and rapidly built up in the trees. Prey population declined by late August, and late season samples had few immature predators relative to adults.

An ANOVA and mean difference test of the number of adult female *T. pyri* collected over the season in the Von Lubkin orchard and mini-orchards showed significant differences (Table 3). Levels found in the orchard, 0m and 100m mini-orchards were significantly higher than at 10m.

Metaseiulus occidentalis was not found in the 0m mini-orchard at Von Lubkin until early August (Fig. 2). As the mites in the species pool orchard increased (Table 3), the number of immigrant adult females increased. Colonization of the 0m trees by *M. occidentalis* occurred by early September.

Metaseiulus occidentalis was detected at the 10m mini-orchard at Von Lubkin two weeks after trees were placed in the field. However, subsequent samples did not recover *M. occidentalis* until early August. *Metaseiulus occidentalis* colonized the 10m trees in

late August and increased at a rate similar to the Von Lubkin species pool orchard.

Metaseiulus occidentalis was collected in the 100m mini-orchard on two occasions in 1987. However, no males or immatures were found thereafter.

Tallman

Samples of mites in the Tallman source species pool orchard were not available prior to 1987.

Typhlodromus pyri was the only predator present in this organically grown orchard, as might be expected in a Hood River Valley orchard site free from pesticide use (Croft et al. 1990). The mean seasonal density of *T. pyri* in the orchard was 0.57/leaf.

The phytoseiids collected from the Tallman mini-orchards are presented in Figure 3. *Typhlodromus pyri* occurred in 0m trees two weeks after the placement of the mini-orchard. Immatures and eggs were collected at the same time, so colonization had occurred earlier. Two adult female *M. occidentalis* were also collected in the first sample. This was the only occurrence of *M. occidentalis* at 0m.

Figure 3. *Metaseiulus occidentalis* and *T. pyri* (all developmental stages) sampled from mini-orchards surrounding the Tallman source species pool orchard in 1987. Results for the two distance (0 and 10 m) treatments are shown for each sample date. There was no 100 m mini-orchard at Tallman.

TALLMAN ORCHARD SITE

1987

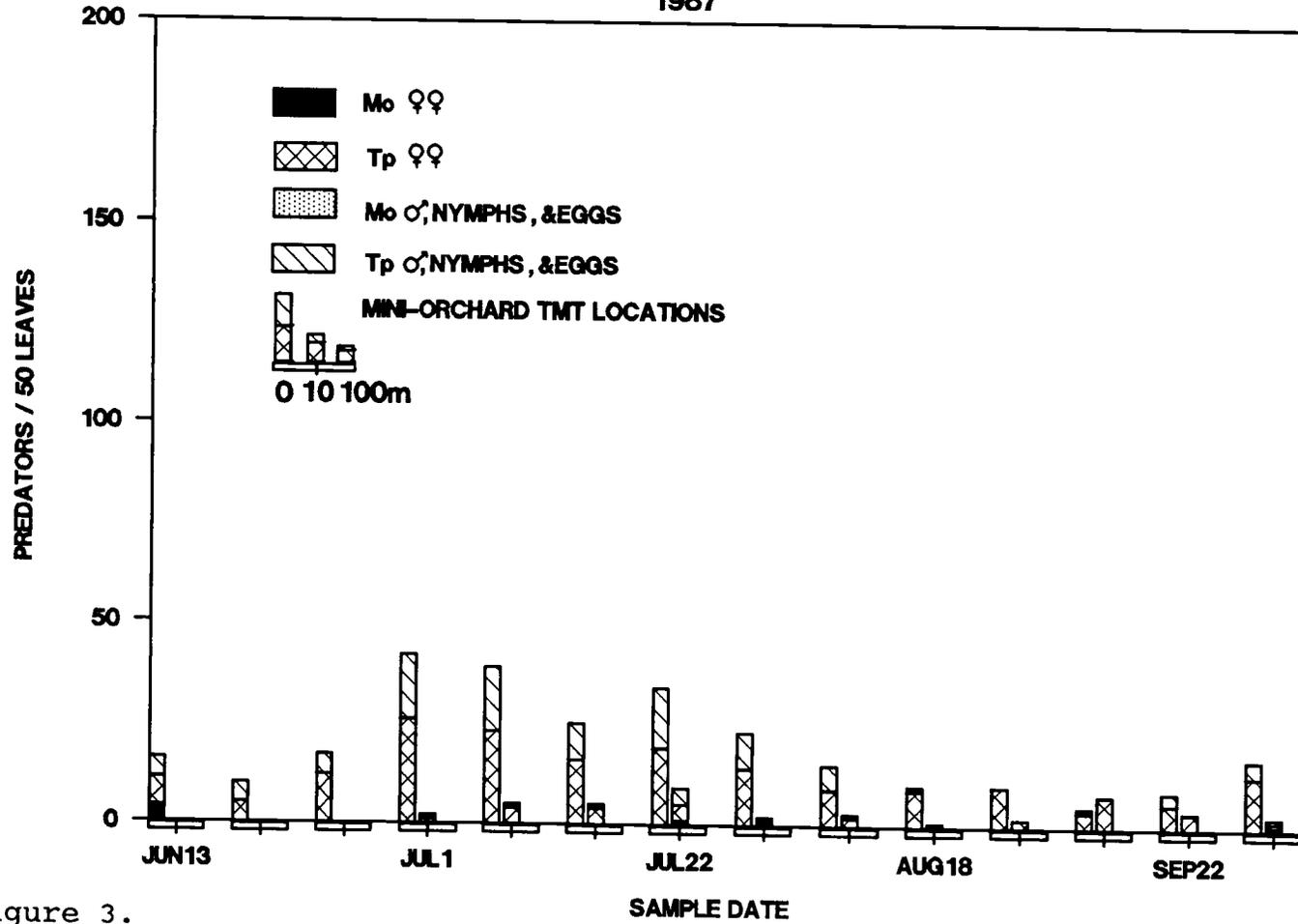


Figure 3.

Typhlodromus pyri, on the other hand continued to increase throughout the season.

Typhlodromus pyri adult females were found in 10m trees at Tallman early in July (Fig. 3). Predators maintained very low numbers through the season and immatures were found in low numbers. *Metaseiulus occidentalis* females were found in three samples in the 10m trees. However, no *M. occidentalis* eggs or immatures were collected thereafter.

A comparison of the seasonal mean densities of predatory mites at the Tallman species pool orchard (Table 3), and the mini-orchards shown in Table 4, revealed that *T. pyri* did not immigrate into the 10m trees as readily as the 0m trees. No significant differences were found between the mean levels of predators in the species pool orchard and the 0m mini-orchard, whereas the 10m trees had approximately one-sixth this amount.

Table 4. Mean number of adult predatory mite females/leaf collected in 1987 in the species pool orchards and mini-orchards at four locations, two sites with *T. pyri* and two sites with *M. occidentalis*. Means for each distance within each orchard which are significantly different are followed by different letters.

Species/Orchard	Orchard	Mini-orchard			SE ¹
		0m	10m	100m	
<i>T. pyri</i>					
Von Lubkin	1.098a	1.193a	0.243b	0.739a	0.125
Tallman	0.571a	0.686a	0.096b	---	0.055
<i>M. occidentalis</i>					
McCurdy	1.683a	1.350ab	1.107b	0.350c	0.151
Benton	1.345b	2.360a	0.736c	0.396d	0.181

¹ SE = Standard error for treatment means from within each experimental orchard

McCurdy

Croft *et al.* (1990) reported the McCurdy orchard to have a 61:39 ratio of *M. occidentalis* to *T. pyri* in 1985-1986, with a mean density of 1.54 phytoseiids/leaf. Counts in 1987 revealed that predatory mites increased to 1.77/leaf and the species ratio changed to 95:05, favoring *M. occidentalis*.

Mini-orchard trees at McCurdy (all three distances) contained *M. occidentalis* immigrants within three weeks after placement (Fig. 4). At 10 and 100m, immatures and eggs were also discovered three weeks after the mini-orchards were established. The 0m trees were colonized by the following week.

After colonization of the 0m trees, the population of *M. occidentalis* at McCurdy continued to increase through July (Fig. 4). Thereafter, predators decreased as fewer prey declined. Numbers of immature predators remained fairly constant relative to adult females collected. *Typhlodromus pyri* was found in the 0m trees on three occasions; however, it did not establish.

Figure 4. *Metaseiulus occidentalis* and *T. pyri* (all developmental stages) sampled from mini-orchards surrounding the McCurdy source species pool orchard in 1987. Results of the distance treatments (0, 10 and 100 m) are shown for each sample date.

MCCURDY ORCHARD SITE 1987

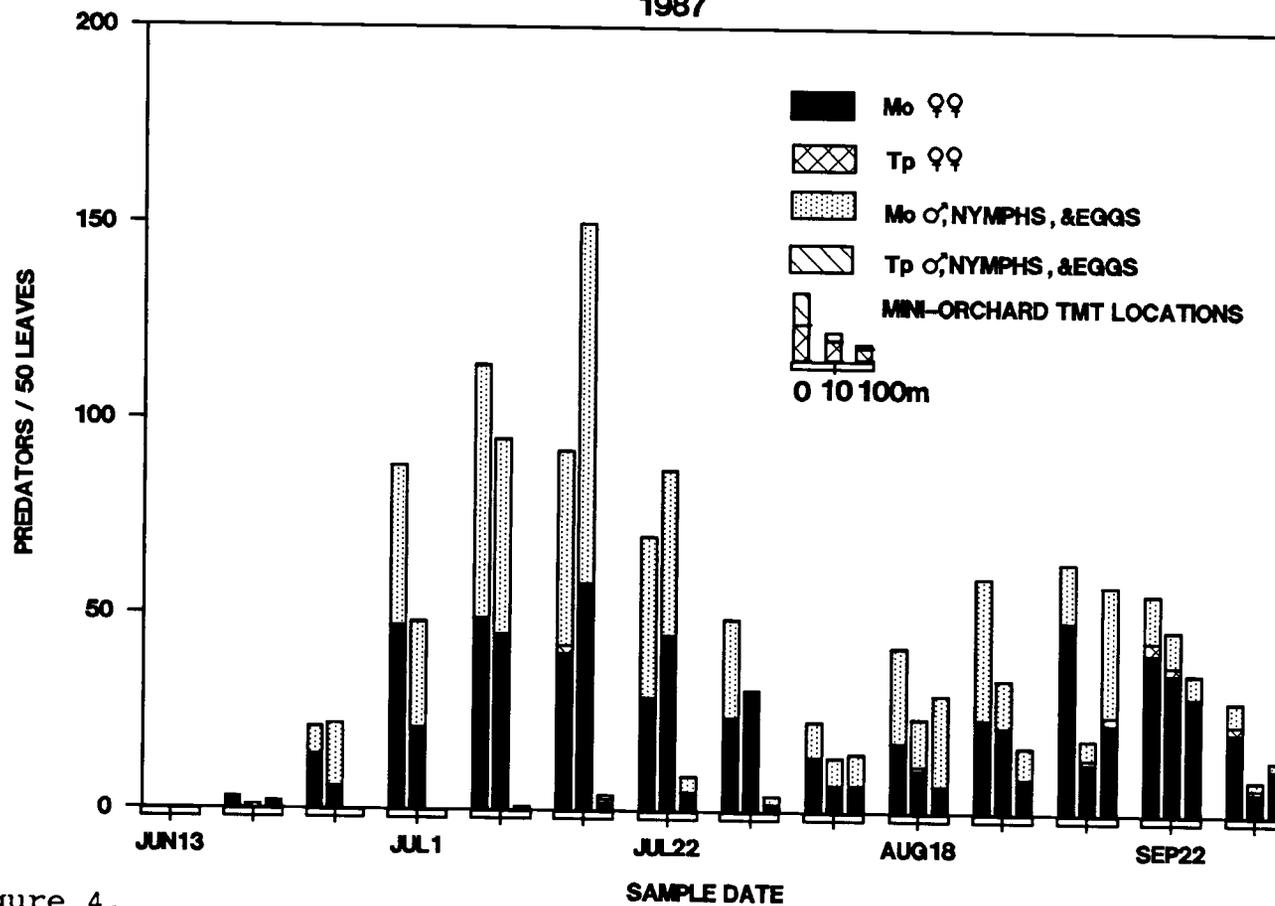


Figure 4.

In the 10m mini-orchard at McCurdy, much of the same patterns of immigration and colonization were observed as at 0m (Fig. 4). *Metaseiulus occidentalis* immigrated into and colonized the 10m trees quickly. A few *T. pyri* were collected, but no immatures were found.

Metaseiulus occidentalis took longer to populate the 100m trees at McCurdy. Although adult females were collected early, only low levels were detected until early August, when the population began to build (Fig. 4).

ANOVA and mean difference tests revealed that significantly fewer female *M. occidentalis* occurred in mini-orchards as distance increased away from the McCurdy orchard source (Table 4). Levels in the orchard and 0m trees were not significantly different; the same was true for the 0m and 10m mini-orchards. There were significantly fewer females between 10 and 100m sites; however, the level in outer mini-orchards versus the source orchard and 0m sites was not as extreme for *T. pyri* in the Von Lubkin and Tallman orchards (Figs. 2 and 3).

Benton

Croft *et al.* (1990) found only *M. occidentalis* at this site in 1985 and 1986. Seasonal counts in 1987 confirmed this, and high levels of *M. occidentalis* were found (1.35 adult females/leaf).

At Benton, *M. occidentalis* quickly immigrated into the mini-orchards from the source orchard (Fig. 5). Adult females were collected at 0m three weeks after the small trees were placed in the field. Populations increased as the season progressed, reaching high levels by mid-season. Colonization of the 0m trees occurred within two weeks after the first immigrants were found. The prey population decreased by late July, and there was a corresponding reduction in *M. occidentalis*.

Adult female *M. occidentalis* were found in the 10m mini-orchard at Benton one week following their arrival in the 0m trees (Fig. 5). Colonization occurred almost immediately thereafter, as eggs and immatures were found. However, the number of adult females reached a peak soon after colonization, then

Figure 5. *Metaseiulus occidentalis* and *T. pyri* (all developmental stages) sampled from mini-orchards surrounding the Benton source species pool orchard in 1987. Results of the distance treatments (0, 10 and 100 m) are shown for each sample date.

BENTON ORCHARD SITE

1987

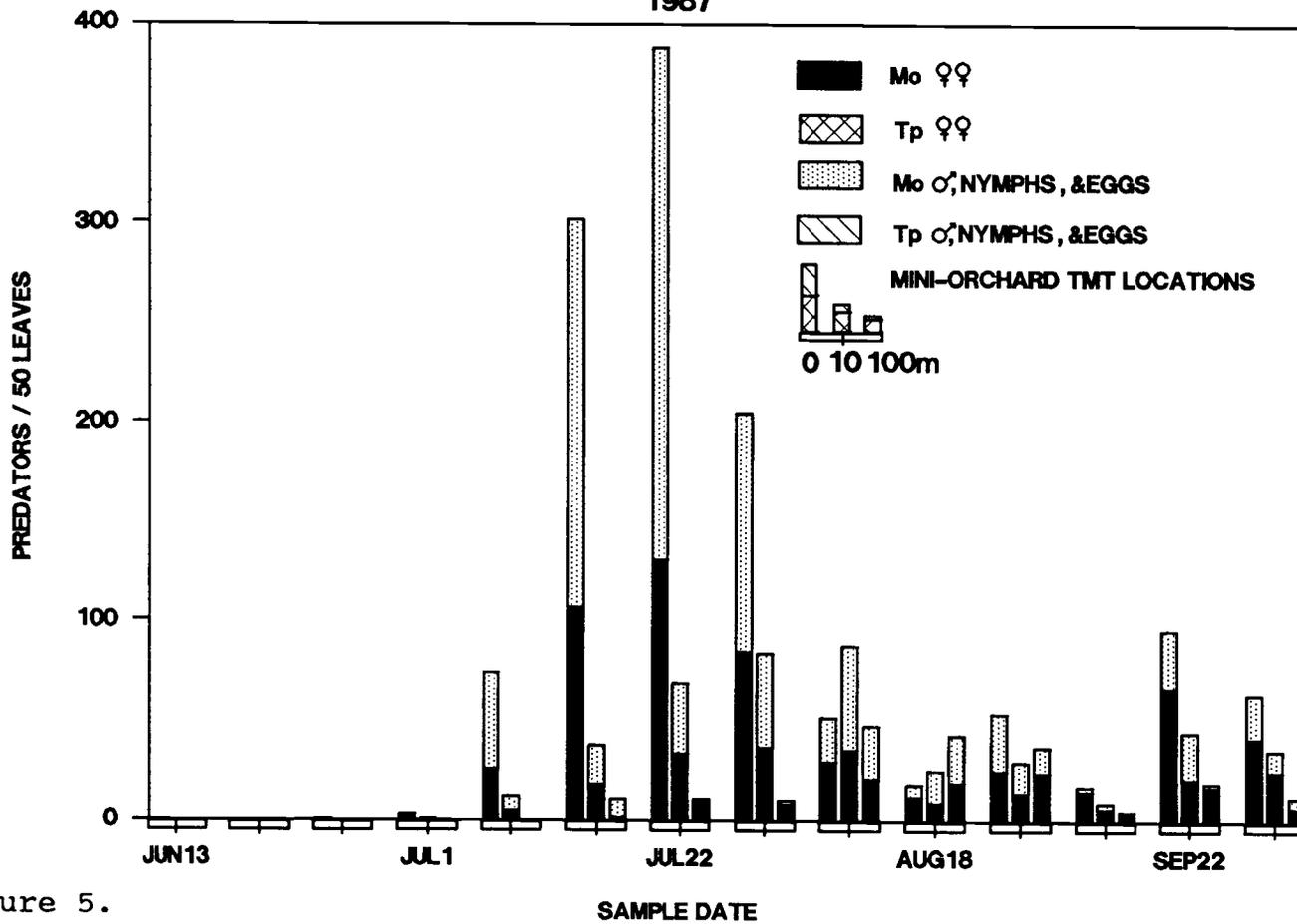


Figure 5.

remained constant thereafter. Prey densities were not reduced until mid-August.

Metaseiulus occidentalis did not immigrate into the 100m mini-orchard at Benton until mid-July, eight weeks after the trees were set out (Fig. 5).

Immatures were also found, so trees had been colonized earlier. While the predator population in the 100m mini-orchard increased slightly throughout the season, the prey were not appreciably reduced.

Statistically significant differences were observed between seasonal levels of *M. occidentalis* at all distances (source orchard, 0m, 10m, 100m) at Benton in 1987 (Table 4). The mean density for 0m was the highest, followed by the Benton source orchard, then the 10 and 100m sites.

Weekly Predatory Mite Trends in Study Orchards and Mini-Orchards in 1988

Von Lubkin

The late season increase in *M. occidentalis* and *T. pyri* at Von Lubkin in 1987 (Table 3) was reflected in counts taken in 1988. Predator mites increased

from 1.11 phytoseiids/leaf to 2.40 in 1988. During this period, the ratio of *M. occidentalis* to *T. pyri* remained near 6:94.

One change made at Von Lubkin in 1988 which improved the evaluation of the dispersal and colonization of *M. occidentalis* and *T. pyri* was the use of two fenvalerate sprays on the ornamental Hawthorne tree. This tree had harbored large populations of *T. pyri* the year before. Pesticide applications were made one month prior to the establishment of the mini-orchards, and the Hawthorne tree was monitored for predator mite populations throughout the season. No contaminating *T. pyri* or *M. occidentalis* were found in this tree in 1988.

The increase in *M. occidentalis* and the use of replicated mini-orchards at Von Lubkin in 1988 allowed a more direct side-by-side comparison of the emigration, immigration and colonization of the two species. The mean and standard deviation of adult females of each species per leaf for each sample date are presented in Figure 6. Overall seasonal mean densities are shown in Table 5.

Figure 6. *Metaseiulus occidentalis* and *T. pyri* adult females from the Von Lubkin orchard and associated mini-orchards in 1988. Lines represent the sample standard error.

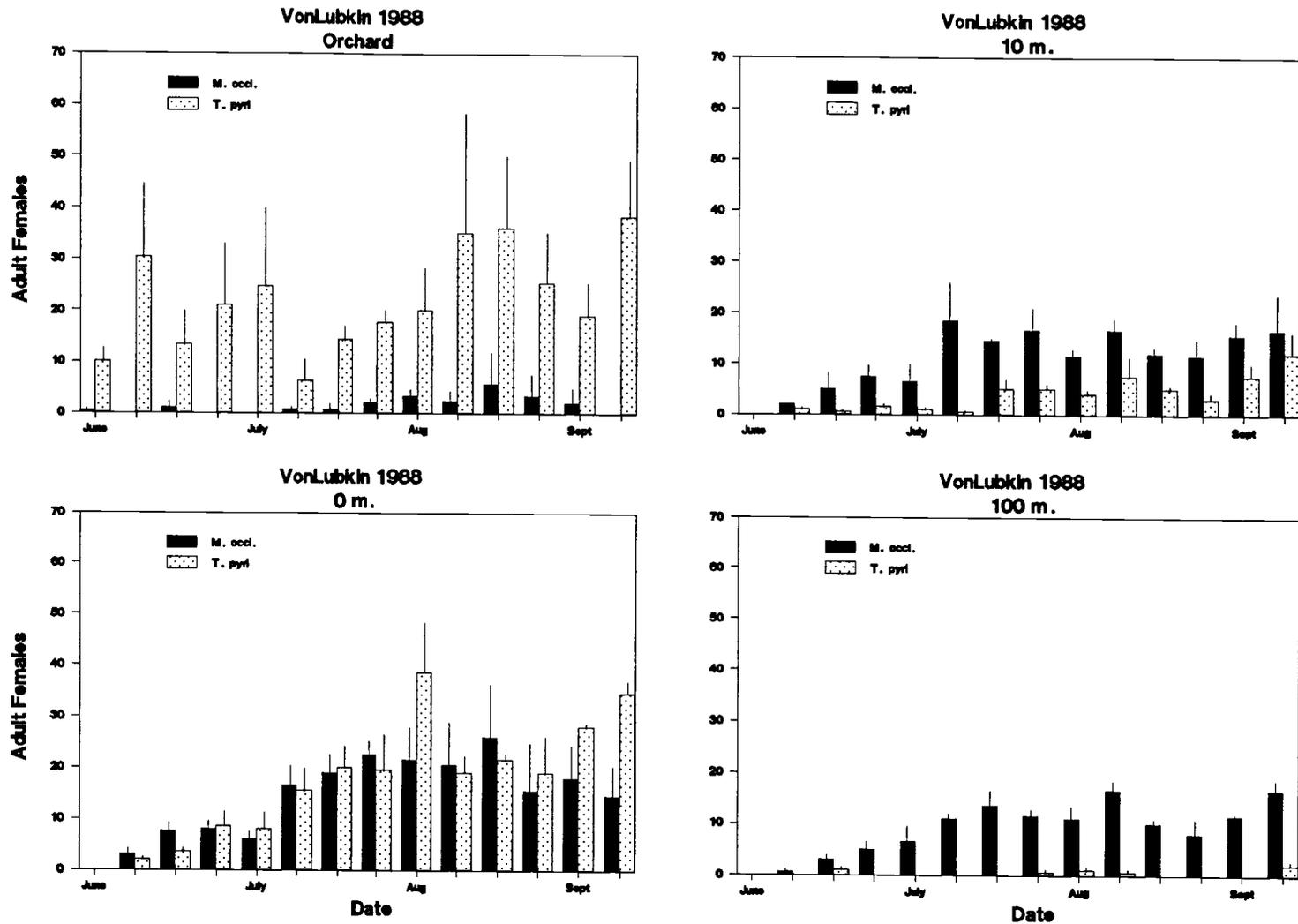


Figure 6.

Table 5. Mean number of adult predatory mite females/leaf from the Von Lubkin orchard and associated mini-orchards in 1988. Means which are significantly different are followed by different letters. Standard error = 0.105

Species	Orchard	Location		
		0m	10m	100m
<i>T. pyri</i>	2.241a	1.702ab	0.387c	0.021d
<i>M. occidentalis</i>	0.155d	1.416b	1.021b	0.896b

There were no significant differences between the number of *T. pyri* females found in the Von Lubkin orchard and in the trees at 0m in 1988 (Table 5). There were also no differences between the levels of *M. occidentalis* and *T. pyri* found in the 0m mini-orchards. Both species colonized the 0m trees within two weeks after establishment. However, there were highly significant differences between the number of *M. occidentalis* found in the source orchard and in the 0m trees, with the source orchard harboring much lower levels.

Both predator species colonized the 10m trees within five weeks after initial placement in the field. Numbers of *T. pyri* in the 10m orchard were about four times less than *M. occidentalis* although *T. pyri* outnumbered *M. occidentalis* in the source orchard by more than 14 times. There was no difference between the density of *M. occidentalis* at 0m and 10m sites (Fig. 6).

An even greater difference between *M. occidentalis* and *T. pyri* occurred at the 100m mini-orchards at Von Lubkin in 1988 (Fig. 6). In contrast to 1987, very few *T. pyri* were detected in the 100m

trees. However, *M. occidentalis* was present in numbers which were not significantly different from those in the 0 and 10m mini-orchards.

McCurdy

The ratio and density of predatory mites changed somewhat at the McCurdy orchard between 1987 and 1988. The ratio of *M. occidentalis* to *T. pyri* shifted to 64:36, near the ratio of 61:39 found by Croft *et al.* (1990). The combined predator density in 1988 was 1.37/leaf.

While logistics did not allow for replication of mini-orchards at McCurdy, the near even ratio of predators permitted a better side-by-side comparison of the two species than in 1987. Numbers of females collected weekly through the season are presented in Figure 7, and the seasonal mean densities for each species are shown in Table 6.

While *M. occidentalis* and *T. pyri* occurred at relatively equal frequency in the source orchard, considerable differences were seen in their densities in mini-orchards (Table 6, Fig. 7). *Metaseiulus*

Figure 7. *Metaseiulus occidentalis* and *T. pyri* adult females from the McCurdy orchard and associated mini-orchards in 1988.

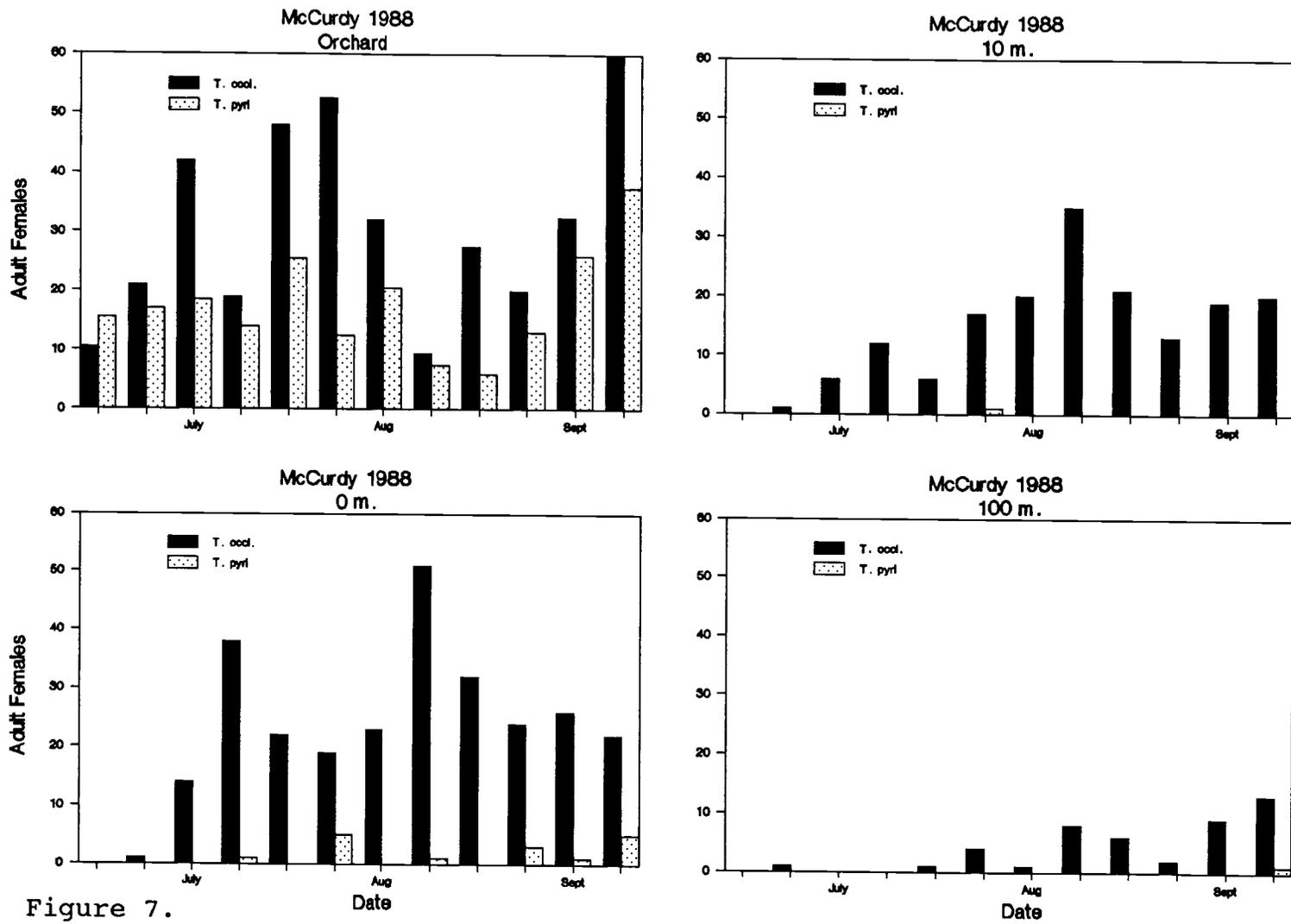


Figure 7.

Table 6. Mean number of adult predatory mite females/leaf from the McCurdy orchard and associated mini-orchards in 1988. Means which are significantly different are followed by different letters. Standard Error = 0.218

<u>Species</u>	<u>Orchard</u>	<u>0m</u>	<u>10m</u>	<u>100m</u>
<i>T. pyri</i>	0.494cd	0.133de	0.083e	0.083e
<i>M. occidentalis</i>	0.879c	2.267a	1.417b	0.375de

occidentalis was present in 0m trees at a significantly higher density than in the source orchard, and colonized trees within two weeks after the mini-orchards were established. *Typhlodromus pyri*, on the other hand, did not colonize the trees until late July.

At 10m, *M. occidentalis* colonized trees after only two weeks and also reached densities higher than within the source orchard (Fig. 7). *Typhlodromus pyri* was only found at 10m on one occasion, and it did not establish. Because of the large standard error in mite samples, the number of *T. pyri* at 0m and 10m was not significantly different. At 10m, *M. occidentalis* was present at a significantly higher level than *T. pyri*.

Metaseiulus occidentalis was detected in the 100m mini-orchard at McCurdy early in the season (Fig. 7), but colonization did not take place until late July. *Typhlodromus pyri* was only found on the last sample date, and it did not colonize the 100m trees. A large standard error contributed to the lack of significance between *M. occidentalis* and *T.*

pyri at 100m, although *M. occidentalis* was found more frequently.

General Patterns of Emigration, Immigration, and
Colonization of Phytoseiids in 1987-88

Results from 1987 and 1988 were taken from different orchards with different species pool compositions, including sites where only *M. occidentalis* was present, where *M. occidentalis* was mixed with *T. pyri*, and where *T. pyri* dominated. From these sites, specific trends were seen in the abilities of *T. pyri* and *M. occidentalis* to immigrate into mini-orchards and colonize the small trees.

Both *T. pyri* and *M. occidentalis* emigrated from source pool orchards. While absolute numbers leaving the orchard trees could not be monitored, high levels of both species in 0m trees documented that mites were dispersing. At both sites in 1987 where *T. pyri* was the dominant species, there were no significant differences in densities in source orchards and 0m mini-orchards. At McCurdy, where *M. occidentalis* predominated, there also was no difference. At

Benton the levels of *M. occidentalis* found in the 0m trees were 1.8 times higher than in the source orchard, possibly because low prey levels may have influenced emigration (Table 4, Fig. 5).

Results from direct side-by-side comparisons of *T. pyri* and *M. occidentalis* in 1988 showed trends similar to those in 1987. While the densities of *T. pyri* found in the Von Lubkin and McCurdy orchards did not differ significantly from those in 0m trees (although the 0m trees maintained lower densities), the levels of *M. occidentalis* in the source orchards and the 0m trees were significantly different (Tables 5 and 6). *Metaseiulus occidentalis* levels in the 0m mini-orchards were 2.6 times higher than in the source trees at McCurdy, and 9.1 times higher at Von Lubkin.

Fluctuating prey levels may have accounted for the fact that higher densities of *M. occidentalis* were found in 0m orchards than within the orchard. *Metaseiulus occidentalis* distribution is closely correlated to the prey distribution (Hoyt 1974; McMurtry 1982), while *T. pyri* is not (McMurtry 1982; Dicke 1988). *Aculus schlechtendali* densities dropped

as the season progressed, so if *M. occidentalis* were dependent upon apple rust mite then dispersal could be stimulated. However, this is not the case at Von Lubkin, where the population of *T. urticae* increased while there was a reduction in *A. schlechtendali*. The increase in *T. urticae* would presumably prevent an exodus of *M. occidentalis*.

Previous studies of the immigration potential of *M. occidentalis* have shown it will disperse more than 200 m in a single season (Hoy et al. 1985). No specific research has been done on the immigration characteristics of *T. pyri*, however some researchers have noted its limited movement (Wearing & Profitt 1982; Baillod et al. 1982). In this study, *M. occidentalis* was consistently able to immigrate over longer distances than *T. pyri*, and did so faster than *T. pyri*. In 1987, *T. pyri* had immigrated to the 0m mini-orchards at Von Lubkin and Tallman within three weeks after the mini-orchards were established (Figs. 2 & 3); the same is true for *M. occidentalis* at McCurdy and Benton (Figs. 4 & 5). In 1988, both *M. occidentalis* and *T. pyri* readily immigrated into the 0m mini-orchards at Von Lubkin (Fig. 6), but *T. pyri*

did not move into the 0m mini-orchards at McCurdy as early as *M. occidentalis* (Fig. 7).

A greater difference was observed between the immigration of *M. occidentalis* and *T. pyri* into the 10m mini-orchards. At all experimental locations in 1987, *M. occidentalis* reached the 10m mini-orchards within three weeks after placement of the potted trees, and continued to immigrate to 10m in high numbers. Whereas, *T. pyri* was only able to equal the rate, but not the level of immigration of *M. occidentalis* at Von Lubkin in 1988. At all other study sites where *T. pyri* was present, including Von Lubkin in 1987, *T. pyri* did not immigrate to the 10m mini-orchards for at least six weeks. At all experimental sites in both 1987 and 1988, *M. occidentalis* was able to reach the 100m mini-orchards if it was initially present in the orchard. *T. pyri* was rarely collected at 100m.

Both *M. occidentalis* and *T. pyri* were able to colonize the mini-orchards once they had immigrated to them. However, at all experimental sites *M. occidentalis* colonized young trees more rapidly than *T. pyri*. This conclusion can be made from the ratio

of adult females in the mini-orchards to the immature forms: the *M. occidentalis* ratio increased with time, whereas *T. pyri* remained constant. Previous work by several researchers had shown that *M. occidentalis* has a higher reproductive rate than *T. pyri*, both in the laboratory and in the field (Croft & McMurtry 1972; Tanigoshi et al. 1975; Badii & McMurtry 1984). This study concludes that *M. occidentalis* also has a higher rate of reproduction than *T. pyri* in young apple trees, and is thus able to colonize young trees at a faster rate.

However, the extremely high relative rate of colonization by *M. occidentalis* observed at Von Lubkin mini-orchards could have been influenced by other factors. One explanation may have been differential favorability for colonization of the small trees. *Typhlodromus pyri* was 14 times more dense than *M. occidentalis* within the Von Lubkin orchard, yet the two species were at about equal densities in 0m mini-orchard. In the source orchard trees where *T. pyri* dominated, populations of *M. occidentalis* may have been suppressed by competition with *T. pyri* or by environmental conditions which

favor *T. pyri*. When these conditions were removed in the mini-orchards, then *M. occidentalis* was no longer suppressed and reproduced at a higher rate.

Metaseiulus occidentalis favors arid conditions (Hoyt 1974), thus may favor the less dense foliage of small trees over the dense, humid canopy of commercial orchards. *Typhlodromus pyri*, on the other hand, favors more humid environs (Helle & Sabelis 1985), thus may prefer orchard canopy to mini-orchard trees. This type of tree-age preference was noted by Croft *et al.* (1990), who found only *M. occidentalis* in trees younger than twelve years old. An exclusion of *T. pyri* from young trees was not found in this study, as *T. pyri* colonized the mini-orchards both within commercial orchards where *T. pyri* was dominant (Von Lubkin), and even where *M. occidentalis* was more abundant (McCurdy).

SUMMARY AND CONCLUSIONS

This study presents a comparison of the relative rates of emigration, immigration, and colonization of young potted apple trees by *M. occidentalis* and *T. pyri*, two important species of predaceous mites. While *M. occidentalis* and *T. pyri* may emigrate from an orchard at near equal rates, their dispersal may be influenced by factors such as prey density and environmental conditions. *Metaseiulus occidentalis* can travel distances greater than 100 m in a single season; *T. pyri* rarely travels further than 10 m and immigrates at a lower rate. Both *M. occidentalis* and *T. pyri* colonize young potted apple trees, but *M. occidentalis* does so faster than *T. pyri*.

Several questions were raised by these studies. First, it would be helpful to know more about the factors which influence the distribution of *M. occidentalis* and *T. pyri* within the HRV. For example, environmental factors and the extent of interspecific competition between *T. pyri* and *M. occidentalis* would be of particular interest. Also, means by which the phytoseiids travel long distances

is another area of needed research. It is unknown whether these mites are carried as aerial planktans directly to distant sites by prevailing winds, or whether long distance dispersal involves several repeated dispersals in the wind. Differences between abilities of *M. occidentalis* and *T. pyri* to disperse over long distances could be behavioral, such as finding the proper orientation to wind currents for maximum lift (Sabelis 1985), or morphological. *Metaseiulus occidentalis* has longer dorsal setae than *T. pyri*; longer setae may influence buoyancy on wind currents by increasing lift and reducing drag during dispersal (Krantz 1973).

Finally, there are many implications for IPM programs from study of dispersal and colonization of predaceous mites. The colonization characteristics of a predator species could be important in mass or periodic release programs. Immigration and emigration are important in that they determine the amount of gene flow into or out of a source pool. This is a significant component of resistance management programs, which seek to minimize

resistance in pest mites and maximize resistance in beneficial mites, such as these two phytoseiids.

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