

The Transfer of *Typhlodromus pyri* on Grape Leaves for Biological Control of *Panonychus ulmi* (Acari: Phytoseiidae, Tetranychidae) in Vineyards in Ontario, Canada

D. B. Marshall¹ and P. J. Lester²

Southern Crop Protection and Food Research Centre, Agriculture and Agri-Food Canada, Vineland, Ontario, Canada L0R 2E0

Received November 30, 1999; accepted December 13, 2000

The phytophagous mite *Panonychus ulmi* Koch has become a significant problem in Ontario vineyards. We attempted to introduce and establish populations of the predatory mite *Typhlodromus pyri* Scheuten for *P. ulmi* biological control. Grape leaves were transferred from a vineyard containing *T. pyri* in early summer 1998, by picking leaves from a donor vineyard and attaching them onto leaves in the release vineyard where *T. pyri* were extremely rare. Two release treatments were used with rates of 8.5 (1×) and 25.5 (3×) mobiles per vine. In the first season, *T. pyri* established in similar densities in both release treatments, which were significantly higher than controls. However, there were no differences among treatments in *P. ulmi* densities in 1998 as a result of predator release. During summer 1999, significantly fewer *P. ulmi* mite-days were observed in release plots compared to the control. *Amblyseius fallacis* (Garman) was common throughout the release vineyard in 1998 and in 1999, but appeared on the vines too late in the season to maintain low *P. ulmi* densities. *T. pyri* appeared to out-compete *A. fallacis* in 1999 because *A. fallacis* densities were significantly lower in plots where *T. pyri* had been released than in control plots. We conclude that *T. pyri* can be effective for *P. ulmi* biological control in Ontario vineyards and may be introduced by transferring leaves. In Europe, transferring prunings has been the standard method of inoculating *T. pyri* into new vineyards. Here we show that transferring leaves is another practical method. © 2001 Academic Press

Key Words: *Typhlodromus pyri*; *Amblyseius fallacis*; *Panonychus ulmi*; release; biocontrol; vineyard; Riesling; Gamay.

INTRODUCTION

Recently, populations of the European red mite, *Panonychus ulmi* Koch (Acari: Tetranychidae), have increased in Ontario vineyards and densities have reached the point of damaging or bronzing grape foliage. Densities of up to 320 *P. ulmi* per leaf have been recorded (Lester *et al.*, 1998), which far exceeds the empirically defined economic injury level for *P. ulmi* of 2–5 mites leaf⁻¹ in European vineyards (Baillod *et al.*, 1979; Boller and Remund, 1983; Schruft *et al.*, 1990). In Ontario, such large *P. ulmi* populations do not impact all vineyards. There may be several reasons for *P. ulmi* becoming pestiferous, including the use of pesticides that can kill or repel phytoseiid mites, which are the primary biological control agent of *P. ulmi* in many crops. Surveys from 1996 to 1999 in vineyards across the Niagara region of Ontario have shown populations of the predator *Typhlodromus pyri* Scheuten (Acari: Phytoseiidae) to be correlated with low densities and the biological control of *P. ulmi*. High *P. ulmi* densities were observed in vineyards with no *T. pyri* or in vineyards with an absence of any phytoseiid predatory mites (Lester *et al.*, 1998; Marshall, unpublished data). In European vineyards, *T. pyri* is an effective biological control agent of *P. ulmi* (Hluchý, 1993; Rivenez *et al.*, 1995; Koleva *et al.*, 1996) and in Canada; *T. pyri* can effectively control *P. ulmi* on apples (Hardman *et al.*, 1997). However, some differences have been noted in the abilities of different *T. pyri* strains to control tetranychid mites (Duso and Pasqualetto, 1993) as well as varying levels of pesticide resistance among strains (Valentin *et al.*, 1994).

Ontario grape growers have limited access to miticides, with Kelthane (dicofol) and Pyramite (pyridaben) being the only currently registered miticides. Kelthane has been in use for more than 34 years (Pree *et al.*, 1989) for *P. ulmi* control in tree fruits and grapes, and many *P. ulmi* populations have developed resistance to this product (Pree and Wagner, 1987).

¹ To whom correspondence should be addressed at Agriculture and Agri-Food Canada, Southern Crop Protection and Food Research Centre, Vineland, Ontario, Canada L0R 2E0. Fax: (905) 562-4335. E-mail: marshalld@em.agr.ca.

² Current address: School of Biological Sciences, Victoria University of Wellington, P.O. Box 600, Wellington, New Zealand.

The use of predatory mites to control *P. ulmi* populations is likely to be a more sustainable method of control than the use of miticides.

In this study, we examined the efficacy of *T. pyri* to control *P. ulmi* populations after introduction into a vineyard with high *P. ulmi* densities. In Europe, the most common method of moving *T. pyri* among vineyards is to transfer prunings and cuttings from vines during the periods when *T. pyri* is in its hibernating, over-wintering phase (e.g., Boller and Remund, 1991; Blommers, 1994). The number of vineyards that can be inoculated is limited only by the availability of prunings with this method of *T. pyri* inoculation. The *T. pyri* densities on these prunings can also be limited by such factors as overwintering mortality (Veerman, 1992). In this study, we chose to assess another method for the transfer of *T. pyri* among vineyards. We collected leaves from a vineyard with high *T. pyri* populations and moved them to a new vineyard, compared two rates of *T. pyri* transfer, and followed the effects of this transfer over two growing seasons. This transfer method has the advantage that growers usually have more leaves to transfer and, unlike prunings, could select the timing of the transfer to correspond with high *T. pyri* densities in the donor vineyard.

MATERIALS AND METHODS

The trial was conducted in a block of c.v. Gamay, planted in 1995 with a vine spacing of 2.74 m by 1.30 m grown using the vertical shoot positioning system. In 1997, foliar bronzing was observed in this block (grower observation). Bronzing is typical in vineyards with high *P. ulmi* populations.

As a donor block for phytoseiid predators, we used a block of c.v. Riesling, planted in 1979. This block was approximately 500 m from the experimental Gamay block and was owned by the same grower. The vine spacing in this Riesling block was 2.74 m by 1.52 m and vines were grown using a vertical shoot positioning training system. Samples taken from this block in 1997 and 1998 indicated high densities of *T. pyri* and low *P. ulmi* densities (Marshall, unpublished data).

In 1998, an area of the Gamay block was selected for the release of predators collected from the Riesling block. Release plots in the Gamay block were arranged according to a randomized complete block design, replicated four times. Each plot consisted of five vines per plot, with two guard vines separating plots. Our aim was to release predators at two rates, approximately 10 (1×) and 30 (3×) phytoseiid mobiles per vine. The numbers of leaves collected to achieve these release rates was based on 100 leaf survey counts from the Riesling block taken earlier in the season on 16 June (Marshall, unpublished data). On 17 June, leaves were collected from the Riesling block and then attached to both sides of the row on the Gamay vines in the release

plots using paper staplers. The species and actual number of mites released were estimated from six replicated samples of 30 leaves, taken on 17 June from the Riesling block.

Release plots were sampled on 17 June, prior to the actual release, when 25 leaves per plot (5 per vine) were collected. All leaf samples were passed through a mite-brushing machine (Henderson and McBurnie, 1943) and counted with the aid of a binocular microscope. Numbers of each life stage of various phytophagous and predatory mites were calculated on a per leaf basis (only living mites were counted). Adult phytoseiid mites were mounted onto microscope slides using Hoyer's medium and later identified.

Postrelease plots were sampled 6 and 28 July, 20 August, 11 September, and 1 October 1998. These samples consisted of 50 leaves per plot, 10 leaves per vine, with 5 leaves picked from each side of the row. In the six samples taken on 17 June from the Riesling donor vineyard, all adult phytoseiids found were mounted for identification. Subsequent samples were collected from this Riesling block and no more than 15 phytoseiid adults were mounted for identification from each sample.

In 1999, samples were first collected on 16 February when wood was collected from the vines from the release plots to determine if phytoseiids were over-wintering on the vines. This sample was small, with only one cutting of 2-year-old or older wood taken per plot for a total of 12 cuttings. Cuttings ranged in length from 18 to 24 cm. Subsequent leaf samples were collected from the release plots on 21 and 31 May, 14 June, 5 and 26 July, 16 August, and 14 and 27 September. The 21 and 31 May samples were 5 leaves per vine with a total of 25 leaves per plot. Subsequent samples were 10 leaves per vine for 50 leaves per plot.

Samples were collected from the area surrounding the release plots to monitor phytophagous and predatory mite populations. In 1998, samples of 100 leaves each were collected on 10, 15, and 25 June, 6 and 22 July, 4 and 25 August, 11 September, and 1 October. During 1999, samples (4 replicates of 25 leaves each, approximately 3 leaves per vine) were taken on 31 May, 14 June, 5, 12, and 26 July, 3 and 16 August, and 14 and 27 September. The final samples on 14 and 27 September were 50 leaves per replicate.

Counts of prerelease *P. ulmi* and phytoseiid mobiles of 17 June 1998 were transformed using $\log_{10}(x + 1)$ and subjected to a one-way analysis of variance. The residuals from each ANOVA were examined for normality and homogeneity of variance. Cumulative mite-days leaf⁻¹ were calculated (Beers *et al.*, 1993) on post-release *P. ulmi* and phytoseiid counts for 1998 and 1999. Phytoseiid mite-days were calculated by determining the number of each species identified compared to the total number of phytoseiids identified and then related to the total count per plot. This proportion was

TABLE 1
Pesticides Applied during 1998 and 1999

Date	Pesticide	Application rate (kg A.I. ha ⁻¹)	Applied to control
1998			
20 May	Sulfur and captan	6.4 and 1.6	Powdery and downy mildew, phomopsis
1 June	Myclobutanil and mancozeb	0.1 and 2.6	Powdery, downy mildew, phomopsis, black rot
18 June	Myclobutanil and captan	0.1 and 1.6	Powdery and downy mildew, phomopsis
2 July	Sulfur and metiram	4.8 and 4.4	Powdery and downy mildew
9 July	Iprodione	0.75	Botrytis bunch rot
13 July	Iprodione	0.75	Botrytis bunch rot
15 July	Dikar and pitstop	3.1 and 0.45	Powdery and downy mildew, black rot
7 August	Sulfur and captan	4.0 and 2.6	Powdery and downy mildew
18 August	Sulfur	4.0	Powdery mildew
1999			
May 14, 15	Sulfur and captan	4.0 and 1.6	Powdery and downy mildew, phomopsis
May 29, 30	Sulfur and folpet	4.0 and 1.5	Powdery and downy mildew, phomopsis
26 June	Myclobutanil and metiram	0.1 and 1.5	Powdery and downy mildew, black rot
12 July	Dikar and pitstop	4.2 and 0.45	Powdery and downy mildew, black rot
30 July	Sulfur, captan, Pitstop and azinphosmethyl	4.8, 2.6, 0.9, and 0.45	Powdery and downy mildew, grape berry moth, leafhoppers
13 August	Sulfur and captan	5.4 and 3.0	Powdery and downy mildew

then calculated on a per leaf basis. Season-end totals for each year were transformed using $\log_{10}(x + 1)$ and analyzed using analysis of variance and the LSD means separation test, using the Statistica statistical software package (Statsoft, 1995). Differences between treatments were considered statistically significant if $P < 0.05$. All density estimates are presented as means \pm 1 standard error of the mean.

Pesticides were applied in 1998 and 1999 to the Gamay block for the control of fungal diseases and insect pests (Table 1). In 1998 pheromone dispensers were introduced into the vineyard for grape berry moth control, alleviating the need for many insecticides.

RESULTS

Analyses of prerelease counts taken from the Gamay release plots showed no significant differences in phytoseiid ($F = 0.50$; $df = 2$; $P > 0.05$) or *P. ulmi* ($F = 0.806$; $df = 2$; $P > 0.05$) densities among treatments prior to *T. pyri* release. At this time, the mean density of phytoseiids in the release block was 0.007 ± 0.004 leaf⁻¹ and 2.347 ± 0.312 leaf⁻¹ for *P. ulmi*. Samples taken from the donor Riesling block showed high mean densities for *T. pyri* of 0.206 ± 0.077 mobiles leaf⁻¹ (1997) and 0.972 ± 0.094 (1998) and low *P. ulmi* densities of 1.450 ± 0.844 (1997) and 0.391 ± 0.138 (1998) (Marshall, unpublished data). Prior to release, the density of phytoseiid species in the donor Riesling plot was 0.850 ± 0.177 leaf⁻¹ and the density of *P. ulmi* was 0.033 ± 0.015 leaf⁻¹. This density of phytoseiids in the donor block was slightly lower than we had observed earlier on 16 June 1998 (Marshall,

unpublished data). The number of phytoseiids released was estimated at 8.5 vine⁻¹ ($3.95 - 13.04$, 95% CI) for the 1 \times release (an estimated total of 42.5 plot⁻¹) and 25.5 vine⁻¹ ($11.87 - 39.13$, 95% CI) for the 3 \times release treatment (127.5 plot⁻¹). A total of 68 phytoseiids were collected from the donor Riesling block on 17 June and all identified as *T. pyri*. One phytoseiid (a *T. pyri*) was identified in the Gamay release plot prior to the release (Table 2).

TABLE 2

Phytoseiid Adults Identified from the Release Area in 1998

Date	Rate	<i>T. pyri</i> number (%)	<i>A. fallacis</i> number (%)	Total number
17 June	0	0 (0)	0 (0)	0
	1 \times	1 (100)	0 (0)	1
	3 \times	0 (0)	0 (0)	0
8 July	0	0 (0)	1 (100)	1
	1 \times	1 (33.3)	2 (66.6)	3
	3 \times	5 (83)	1 (17)	6
28 July	0	0 (0)	1 (100)	1
	1 \times	2 (100)	0 (0)	2
	3 \times	1 (100)	0 (0)	1
20 August	0	0 (0)	2 (100)	2
	1 \times	11 (58)	8 (42)	19
	3 \times	10 (77)	3 (23)	13
11 September	0	0 (0)	12 (100)	12
	1 \times	10 (77)	3 (23)	13
	3 \times	10 (48)	11 (52)	21
1 October	0	0 (0)	0 (0)	0
	1 \times	2 (50)	2 (50)	4
	3 \times	0 (0)	0 (0)	0

Note. Total is the total number for each treatment.

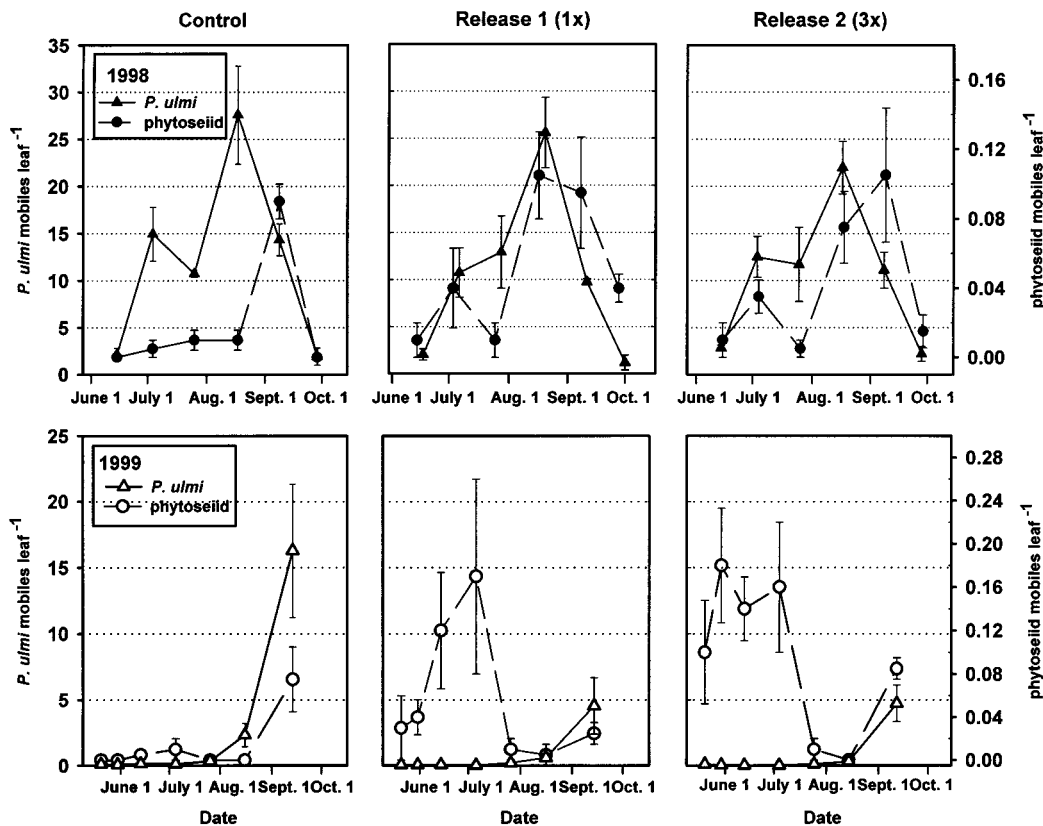


FIG. 1. Seasonal changes in abundance of *P. ulmi* and phytoseiid mobiles in control and release plots for the 1998 and 1999 seasons. Phytoseiid counts are the combined total of all species found. Values are means of four replicates \pm 1 standard error.

Mite Densities in 1998

Differences in phytoseiid densities among treatments were observed in the first sample 19 days post-release. On 6 July, 0.040 ± 0.023 and 0.035 ± 0.010 phytoseiids leaf⁻¹ were observed in the 1 \times release and 3 \times release treatments, respectively. In the control a mean density of phytoseiids was 0.005 ± 0.005 leaf⁻¹. The next sample on 28 July indicated that the phytoseiid density had decreased in the two release treatments (Fig. 1), but this may have been related to an application of Dikar on 15 July (Table 1).

In the 20 August sample, phytoseiid densities in the release treatment had increased to 0.105 ± 0.025 and 0.075 ± 0.021 phytoseiids leaf⁻¹ in the 1 \times release and 3 \times release treatments, respectively (Fig. 1). These densities were higher than in the control treatment (0.010 ± 0.006 phytoseiids leaf⁻¹). Samples after 20 August showed similar differences between treatments, but the highest phytoseiid density was observed at the end of 1998 in the 1 \times release treatment.

The numbers of *T. pyri* mite-days were significantly higher in the 1 \times (3.524 ± 1.128) and 3 \times (2.761 ± 0.562) treatments than in the control (0 ± 0). The highest number of *T. pyri* mite-days was observed in the 1 \times release treatment. The number of *T. pyri* mite-days in the 1 \times and 3 \times release was not significantly

different (Table 3). In control plots, no *T. pyri* were found (Table 2).

Amblyseius fallacis were found in both control (16 identified season-long) and release plots (30), with most found in the 20 August (total of 13 from all plots) and 11 September (26) samples. The number of cumulative mite-days leaf⁻¹ calculated for each treatment were not significantly different for *A. fallacis* ($P < 0.05$) (Table 3).

Samples (100 leaves each) from the remainder of the Gamay vineyard outside the release area produced very few phytoseiid mites. Only 12 phytoseiids were collected from nine surveys of 100 leaves each. Nine of these 12 were identified: 7 were *A. fallacis* (identified from the last three samples), 25 August (1 *A. fallacis*), 11 September (5), and 1 October (1); one was an *A. andersoni* found on 25 June; and one *T. pyri* was found on 11 September.

No significant differences were observed in *P. ulmi* densities among treatments (Fig. 1). The peak density of *P. ulmi* was observed on 20 August, at 27.600 ± 5.214 leaf⁻¹ in the control treatment. At this time, 25.605 ± 3.738 and 21.990 ± 2.806 *P. ulmi* leaf⁻¹ were observed in the 1 \times release and 3 \times release treatments, respectively (Fig. 1). The *P. ulmi* mite day analysis reflected these results. The largest number of cumula-

TABLE 3
Effects of the 1998 Release on Cumulative Mite-Days in 1998

Effect	df	MS (effect)	F statistic	LSD ($P < 0.05$) (LSD – means in parentheses) ^a
<i>P. ulmi</i>	2, 9	0.006	0.755	Control (1510) = 1× (1324) = 3× (1279)
<i>T. pyri</i>	2, 9	0.458	18.272*	Control (0) < 1× (3.52) = 3× (2.76)
<i>A. fallacis</i>	2, 9	0.008	0.661*	Control (1.32) = 1× (1.19) = 3× (1.02)

Note. Data are results from one-way ANOVA results on $\log_{10}(X + 1)$ transformed cumulative mite-days leaf⁻¹ calculated until 1 October 1998 for *P. ulmi* and phytoseiid mobiles. *T. pyri* and *A. fallacis* mite-days are calculated from the proportion identified, as described in the text. Significance of *F* statistic: * $P < 0.05$.

^a Means calculated from nontransformed data.

tive mite-days was observed in the control treatment. However, the one-way ANOVA indicated that the number of mite-days in the control treatment was not significantly different from either of the release treatments (Table 3).

Mite Densities in 1999

Samples of woody vines on 16 February 1999 showed phytoseiids over-wintering under the loose bark. Three phytoseiids were found from a cutting from a vine in replication 2 of the 3× treatment; two *T. pyri* and one *A. fallacis*.

P. ulmi densities were low early in the 1999 growing season. On 21 May *P. ulmi* densities were 0.10 ± 0.01 in controls, 0.06 ± 0.03 in the 1× treatment, and 0.11 ± 0.01 in the 3× treatment (Fig. 1). Densities of *P. ulmi* in the 3× release declined the first three samples of the season with densities of 0.11 ± 0.05 on 21 May, 0.04 ± 0.04 on 31 May, and 0.02 ± 0.01 on 14 June. Densities in the control plots remained higher than release plots for the remainder of the season and were 15.60 ± 1.55 in the final sample on 27 September (Fig. 1).

In the first sample of the season (21 May) phytoseiids were observed in the 1× (0.03 ± 0.03) and 3× (0.10 ± 0.05 mobiles leaf⁻¹) release treatments. No phytoseiids were found in the control plots this first sample (Fig. 1). Phytoseiid densities increased to a maximum of 0.18 ± 0.06 mobiles leaf⁻¹ in the 31 May sample of the 3× release treatment and remained at these levels until a sharp decline in numbers was seen in the 26 July sample. Phytoseiid densities in the control, 1× release treatment, and 3× release treatment plots in the 5 July sample were 0.01 ± 0.01 , 0.17 ± 0.09 , and 0.16 ± 0.06 mobiles leaf⁻¹, respectively (Fig. 1). A sharp decline in phytoseiid numbers was observed following an application of the acaricide/fungicide Dikar (common name dinocap, mancozeb) on 12 July (Table 1). A sample taken on 26 July showed phytoseiid numbers reduced to 0.0 ± 0.0 , 0.01 ± 0.01 , and 0.01 ± 0.01 mobiles leaf⁻¹ in control, 1× release treatment, and 3× release treatment, respectively (Fig. 1).

In the final sample of the season, 27 September, phytoseiid numbers appeared to recover somewhat, to

0.08 ± 0.03 , 0.03 ± 0.01 , and 0.09 ± 0.01 mobiles leaf⁻¹ in control, 1× release treatment, and 3× release treatment plots, respectively. The majority of phytoseiids in control plots in the last two samples 14 and 27 September were identified as *A. fallacis* (Table 4). Only two *T. pyri* were identified from controls, one on 5 July and one on 27 September.

In 1999, the largest numbers of *P. ulmi* mite-days were observed in control plots 515.36 ± 139.93 (21 May to 27 September), while significantly fewer were observed in the 1× (142.67 ± 56.60) and 3× releases (152.94 ± 42.88). Mite-days calculated for 1× release treatment were not significantly different from the 3× release treatment (Table 5).

TABLE 4
Phytoseiid Adults Identified from the Release Area in 1999

Date	Rate	<i>T. pyri</i> number (%)	<i>A. fallacis</i> number (%)	Total number
21 May	0	0 (0)	0 (0)	0
	1×	3 (100)	0 (0)	3
	3×	2 (100)	0 (0)	2
31 May	0	0 (0)	0 (0)	0
	1×	3 (100)	0 (0)	3
	3×	5 (100)	0 (0)	5
14 June	0	0 (0)	0 (0)	0
	1×	20 (100)	0 (0)	20
	3×	13 (100)	0 (0)	13
5 July	0	1 (100)	0 (0)	1
	1×	24 (100)	0 (0)	24
	3×	18 (100)	0 (0)	18
26 July	0	0 (0)	0 (0)	0
	1×	1 (100)	0 (0)	1
	3×	0 (100)	0 (0)	0
16 August	0	0 (0)	0 (0)	0
	1×	0 (0)	0 (0)	0
	3×	0 (0)	0 (0)	0
14 September	0	0 (0)	14 (100)	14
	1×	3 (60)	2 (40)	5
	3×	13 (81)	3 (19)	16
27 September	0	1 (7)	13 (93)	14
	1×	10 (63)	6 (37)	16
	3×	6 (60)	4 (40)	10

Note. Total is the total number identified for each treatment.

TABLE 5

Effects of the 1998 Release on Cumulative Mite-Days in 1999

Effect	df	MS (effect)	F statistic	LSD ($P < 0.05$) (LSD – means in parentheses) ^a
<i>P. ulmi</i>	2, 9	0.435	6.717*	Control (515.4) > 1× (142.7) = 3× (152.9)
<i>T. pyri</i>	2, 9	0.879	10.593*	Control (0.1) < 1× (7.0) = 3× (8.6)
<i>A. fallacis</i>	2, 9	0.144	6.134*	Control (2.1) > 1× (0.4) = 3× (0.5)

Note. Data are results from one-way ANOVA results on $\log_{10}(X + 1)$ transformed cumulative mite-days leaf⁻¹ calculated until 27 September 1999 for *P. ulmi* and phytoseiid mobiles. *T. pyri* and *A. fallacis* mite-days are calculated from the proportion identified. Significance of *F* statistic: * $P < 0.05$.

^a Means are from nontransformed values.

Analyzing only mite-days attributable to *T. pyri* resulted in significantly higher mite-days in release treatments (1×, 6.96 ± 3.33 ; 3×, 8.57 ± 2.48) than in control treatments (0.14 ± 0.10). The highest number of mite-days attributable to *A. fallacis* was in control treatments (2.19 ± 0.57) compared to the release treatments (1×, 0.44 ± 0.26 ; 3×, 0.46 ± 0.13) (Table 5).

DISCUSSION

Criteria for a successful biological control organism include the following: the ability of the predator to establish soon after release, to survive the spray regime, to effect biological control of the target pests, to disperse to pest subpopulations, to over-winter, and to achieve biological control in the following year Hoy (1982). In our study, *T. pyri* met these criteria. Soon after release, *T. pyri* established in release treatments, culminating in significantly higher numbers of mite-days compared to control treatments. However, in the first year no difference was observed in *P. ulmi* densities between treatments. After successfully over-wintering *T. pyri* were observed in the first sample of 1999 in release treatments, and densities increased to a higher level than *P. ulmi* in the 3× treatment by 31 May and continued higher in 1× and 3× plots until 5 July. A sample on 26 July showed reduced phytoseiid numbers after a 15 July Dikar application. Despite this, *P. ulmi* were controlled in release treatments at much lower densities than in 1998, and significantly lower *P. ulmi* densities were observed in release treatments than the control.

The observed success of *T. pyri* in the control of *P. ulmi* is consistent with results obtained from European vineyards (Hluchý, 1993; Rivenez *et al.*, 1995; Koleva *et al.*, 1996). In our test, control of *P. ulmi* was observed only in the year after release. In apple orchards, control of *P. ulmi* from releases of *T. pyri* have required more than 1 year. For example, Hardman *et al.* (1997) in Nova Scotia observed no significant differences between release and control treatments in the release year of *T. pyri*, but lower densities were observed in following years. Other studies have shown that re-

leases of *T. pyri* can take 1–3 years to establish and regulate populations of spider mites and rust mites (Pultar *et al.*, 1992; Blommers, 1994; Hardman *et al.*, 1995).

Although *A. fallacis* occurred in the release area in 1998 and 1999, *P. ulmi* still reached relatively high densities in control plots, perhaps because *A. fallacis* reached densities greater than 0.05 mobiles leaf⁻¹ only in September of both years. The occurrence and late season increase in *A. fallacis* numbers have been observed in other vineyards in Niagara (Marshall, unpublished data). These increases in density are probably a response to increasing *P. ulmi* populations. *Typhlodromus pyri* was observed on the leaves in relatively high densities from early in the growing season. This is characteristic of *T. pyri* in vineyards and orchards and has been suggested as one of the reasons that *T. pyri* is effective in *P. ulmi* control (Hluchý, 1993; Duso, 1992; Blommers, 1994; Hardman *et al.*, 1997). *T. pyri* also has the ability to subsist on alternative food sources such as fungi and pollen (Overmeer, 1985; Engle, 1990; Nyrop, 1998) and this may affect early season abundance. In vineyards elsewhere, *T. pyri* persists under low prey densities to out-compete *Amblyseius* species (Camporese and Duso, 1996). Both *A. fallacis* and *T. pyri* are under investigation as biological control agents for *P. ulmi* in Ontario vineyards. The population dynamics observed in this study are consistent with other release studies, which indicate that *T. pyri* seems to have the most potential for biological control of *P. ulmi* in Ontario vineyards (Marshall and Lester, unpublished data).

In 1998 *A. fallacis* was observed in all plots. In 1999, large numbers of *A. fallacis* were found only in control plots and at significantly higher densities than in plots where *T. pyri* was released. This may indicate that *T. pyri* was out-competing *A. fallacis*. This may be attributed to *T. pyri* reducing prey densities in release plots and making it difficult for *A. fallacis* to establish. There may also be some other intraguild interaction. *T. pyri* can feed on phytoseiid eggs including those of *A. fallacis*, but *A. fallacis* rarely feeds on *T. pyri* (Croft *et al.*, 1996). Whatever the reason for the apparent ability of

T. pyri to out-compete *A. fallacis*, the results of these studies are encouraging because *T. pyri* has high biological control potential that can be introduced to out-compete a resident predator that appears ineffective for control of *P. ulmi*.

A factor that may complicate the success of *T. pyri* in Ontario vineyards is the use of detrimental or harmful pesticides. An application of Dikar in July 1998 reduced *T. pyri* densities in the following sample. Hardman *et al.* (1991) noted that numbers of *T. pyri* in apple orchards were reduced following applications of the fungicide/acaricide Dikar. In 1998, the Gamay planting was treated with Dikar by spraying every other row and effects were minimal. In 1999, the grower upgraded his sprayer to a more efficient recirculating machine using curtains or shields to enclose the spray area and recover run-off spray mix and applied Dikar to all rows. This may explain the sharp decline in *T. pyri* following the 12 July Dikar application. This decline in *T. pyri* numbers in release plots might have allowed *P. ulmi* populations to increase. The effects of lower phytoseiid populations were seen in the control plots where *P. ulmi* numbers were highest at season end. Metiram may also reduce egg hatch in *T. pyri* (Baynon and Penman, 1987), but seemed to have little effect on this *T. pyri* strain.

The *T. pyri* migration dynamics were of interest. Although there were only two guard vines between control and release plots, *T. pyri* was slow to move into control plots. During the second season only two specimens of *T. pyri* were identified from control plots, one on 5 July and a second on 27 September. *T. pyri* is known for its slow migration in apple (Dunley and Croft, 1990; Marshall *et al.*, submitted for publication). Further work is needed to examine the optimal placement and number of *T. pyri* in vineyards, as well as work on other grape varieties.

In a 'Concord' variety vineyard, we have established an organophosphate- and pyrethroid-resistant *T. pyri* strain (Marshall and Lester, unpublished data). This strain has been used successfully for biological control in Canadian apple orchards (Hardman *et al.*, 1997) and may be useful in vineyards. These results do suggest that *T. pyri* is likely to be useful in a number of grape varieties. Here, we have shown that the transfer of infested leaves is a practical and useful way of introducing *T. pyri* into a vineyard. The most common method of transferring *T. pyri* between vineyards in Europe is to move prunings and cuttings during the periods when *T. pyri* is in its hibernating, over-wintering phase (Boller and Remund, 1991; Blommers, 1994). The transfer of leaves is an effective way of moving a known number of *T. pyri* between vineyards, compared to moving woodcuttings where unknown numbers of phytoseiids are transferred. Transferring 8.5 or 25.5 *T. pyri* per vine early in the growing season resulted in a similar density of *T. pyri* in the year of transfer. In the

following year, densities prior to the Dikar application rose to similar levels by the 5 July sample. These results indicate small transfers may be just as effective as larger *T. pyri* introductions. We suggest moving leaves into young vineyards with small vines before the development of high populations of *P. ulmi*. Such an early inoculative transfer would reduce the numbers of leaves to be moved between vineyards.

ACKNOWLEDGMENTS

The authors thank Dr. Alan Tomlin for his advice on this project, Dr. Howard Thistlewood for his efforts in initiating research on this problem of mites on grape, Dr. David Pree and Dr. Michael Hardman for their preliminary reviews of the manuscript, and Hitesh Jain, Sarah Ball, Heidi Fast, Mark Settle, and Lisa Wambold for their technical assistance, as well as John and Kevin Watson who kindly allowed this research in their vineyards.

REFERENCES

- Baillo, M., Bassino, J. P., and Piganeau, P. 1979. L'estimation du risque provoqué par l'acarien rouge (*Panonychus ulmi* Koch) et l'acarien des charmillles (*Eotetranychus carpini* Oud.) en viticulture. *Rev. Suisse Vitic. Arboric. Hortic.* **11**, 123-130.
- Baynon, G. T., and Penman, D. R. 1987. The effects of mancozeb and metiram on the predatory mite, *Typhlodromus pyri*. *Proc. New Zealand Weed Pest Con. Conf.*, 104-107.
- Beers, E. H., Brunner, J. F., Willett, M. J., and Warner, G. M. 1993. "Orchard Pest Management. A Resource Book for the Pacific Northwest." Good Fruit Grower, Washington.
- Blommers, L. H. M. 1994. Integrated pest management in European apple orchards. *Annu. Rev. Entomol.* **39**, 213-241.
- Boller, E., and Remund, U. 1983. Methoden zur Abschätzung des Befallsrisikos durch Spinnmilben und Traubenwickler im ostschweizerischen Rebbau. *Kontrollmethoden und Toleranzgrenzen für Spinnmilben. Schweiz. Z. Obst-Weinbau* **119**, 257-260.
- Boller, E., and Remund, U. 1991. Large-scale field colonization with the predatory mite *Typhlodromus pyri*. *Schweizerische Zeitschrift Obst Weinbau* **127**, 280-283.
- Croft, B. A., Kim, S. S., and Kim, D. I. 1996. Intra- and interspecific predation on four life stage groups by the adult females of *Metaseiulus occidentalis*, *Typhlodromus pyri*, *Neoseiulus fallacis* and *Amblyseius andersoni*. *Exp. Appl. Acarol.* **20**, 435-444.
- Dunley, J. E., and Croft, B. A. 1990. Dispersal between and colonization of apple by *Metaseiulus occidentalis* and *Typhlodromus pyri* (Acarina: Phytoseiidae). *Exp. Appl. Acarol.* **10**, 137-149.
- Duso, C. 1992. Role of *Amblyseius aberrans* (Oud.), *Typhlodromus pyri* Scheuten and *Amblyseius andersoni* (Chant) (Acari, Phytoseiidae) in vineyards. III. Influence of variety characteristics on the success of *A. aberrans* and *T. pyri* releases. *J. Appl. Entomol.* **114**, 455-462.
- Engle, R. 1990. Alternative prey and other food resources of the phytoseiid mite *Typhlodromus pyri* (Scheuten). International Organization for Biological Control/West Palearctic Region Section, Working Group "Integrated Control in Viticulture" Bulletin Vol. 13, pp. 124-127.
- Hardman, J. M., Rogers, R. E. L., Nyrop, J. P., and Frisch, T. 1991. Effect of pesticide applications on abundance of European red mite (Acari: Tetranychidae) and *Typhlodromus pyri* (Acari: Phytoseiidae) in Nova Scotian apple orchards. *J. Econ. Entomol.* **84**, 570-589.

- Hardman, J. M., Smith, R. F., and Bent, E. 1995. Effects of different integrated pest management programs on biological control of mites on apple by predatory mites (Acari) in Nova Scotia. *Environ. Entomol.* **24**, 125–142.
- Hardman, J. M., Rogers, M. L., Gaul, S. O., and Bent, E. D. 1997. Insectary rearing and initial testing in Canada of an organophosphate/pyrethroid-resistant strain of the predator mite *Typhlodromus pyri* (Acari: Phytoseiidae) from New Zealand. *Envir. Entomol.* **26**, 1424–1436.
- Henderson, C. F., and McBurnie, H. V. 1943. Sampling techniques for determining populations of the citrus red mite and its predators. *U.S. Dep. Agric. Circ.* **671**.
- Hluchý, M. 1993. Studies on biological control of the wine blister mite *Calepitrimerus vitis* Nal. (Acari, Eriophyidae) by means of the predatory mite *Typhlodromus pyri* Scheut. (Acari, Phytoseiidae). *J. Appl. Entomol.* **116**, 449–458.
- Hoy, M. A. 1982. Aerial dispersal and field efficacy of a genetically improved strain of the spider mite predator *Metaseiulus occidentalis*. *Entomol. Exp. Appl.* **32**, 205–212.
- Koleva, R., Ferenczy, A., and Jenser, G. 1996. Effect of various plant protection programs on mite populations in vineyards. *Hort. Sci.* **28**, 79–82.
- Lester, P. J., Thistlewood, H. M. A., Ball, S., and Harmsen, R. 1998. European red mite (*Panonychus ulmi* Koch): A new problem in Canadian vineyards. *Proc. Ontario Entomol. Soc.* **128**, 105–107.
- Marshall, D. B., Thistlewood, H. M. A. and Lester, P. J. Release, establishment and movement of the predator *Typhlodromus pyri* (Acari:Phytoseiidae) on apple. Submitted for publication.
- Nyrop, J. P., English-Loeb, G., and Roda, A. 1998. Conservation biological control of spider mites in perennial cropping systems. In "Conservation Biological Control" (P. Barbosa, Ed.), pp. 307–333. Academic Press, New York.
- Overmeer, W. P. J. 1985. Alternative prey and other food resources, In "Spider Mites: Their biology, Natural Enemies and Control" (W. Helle and M. W. Sabelis, Eds.), Vol. 1B, pp. 131–140. Elsevier, Amsterdam.
- Pree, D. J., and Wagner, H. W. 1987. Occurrence of cyhexatin and dicofol resistance in the European red mite, *Panonychus ulmi* (Koch) (Acari: Tetranychidae), in southern Ontario. *Can. Entomol.* **119**, 287–290.
- Pree, D. J., Cole, K. J., and Fisher, P. A. 1989. Comparison of leaf disk and petri dish assays for the assessment of dicofol resistance in populations of the European red mite from southern Ontario. *Can. Entomol.* **121**, 771–776.
- Pultar, O., Pliva, J., and Muska, J. 1992. *Typhlodromus pyri* Scheut. as a biological control agent of spider mites in Czechoslovakia large scale fruit production. *Acta Phytopathol. Entomol. Hung.* **27**, 513–515.
- Rivenez, M. O., Thibault, J., and Lesage, V. 1995. *Typhlodromus pyri* has become a well-established partner in the Loire Valley. *Phytoma* **472**, 32–36.
- Schruff, G., Kassenmeyer, H. H., and Kast, W. K. 1990. Pflanzenschutz im Weinbau. Staatliches Weinbauinstitut, Freiburg and Staatl. Lehr- und Versuchsanstalt, Weinberg, Deutschland.
- Statsoft. 1995. "Statistica for Windows, Volume I, General Conventions and Statistics 1." 2nd ed. Statsoft Inc., Tulsa, OK.
- Valentin, G., Kreiter, S., and Jacquet, C. 1994. Study of the presence of *Typhlodromus pyri* in the vineyard. Some results from Champagne. *Phytoma* **466**, 33–38.
- Veerman, A. 1992. Diapause in phytoseiid mites: A review. *Exp. Appl. Acarol.* **14**, 1–60.