Schaber, B.D. and Entz T. 1988. Effect of spring burning on insects in seed alfalfa fields. J. Econ. Ent. 81:668-672.

Schaber, B.D. and T. Entz. 1991. Effect of annual and/or biennial burning of seed alfalfa stubble on populations of alfalfa weevil and pea aphid. Ann. Appl. Biol. 119:425-431.

Schaber, B.D. and K.W. Richards. 1979. Integrated pest management on alfalfa grown for seed in southern Alberta. Forage Notes. 24:17-19.

Tippens, H.H. 1964. Effect of winter burning on some pests of alfalfa. J. Econ. Ent. 57:1003-1004.

Phytoseiid mites associated with spider mites on hops in the Willamette Valley, Oregon

W.B. STRONG and B.A. CROFT

DEPARTMENT OF ENTOMOLOGY, OREGON STATE UNIVERSITY, CORVALLIS, OR 97331

ABSTRACT

Densities and damage by twospotted spider mites, *Tetranychus urticae* Koch and levels of phytoseiid mites on hops were assessed in 34 commercial fields and at 11-19 sites of escaped hops in the Willamette valley of western Oregon in 1991-1992. *Amblyseius fallacis* (Garman), *Typhlodromus pyri* Scheuten, *Amblyseius andersoni* Chant and *Metaseiulus occidentalis* (Nesbitt) were most common. On escaped hops, *T. pyri* was more common than other phytoseiids. It occurred widely on plants surrounding commercial hops including blackberry and other rosaceous plants and probably is a vagrant on escaped hops. *A. fallacis* was most common in commercial hops making up 88% of all specimens, followed by many fewer *M. occidentalis* and *T. pyri*. Early spring survival of *A. fallacis* in commercial hops was poor because of certain cultural practices used in the spring. Means to improve biological control of spider mites on hops are discussed including amended methods of hop culture, use of selective pesticides and inoculative releases of predaceous mites.

Additional keywords: *Amblyseius fallacis, Metaseiulus occidentalis, Typhlodromus pyri, Amblyseius andersoni, Tetranychus urticae*

INTRODUCTION

Two-spotted spider mite (*Tetranychus urticae* Koch) (TSSM) is a major pest of hops and associated crops in the Willamette valley, Oregon. It overwinters in dead plant materials or on the hop crown, emerging in early spring to feed on weeds and new hops shoots (Cone *et al.* 1986, Cranham 1985). Control of TSSM usually requires from one to several miticide sprays each summer. Other pesticides such as aphicides sprayed for hop aphid (*Phorodon humuli* (Shrank)) and fungicides used for disease control may also affect TSSM and its predators. Because of pesticide resistance in TSSM on hops (Campbell 1985), chemical control has been difficult. A biological control program for TSSM would be a desirable alternative to replace pesticides or to augment their use.

Several biological control agents against TSSM have been reported from hops in arid regions of western North America, but their usefulness has been limited because of non-selective pesticide use (Pruszynski & Cone, 1972). These agents include several insect predators and phytoseiid mites. In central Washington, *Metaseiulus occidentalis* (Nesbitt) was the most common phytoseiid; it emerged from the subterrenian crowns of hops in early April and then became sparse, reappearing in July (Pruszynski & Cone, 1973). Although there appeared to be some pesticide tolerance in the central Washington strain of *M. occidentalis,* it did not control TSSM to low levels.

Little is known about biological control on hops in the milder, more humid regions of western North America. This study was conducted to determine the beneficial species composition and incidence of phytoseiids and spider mites on escaped and commercial hops in the more humid regions of Oregon, to measure early spring mortality of phytoseiids, and to monitor the dispersal of phytoseiids and TSSMs within and between hops and other crops.

MATERIALS AND METHODS

Commercial fields survey

Thirty-four commercial hop fields were surveyed 3 times each in 1991 and again in 1992. From each field, 50 leaves were taken, 5 each from plants near 10 support poles. These poles support wires at a height of 6 m, from which heavy twine is suspended; the hop vines grow up the twine. Cracks in the wooden poles and in debris at the soil-pole interface are overwintering sites for TSSM (Cone *et al.* 1986) and presumably for phytoseiids. Poles were selected from the field edge to about 50 m toward the field interior. In May, all leaves were collected from near the ground. In 1991, later samples were from 0-2 m, since TSSMs (and phytoseiids) are con-

Table 1

Tetranychus urticae levels and phytoseiid mites found in commercial hop surveys, 1991-1992.

	1991			1992		
	Early	Mid	Late	Early	Mid	Late
Fields	34	34	34	32	31	29
% fields with mites	38%	76%	97%	81%	100%	86%
Mites/leaf in fields with mites[1]	.31±.16	.66±.25	3.15± .87	.91±.30	3.06±1.34	.93± .46
Mean damage on infested leaves in fields with mites[1]	1.10±.13	1.30±.08	2.16± .27	1.29±.08	1.46± .08	1.70± .07
Phytoseiids/field	.06±.04	.15±.09	2.85±1.87	.63±.37	3.65±1.57	25.2 ±14.5
A. fallacis	2		76	10	83	688
T. pyri		4		6	3	
M. occidentalis					2	24
Unknown (immatures)		1	21	4	25	18
Total phytoseiids	2	5	97	20	113	730

1. means ± SE

Table 2

Commercial hop fields with elevated levels of *Tetranychus urticae* and/or *Amblyseius fallacis*.

Year	Period	Field	Mites/leaf[1]	Damage/infested leaf	Phytoseiids/leaf
1991	late	19	2.30±0.99	1.83±0.42	0.13±0.10
1991	late	24	16.91±3.15	2.74±0.18	0.69±0.24
1991	late	27	15.50±1.97	2.24±0.13	0.02±0.02
1991	late	28	19.82±4.56	2.59±0.20	0
1991	late	29	10.08±1.87	1.83±0.14	0
1991	late	30	6.40±1.88	3.04±0.15	1.20±0.22
1991	late	34	6.64±1.46	1.93±0.14	0
1992	Mid	18	20.02±4.47	2.58±0.14	0.86±0.40
1992	Mid	23	38.24±8.17	2.87±0.18	0.04±0.03
1992	Late	7	10.48±1.28	2.77±0.12	6.28±1.17
1992	Late	11	2.24±0.33	1.61±0.10	5.92±1.06

1. means ± SE

centrated in these areas at these times (Sites & Cone, 1985). Later samples in 1992 were taken from the ground to 6 m.

Survey times were early-season (May 3-10 in 1991, May 18-28 in 1992), when basal leaves were present but before the hop shoots started climbing the twine; mid-season (June 14 in 1991, June 8-23 in 1992), when shoots had twined 2-3 m up the twine; and pre-harvest (Aug 3, 1991; Aug 17-18, 1992), when flowers had formed on side-arms growing from the main hop stem.

The hop leaves were observed under a binocular microscope at 10X; all life stages of phytoseiids were counted and adults were mounted in Hoyer's solution on a microscope slide for species identification. TSSM adult females were counted, and leaves were scored for damage on a scale of 0 to 5 (0= no damage, 1= light damage to one leaf lobe, 2= light damage to 2 lobes, 3= light damage to 3 or more lobes, 4= heavy damage to 3 or more lobes, and 5= heavy damage over entire leaf surface).

Escaped hops survey

Several sites in the Willamette Valley were found with escaped, unsprayed hops. Typical sites were in field headlands, road verges, and along ditches and fencerows. Most sites were near commercial hops or other crops, which could harbor spider mites or predatory mites. Hop leaf collections were made from 0-2 m; leaves with TSSM were selected where possible. In 1991, 14 samples of 50 leaves each were taken from July 9 to August 5 from 11 sites. In 1992, three surveys of 25 leaves per sample were made on May 8 (13 sites), between June 8-18 (19 sites) and on July 29 (16 sites). Adult female TSSM were counted and phytoseiids were counted and identified.

Early Spring Survival study

A single field of the Perle variety of hops (Field #30 in the commercial fields survey), which had large numbers of phytoseiids the previous fall, was selected in 1992. On March 16, before the hop plants started growing (hop plants are perennial and die back every year), 4 bags of live bean plants in vermiculite were leaned against poles. The bean plants had light infestations of spider mites to attract phytoseiids; they were replaced with fresh plants on March 30, April 6 (2 extra bags were added to total 6), and April 13. On the latter two dates 35 and 50 hop leaves, respectively, were also collected from new shoots. Hop leaves and bean plants were observed for mites and the phytoseiids were collected for identification.

Transect surveys

Two commercial hop fields were selected to monitor dispersal of TSSM and phytoseiids from adjacent crops (berries). Field #27 had strawberries upwind; field #33 had strawberries downwind and caneberries upwind. At each hop/berry interface, 50 leaves were collected from a transect running from 40 m within the berry field to 40 m within the hop field. Five leaves were collected at each of 10 sites along the transect: at 0, 10, 20, 30, and 40 m from the interface. Leaves from hop fields were collected from plants near support poles. Predators were counted and each leaf scored for damage on the 0-5 scale described above. This procedure was repeated three times in 1991, on the same dates that commercial fields were surveyed.

RESULTS AND DISCUSSION

Commercial fields survey

TSSMs were generally low in number in 1991, presumably due to the cool, wet weather that prevailed (Table 1). In early-season, infestations were detected in 13 fields (38% of total) but mean densities of females/leaf in infested fields and mean damage ratings on infested leaves of infested fields were all low. Only two predator specimens, both *Amblyseius fallacis* (Garman), were found in early-season. At mid-season, more fields had TSSMs, infested fields had more mites/leaf, and damage was higher on infested leaves in infested fields (these figures are not significant at $P \leq .05$ in 1991). Again, few predators were found (5 specimens). At preharvest, most fields had TSSMs (97%), there were significantly higher ($P < .05$) densities in infested fields, and damage was significantly higher ($P < .05$) with some leaves rating 5. TSSMs in four fields exceeded 10/leaf (Table 2), levels high enough to cause economic damage (Jim Todd[1], pers. comm.). However, more predators were found at this time (Table 1); most were *A. fallacis*. These predators mostly were found in three fields, with high concentrations in fields #24 and #30 (Table 2).

In 1992, TSSMs were generally more dense than in 1991 (Table 1). Percent fields infested, mean number of TSSMs, and mean damage levels on infested leaves in infested fields were all higher in early- and mid-season. However, late-season samples were lower in all three categories than in 1991. This decline was probably due to spraying in response to perceived conditions favourable for TSSM (1992 was warmer and dryer than 1991). By mid-season, two fields had TSSM levels higher than 10/leaf, and a third had elevated levels in late-season (Table 2). Eighteen of all 1992 samples had TSSM levels at 1-6 per leaf; all 71 other samples were below 1 TSSM/leaf. Thus despite early and mid-season TSSMs being significantly ($P < .02$) higher in 1992 than 1991, they posed no greater threat to the crop in 1992.

In both years, the most common phytoseiid collected in commercial hops was *A. fallacis*. It was the only species found in late-season 1991. *Typhlodromus pyri* Scheuten was found in early and mid-season, but was absent by late-season. Cultural practices such as spraying may be detrimental to *T. pyri* which probably migrates into hops. *M. occidentalis* was not found in 1991, but it occurred in late-season, 1992. Its occurrence may have been related to the hot dry weather of 1992 (Croft *et al.* 1990).

Table 3
Tetranychus urticae and phytoseiid mites found in escaped hop sites.

	1991	Early 92	Mid 92	Late 92
Samples	14	13	19	16
Sample n	50	25	25	25
Mites/sample	8.5 ±2.07	12.0 ±6.26	25.60±6.37	31.10±8.90
Mites/leaf	.24± .07	.48± .15	1.04± .14	1.17± .35
Phytoseiids/sample[1]	4.70±1.28	6.38±2.87	6.74±2.27	3.19±1.29
Amblyseius fallacis	2	4	2	2
Typhlodromus pyri	58	57	32	31
Metaseiulus occidentalis	2	22	3	
Amblyseius andersoni	2	7	27	4
Amblyseius exopodalis		3		
Typhlodromus arboreus	2			
Typhlodromus mahri		2		
Typhlodromus caudiglans	2			
Unknown phytoseiids[2]	6	10	45	11
Total phytoseiids	74	83	128	51

1 Means ± SE.

2 Unknowns were immatures which are unidentifiable.

Table 4
Spring trapping of overwintered *Amblyseius fallacis* in field #30, 1992.

		PHYTOSEIIDS				
DATE	pots	Females	Males	Juveniles	Eggs	Bean Plant Condition
March 30	2	19	0	2	Many	Dry, some green
April 6	4	6	1	0	Few	Frosted, some green
April 13	6	0	0	0	0	Frosted, some green
April 20	5	0	0	0	0	Good, slightly dry

Phytoseiids increased in commercial hops from low (very low in 1991) to substantial by late-season, especially in 1992 (Table 1). Despite the presence of some TSSM, predators were not abundant in early- and mid-season (highest level was 3.65 +– 1.57 predators / field, or 0.073 predators / leaf). At pre-harvest, predators were abundant in only two of the fields in 1991 (Table 2), but were abundant in more fields in 1992. Of nine fields where TSSMs exceeded 5 mites/leaf (Table 2), five had few predators (similar to other fields with low TSSM counts), while four had some of the highest predator numbers sampled. This indicated that phytoseiids, when present in commercial fields, may respond numerically to TSSM. Their ability to regulate TSSM probably depends on their timing of entry into hops.

Two fields in 1992 had very high levels of phytoseiids (Table 2). Although the cultural and pesticide histories of these fields were examined, no consistent differences were found between these fields and others which might explain the greater incidence of phytoseiids.

Escaped hops survey

Mite numbers were very low on escaped hops in 1991 (Table 3). This season was cool and wet, which was not conducive to buildup of TSSM. 1992 was warmer and drier than 1991 though. TSSM numbers in 1992 started low and increased through to late-season, reaching a mean density of 1.17±.36 mites/leaf. Although this was nearly 5-fold more than in 1991, it still was a non-economic level of mites from a grower's point of view. In none of the 1991 samples did the TSSM adults exceed 1/leaf. In 1992, the sample with the most TSSMs (excluding the outlier) was 3.52/leaf. Thus it seems that favorable conditions for mites in 1992 resulted in increased TSSM over 1991 but still below those that would be of economic concern if present in commercial hops.

In both years the majority of predators found on escaped hops were *T. pyri*, which is a generalist feeder usually associated with rosaceous plants (Hadam et al. 1986). *T. pyri* may be a vagrant on hops as a result of its association with other plant species, including wild blackberry or other rosaceous plants. *A. fallacis* was infrequently found on escaped hops, although it was common in commercial hops. Twenty-five *M. occidentalis* were found on escaped plants in 1992 but only 2 were found in 1991, possibly because this is a heat- and dry-adapted predator (Croft *et al.*, 1990) and 1992 was the hotter, drier year. Nearly all *Amblyseius andersoni* (Chant) found in 1992 were from a single humid site near a river; *A. andersoni* is a humidity-adapted predator (Messing & Croft, 1991). Otherwise its abundance was like that of *A. fallacis*. Other species were found infrequently.

Thus it appears that biological control is occurring actively on escaped hops. TSSM numbers from unsprayed sites compared favorably with those in commercial hops, in which mite control is largely brought about with pesticides. The low variation in mite numbers in escaped hops (no high peaks) compared to commercial hops indicates that biological control of TSSM may be effective and dependable.

There was a wide variation in the habitat and vegetation surrounding unsprayed hops, ranging from dry in full sunshine with low floral diversity nearby (*e.g.* road verges) to humid and shady with high floral diversity (*e.g.* forested areas next to fields). The incidence of phytoseiids and TSSMs seemed unrelated to habitat, indicating that the habitat of a commercial field might be suitable for biological control of TSSM by phytoseiids.

Early Spring Survival study.

Phytoseiids (*A. fallacis*) were active and out of diapause by March 30 (Table 4), before the hop vines started growing. However, by April 13 no more were found on trap plants. Up to April 6 there was virtually no vegetation in the field, either weeds or hop vines, which is normal in overwintering hop fields. The 1991/92 winter was very warm with no prolonged frost; it seems likely that phytoseiids were active at times during the winter and early spring before plant growth occurred, feeding upon TSSM. Since there was no green matter present for spider mites to feed on, the phytoseiids may have overexploited TSSM and then starved.

Early hop leaf collections contained two *A. fallacis* females, one juvenile and several eggs found on April 6, a single female on April 13, and no predators on April 20. A few TSSMs were found on the hop leaves from April 13 and 20; any predators present would probably have been

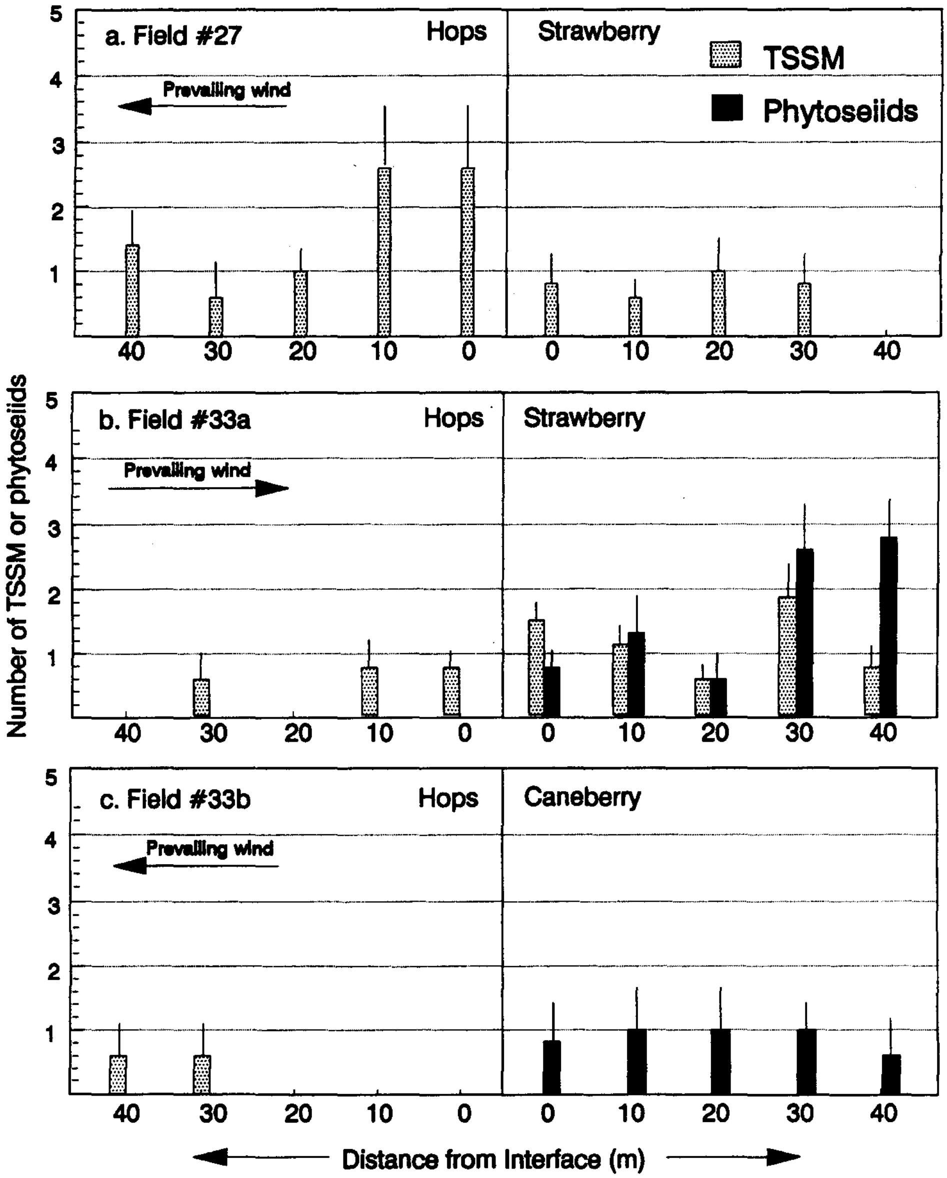

Figure 1. Levels of Tetranychus urticae (TSSM) and phytoseiid mites (Amblyseius fallacis, Typhlodromus pyri) found in mid-season transect surveys of hop yards and adjacent crops, 1991 (lines are SE's).

associated with these TSSMs. It appears that although the phytoseiids overwintered successfully, hop plants may become active too late to support the early spider mite colonies required for early spring survival of phytoseiids .

Transect surveys

A general trend was noted that TSSMs often were present in crops surrounding hops at higher levels than in hops in early-season and that they dispersed into the hops as the season progressed. Three examples of this are presented in Figure 1, all of which are from the mid-season sample period. In Field #27, no TSSM were found in hops in early-season despite levels in the adjacent strawberries of .24 TSSM/leaf, but by mid-season an edge effect was apparent (Figure 1a). Possibly the TSSM moved into the hops on prevailing winds; both TSSM and phytoseiids are capable of dispersing on wind (Johnson & Croft, 1976; Kennedy & Smitley, 1985; Sabelis & Dicke, 1985). As the season progressed, this apparent edge effect diminished. In contrast, field #33a had a prevailing wind blowing the opposite way. Again, in early-season there were neither TSSM nor phytoseiids in the hops; by mid-season there was an apparent edge effect but at much lower numbers than Field #27 (Figure 1b). Also, the abundant phytoseiids in strawberry never moved over into hops, despite being the highly dispersive species, *A. fallacis* (Johnson & Croft, 1976). The data from Field #33b indicate that the species of phytoseiid is also important in dispersal (Figure 1c). Despite prevailing winds from the caneberries to the hops, phytoseiids were not detected in the hops. The phytoseiid found in the caneberries was exclusively *T. pyri,* which is known to be a relatively poor disperser (Boller *et al.,* 1988; Croft *et al.,* 1990).

Apparently both spider mites and predators overwinter well in surrounding crops but poorly in hops; they then disperse into hops at rates depending on species, prevailing wind direction, and possibly other factors. Although the data in Figure 1 are from limited sites and show considerable variability, they indicate the need for further investigation into early-season movement of predators and TSSM in relation to surrounding crops and prevailing wind direction.

CONCLUSIONS

It appears that despite intensive spraying, TSSMs and damage from these pests increase seasonally in most commercial hop fields. In six fields at pre-harvest, TSSMs exceeded 10 per leaf, a large proportion of leaves had mites, and damage ratings were high. Although economic impact of these TSSM levels needs more definitive research, an alternative management method to pesticides is desirable.

Presumably biological control of TSSM using phytoseiids would be possible in hops except for 3 conditions: limited ability of phytoseiids to establish populations in the early spring, their lack of early-season dispersal into hops, and use of pesticides and cultural practices harmful to predators. The differential early-spring survivorship of phytoseiids and TSSM makes hops similar to a perennial crop for TSSM, but more like an annual crop for phytoseiids. With their low dispersal rates into hop fields from surrounding crops, phytoseiids may need re-introduction each year. This was the conclusion of Cranham (1985) who felt that stable biological control in hops was unlikey due to the annual nature of the crop.

Use of some cultural practices and insecticides in hop culture are difficult to avoid, but others may be modified. Planting ground covers favorable to survival of phytoseiids, and eliminating leaf stripping and hilling around hops, both of which remove leaves haboring phytoseiids early in spring may be helpful. Pesticide changes may include eliminating pyrethroids and using insecticides more compatible with phytoseiids (Croft 1990). However, even with these modifications, the early spring pool of phytoseiids may be too small to ensure biological control and thus supplementary releases may be required.

Supplementary releases would be most economical when used in an inoculative manner. From these studies, the key time to release would be early spring, when TSSM start to develop but naturally-occurring phytoseiids are rare. The number of releases, release location (within and between plants) and release density of phytoseiids have yet to be determined. The results of this study indicate that four species should be tried: *T. pyri* and *A. andersoni,* found mostly on escaped hops; *M. occidentalis,* found on both escaped and commercial hops; and *A. fallacis,* found mostly in commercial hops. The other phytoseiids collected in this study were probably incidentals and unlikely to play a major role in biological control. It is likely that *A. fallacis* and *M. occidentalis* will have the greatest commercial impact, since they were the only species that were abundant in commercial hops. A mixture of both species might be advisable. The microhabitat on a hop plant may vary from cool and humid (suitable for *A. fallacis*) at the bottom to warm and dry (suitable for *M. occidentalis*) near the top. Moreover, since future weather conditions at the time of release are unpredictable, releasing both species might ensure control regardless of weather conditions.

NOTE

1. Jim Todd, Willamette Agricultural Consulting, 7555 Conifer St NE, Salem, OR 97301.

REFERENCES CITED

Boller, E. F., U. Remund and M. P. Candolfi. 1988. Hedges as potential sources of *Typhlodromus pyri*, the most important predatory mite in vineyards of northern Switzerland. Entomophaga 33(2): 249-255.

Campbell, C. A. M. 1985. Hops (*Humulus lupulus*). In N. W. Hussey and N. Scopes. *Biological Pest Control: the Glasshouse Experience*. Ithica, NY, Cornell University Press. 192-194.

Cone, W. W., L. C. Wright and T. E. Wildman. 1986. Reproduction by overwintered *Tetranychus urticae* (Acari: Tetranychidae) on hops. Ann. Entomol. Soc. Am. 79: 837-840.

Cranham, J. E. 1985. Hop. In W. Helle and M. W. Sabelis. *Spider Mites: their Biology, Natural Enemies, and Control*, Vol. 1B. New York, Elsevier. 367-370.

Croft, B.A. 1990. Arthropod Biological Control Agents & Pesticides. Wiley Intersci. J. Wiley, N.Y. 723 pp.

Croft, B. A., P. Shearer, G. J. Fields and H. W. Riedl. 1990. Distribution of *Metaseiulus occidentalis* (Nesbitt) and *Typhlodromus pyri* Scheuten (Parasitiformes: Phytoseiidae) in apple orchards of the Hood River Valley, Oregon. Can. Entomol. 122: 5-14.

Hadam, J. J., M. T. Aliniazee and B. A. Croft. 1986. Phytoseiid mites (Parasitiformes: Phytoseiidae) of major crops in Willamette Valley, Oregon, and pesticide resistance in *Typhlodromus pyri* Scheuten. Environ. Entomol. 15: 1255-1263.

Johnson, D. T. and B. A. Croft. 1976. Laboratory study of the dispersal behavior of *Amblyseius fallacis* (Acarina: Phytoseiidae). Ann. Ent. Soc. Am. 69(6): 1019-1023.

Kennedy, G. G. and D. R. Smitley. 1985. Dispersal. In W. Helle and M. W. Sabelis. *Spider Mites: their Biology, Natural Enemies and Control* Vol. 1A. New York, Elsevier. 233-242.

Messing, R. H. and B. A. Croft. 1991. Biosystematics of *Amblyseius andersoni* and *A. potentillae* (Acarina: Phytoseiidae): Implications for biological control. Exp. Appl. Acarol. 10: 267-278.

Pruszynski, S. and W. W. Cone. 1972. Relationships between *Phytoseiulus persimilis* and other enemies of the twospotted spider mite on hops. Environ. Entomol. 1(4): 431-433.

Pruszynski, S. and W. W. Cone. 1973. Biological observations of *Typhlodromus occidentalis* (Acarina: Phytoseiidae) on hops. Ann. Ent. Soc. Am. 66(1): 47-51.

Sabelis, M. W. and M. Dicke. 1985. Long-range dispersal and searching behaviour. In W. Helle and M. W. Sabelis. *Spider Mites: their Biology, Natural Enemies, and Control* Vol. 1B. New York, Elsevier. 141-160.

Sites, R. W. and W. W. Cone. 1985. Vertical dispersion of twospotted spider mites on hops throughout the growing season. J. Entomol. Soc. Brit. Columbia 82: 22-25.