Sources of Spring and Fall Hop Aphid, *Phorodon humuli* (Schrank), (Homoptera: Aphididae) Migrants in South Central Washington

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ABSTRACT

The hop aphid, *Phorodon humuli* (Schrank), flies from hop, *Humulus lupulus* L., to its overwintering *Prunus* spp. hosts in the fall. The sources of these aphids were not known because much of the aphid flight occurs after hop plants are removed from fields during harvest. We found that the bottoms of hop plants remaining alive in harvested hop yards averaged 1.7 to 5.8 hop aphids per leaf in three years of sampling. Unharvested hop plants remaining after harvest averaged 32.8 to 127.1 aphids per leaf in two years. Feral hops were also infested with hop aphids in late summer and early fall. Sources for the spring aphid flight from *Prunus* spp. to hop included *Prunus cerasifera* Ehrhart, which averaged 44.0 to 105.1 aphids per shoot in two years of sampling. Fruit-type *Prunus* spp. trees growing on residential properties averaged 0.9 and 11.3 aphids per shoot in the same years but few of these trees were found. Plum and prune orchards averaged 0 to 5.5 aphids per shoot in two years and estimates indicate that orchard trees are much more numerous than other hop aphid host trees. Potential alternative management strategies for hop aphid control are discussed.

Key Words: Homoptera, *Phorodon humuli*, hop, *Humulus lupulus*, *Prunus*, host plants

INTRODUCTION

The hop aphid, *Phorodon humuli* (Schrank), is an important pest of hop, *Humulus lupulus* L., in south central Washington state (WA) and in most hop-growing areas of the Northern Hemisphere (Neve 1991). It is a holocyclic aphid that overwinters in the egg stage on purple-leafed ornamental flowering plum, *Prunus cerasifera* Ehrhart (also known as cherry plum or Myrobalan plum), *Prunus divaricata* Ledebour, *Prunus domestica* L., *Prunus insititia* L., *Prunus mahaleb* L., and *Prunus spinosa* L. (Blackman and Eastop 1994). Eggs hatch in February and March followed by a variable number of generations of parthenogenetic wingless females. The winged females that fly to hop appear in WA in early to mid-May and flight continues from mid-July to early August (Wright *et al.* 1995). Hop is the aphid's only secondary (summer) host (Born 1968; Miciński and Ruszkiewicz 1974; Eppler 1986). Parthenogenetic, wingless females are produced on hop during the summer (Campbell 1985; Campbell and Tregidga 2005). In late August, gynoparae (winged females) are produced on hop, which begin the flight back to *Prunus* spp. Winged males that fly from hop to *Prunus* spp. appear about mid-September. Aphid flight often continues into November and is terminated by foliage-killing frost (Wright *et al.* 1995). The gynoparae give birth to a generation of wingless females, the oviparae, which mate with winged males and lay the overwintering eggs on *Prunus* spp. buds and stems. Neither hop aphids nor their eggs have been reported on hop during the winter. Further-

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more, gynoparae do not settle on hop leaves or reproduce on hop (Campbell and Tregidga 2005).

The aerial parts of hop plants are killed by fall frosts and only the hop roots, which are several cm below the soil surface, survive the winter. In the spring, shoots grow from the roots and they are trained to grow up fiber strings which are tied to a trellis that is about 5 m tall. During harvest (mid-August to mid-September) hop plants are cut at the top of the trellis and about 1 m above ground, removed from the fields and taken to stationary picking machines where the cones are separated from the leaves and stems. The cones are dried in large kilns at 60 °C and the waste leaves and stems are chopped and spread on the fields soon after harvest or after being stored in large piles. It is considered unlikely that many aphids could survive the picking process (Campbell and Tregidga 2005). Following harvest, about 1 m of basal foliage remains alive in hop fields until it is killed by frost. The amount of foliage remaining is quite variable ranging from a few leaves to hundreds of leaves per plant. Intact plants growing up trellis poles remain in some hop yards following harvest and feral (wild) hop plants are also present in the hop-growing region of WA (James *et al.* 2001). Approximately half of the gynoparae and very few males have flown by the end of harvest (Wright *et al.* 1995). One of our objectives was to determine if harvested and unharvested hop plants remaining alive in the fields after harvest, as well as feral hop plants, could be a source of fall migrants.

Another objective was to determine the source of aphids that fly from *Prunus* spp. to hop in the spring and summer. The hop-growing area of Washington is an area of diverse agriculture including a small number of plum or prune, *Prunus domestica* L., orchards. In addition, landowners have planted ornamental and fruit *Prunus* spp. near residences, businesses, and in parks. Determining the sources of the spring and fall migrants not only adds to our knowledge of the aphid's life cycle but also may reveal alternatives to the traditional control methods that are used on hops during the growing season.

MATERIALS AND METHODS

Aphids in harvested hop yards. Hop yards selected for sampling in three years (1984, 1987, 1989) were in the Prosser - Grandview area of the Yakima Valley, WA. In 1984, plants in 11 harvested hop yards were sampled between 25 September and 19 October. Apterae were identified in all field studies described in this manuscript with the aid of a 10X hand lens and the descriptions in Blackman and Eastop (1984). Hop aphids were counted in the field on one leaf per plant from each of 200 randomly selected plants in eight hop yards and from 100 plants in three yards. One leaf was sampled from each of 100 randomly selected plants per yard: in 27 hop yards (one yard had 94 samples) from 25 September to 6 October, 1987; and in 33 hop yards (one yard had 89 samples) from 15 September to 9 October, 1989.

A small number of hop yards had varying numbers of unharvested, intact hop plants growing up the trellis poles. Six to 100 (mean = 43.7) randomly selected unharvested plants were sampled in each of 11 yards between 25 September and 7 October, 1987 and 11 to 58 (mean = 27.2) unharvested plants were sampled in each of nine yards from 15 to 29 September 1989. One leaf from about the 2 m height, which is a representative sample (Wright *et al.*1990), was sampled per plant. The varieties sampled in all years were Cascade, L1 (Cluster), and Galena.

The mean aphids per leaf on harvested plants was compared with the mean per leaf on unharvested pole plants using the non-parametric Wilcoxon Rank Sum test computed by the NPAR1WAY procedure of SAS (SAS Institute 1988).

Aphids on feral hop plants. Six sites with feral hop plants were located in the

Yakima Valley of south central WA (James *et al.* 2001). The plants grew on fences, or poles, usually near roads. In 1999, the plants were sampled on 7 to 8 September and 11 to 12 October and in 2000, on 14 to 22 August and 18 to 19 September. Thirty leaves were collected randomly per site and the number of aphids per leaf were counted under a stereomicroscope in the laboratory.

Survey of hop aphids on *Prunus* in the spring. The survey area was divided into two adjacent hop growing areas of WA: one in western Benton County near Prosser, and the other in eastern Yakima County near Sunnyside, Grandview, and Mabton. Each area was about 15,540 ha. Surveys were conducted in 1990 (18 to 26 June) and 1991 (25 June to 5 July). In 1990 we drove the roads in an unsystematic pattern and located *P. cerasifera* and fruit varieties of *P. domestica* by sight. Orchards were sampled by selecting 10 trees at random and sampling 10 shoots per tree. Hop aphids in spring are concentrated on the new foliage near the tips of the shoots (Wright *et al.* 1995). In addition to the hop aphid, we found the mealy plum aphid, *Hyalopterus pruni* (Geoffroy), and the leaf-curling plum aphid, *Brachycaudus helichrysi* (Kaltenbach). Ornamental and fruit trees at residences and commercial properties that were not orchards were sampled by examining 10 shoots per tree or shrub. Some small trees did not have 10 shoots, so fewer shoots were sampled on those trees. Aphid numbers were expressed as the number per shoot. Usually every tree at a site was sampled but if a property had more than three or four trees, a subsample of trees was selected. In 1991, the survey was done systematically. Most of the roads in the surveyed area are laid out in a grid of squares that are 1.6 km on a side. Road sections of 1.6 km each were selected at random on a map and 14 % of the roads in each area were surveyed as in 1990. For orchards, the number of trees per ha was calculated by multiplying the number of orchards in the surveyed area by 1,272, which was the average number of trees per plum and prune farm in Benton and Yakima counties (the counties of hop production) in 1992 (National Agricultural Statistics Service 1992) and dividing by the area surveyed. The number of trees not in orchards was determined by dividing the number of trees in the survey by the hectares in the area surveyed.

RESULTS

Aphids in harvested hop yards. We found hop aphids on the bases of harvested hop plants and on unharvested plants growing on trellis poles (Table 1). The unharvested plants had significantly more aphids per leaf than the harvested plants. Only two yards in the three years of sampling had no aphids in the samples.

Aphids on feral hop plants. In 1999, we found a mean of 0.7 aphids per leaf on 7 to 8 September (range = 0 to1.6) and 20.9 on 11 to 12 October (range = 0 to 93.6). In 2000, there was a mean of 0.7 per leaf (range = 0 to 1.7) on 14 to 22 August and 11.7 (range = 0 to 30.3) on 18 to 19 September.

Survey of aphids on *Prunus* in the spring. In 1990, 14 commercial prune orchards were sampled and hop aphids were found in four of them. The mean number of aphids per shoot in all orchards was 5.5 but most of the aphids were found in one orchard that averaged 81.0 aphids per shoot. Fruit-type *Prunus* were found at three residences with one tree each and aphids were found on two of the trees. The mean from all three trees was 0.9 aphids per shoot. Seventy-two purple-leafed ornamental plum trees were sampled at 42 sites and hop aphids were found on 50 trees at 32 sites. The number of trees sampled per site ranged from one to eight. The mean number of hop aphids on all ornamental trees was 44.0 per shoot.

In 1991, we found four commercial prune orchards and no hop aphids were found in any of them. A total of seven fruit-type plums were found at five residences

Table 1.
Mean number of hop aphids per leaf on harvested and unharvested hop plants remaining in hop yards in September and October. N, total number of leaves sampled (one leaf per plant). Z, test statistic for Wilcoxon Rank Sum test.

Year	Plant type	Mean aphids (range)	N	Z
1984	harvested	4.4 (0.2 – 13.2)	1,900	na
1987	harvested	1.7 (0 – 18.9)	2,694	8.2[1]
	unharvested	32.8 (0.2 – 316.5)	481	
1989	harvested	5.8 (0 – 56.4)	3,289	14.8[1]
	unharvested	127.1 (0.2 – 481.6)	245	

[1] $P<0.0001$.

but aphids were found on only two trees at one site with an average of 39.5 aphids per shoot. The mean for all fruit trees at residences was 11.3 aphids per shoot. We sampled 57 purple-leafed ornamental plum trees at 37 sites and hop aphids were found on 36 trees at 27 sites. The mean number of hop aphids on all trees was 105.1 per shoot. The estimated number of trees per ha was 1.16 for orchard trees, 0.017 for purple-leaf ornamental flowering trees and 0.0016 for fruit trees at residences.

DISCUSSION

Hop aphids were common in harvested hop yards, indicating that harvested hop yards were a major source of the aphids for the fall flight to *Prunus*. Hop plants growing up the trellis poles had more leaves than the bottoms of harvested plants and were infested with more aphids per leaf (Table 1); however, unharvested plants were uncommon compared to the number of harvested plants, so they probably contribute a small proportion of the hop aphids produced over the whole area.

Feral hop plants were infested with hop aphids, occasionally with high numbers. Hop is not native to the Pacific Northwest (Hitchcock and Cronquist 1973) and only female plants that produce seedless hop cones are grown commercially in WA. These factors may restrict the number of feral hops growing in south central WA. Wild hops may be an important source of fall migrants in England (Campbell and Tregidga 2005). Our observations indicate that feral hops in south central Washington are scarce compared to the number of commercial hop plants but a more intensive survey would be needed to determine the population size of feral hops.

Our survey of *Prunus* spp. indicates that purple-leafed ornamental flowering plums were a major source of spring migrant hop aphids. Only one commercial prune orchard was heavily infested with hop aphids but, because of the large number of trees in this orchard, it could be a significant source of aphids. Orchard trees are usually sprayed with insecticides to control aphids and this is probably the main reason aphid numbers were generally low in orchards. Since this survey was done, the plum and prune industry has declined from 565 ha in Benton and Yakima counties in 1992 to 311 ha in 2002 (National Agricultural Statistics Service 1992; 2002). The ornamental varieties were much less abundant than orchard trees but they were infested with higher densities and they were well dispersed throughout the survey area.

Knowing the sources of the spring and fall migrating aphids and the timing of the flights suggests some alternative aphid controls. As gynoparae start flying before harvest is completed and males start flying near the end of harvest in mid to late Sep-

tember (Wright *et al.* 1995), controlling aphids in harvested hop yards would reduce the number of gynoparae but should be more effective in reducing the number of males. The desired result would be a reduction in the number of mated females and eggs on *Prunus* spp. Potential control of aphids in harvested hop yards could involve insecticide applications, destroying the foliage with cultivation, or defoliation with herbicides. Because unharvested plants contribute nothing to the harvest, permanently removing them or cutting them off at the base during harvest would be a good field sanitation practice. A potential secondary problem may be the disruption of insect and mite natural enemies in hop yards (Strong and Croft 1993; James *et al.* 2001).

Successful control of hop aphids on harvested hops would depend on hop growers over a large area cooperating in a fall control program. Controls would have to be applied as soon after harvest as possible and would need to be extremely effective. Workers in Idaho developed an area-wide program to reduce potato leaf roll virus by reducing the number of green peach aphids, *Myzus persicae* (Sulzer), in the spring before the aphids flew to potatoes (Bishop 1967). They sprayed insecticides on introduced flower and vegetable transplants and home gardens, and removed the aphid's overwintering hosts, peach and apricot trees. This program was successful in reducing aphids and potato leaf roll virus when spraying was thorough and well timed. The small size and isolation of the potato-growing areas were important factors in the program's success.

The hop-growing region of Washington is isolated from other hop-growing areas, so perhaps a similar area-wide program could be effective against the hop aphid. Controlling aphids in prune and plum orchards would be essential. For ornamental trees, one potential method would be the removal of *Prunus* spp. host trees, especially *P. cerasifera*. Dixon and Kindlmann (1990) present theoretical evidence that aphid abundance is directly related to host plant abundance and the number of hop aphids caught in suction traps in England and Washington is related to the abundance of host plants in the area (Taylor *et al.* 1979, Wright *et al.* 1995). This suggests that the hop aphid populations may be susceptible to manipulations of host plant abundance. Hymenopterous parasitoids commonly attack hop aphids on *Prunus* spp. in the spring (Wright and James 2001). Perhaps parasitoids and predators could be managed to reduce the number of spring migrants flying to hops. Spraying ornamental *Prunus* spp. may be effective but could have negative impacts on natural enemies. Because the hop aphid can migrate over long distances (Taylor *et al.*1979), any area-wide program would need to cover a large area to be effective. To be successful, any alternative control would have to provide significantly superior control, be safer to people or the environment, or cost less than traditional methods.

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