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Influence of companion planting on damson hop aphid *Phorodon humuli*, two spotted spider mite *Tetranychus urticae*, and their antagonists in low trellis hops

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ABSTRACT

The effects on population development of damson-hop aphid *Phorodon humuli* and two-spotted spider mite *Tetranychus urticae* from planting drive rows with grass (2002-3 only), *Brassica juncea*, *Phacelia tanacetifolia* (2004-6 only), a meadow-mix of grass and flowering plants were compared with a bare soil control on aphid-susceptible low trellis hop (*Humulus lupulus* L.) cultivars First Gold (FGO) and Herald (HER) in 2002-4 and on partially aphid-resistant cultivar Boadicea (BOA) in 2004-6. Aphid and mite natural enemies were monitored from beat and foliage samples. Irrespective of ground cover treatment, generalist predators prevented damaging aphid populations from developing on BOA each year, and a combination of aphid–specific and generalists on FGO/HER in two of the three years experiments. Fewest migrant aphids settled, and lower aphid populations ensued, on FGO/HER with meadow-mix than other treatments, but the difference was insufficient to prevent peak populations of *ca* 1000 per leaf in 2004. Numbers of aphidiid parasitoids reflected aphid population densities on leaves with the highest numbers on FGO/HER in 2004, and none on BOA in any year. Seven species of primary parasitoids were recorded, dominated by *Aphidius matricariae* and *A. picipes* (95%), and eight species of hyperparasitoids which became increasingly prevalent as the season progressed. Spider mite population densities remained below ten actives per leaf in all but one year. They were regulated by a combination of phytoseiid mites (six species dominated by *Typhlodromus pyri*) and insect predators. Hops with meadow-mix had the highest population densities of spider mites, but also the highest numbers of phytoseiids. Although companion plants depressed average cone weight by *ca* 18% compared with the bare soil control, that loss may be preventable by using additional fertilizers, in which case permanent meadow-mix would provide a suitable companion plant treatment for biological control of both *P. humuli* and *T. urticae* on aphid-resistant low trellis cultivars such as BOA, but used alone is unreliable on aphid-susceptible cultivars.

1. Introduction

The damson-hop aphid, *Phorodon humuli* (Schrank) and two-spotted spider mite, *Tetranychus urticae* Koch are the key pests on hops (*Humulus lupulus* L.) in the northern hemisphere (Neve, 1991). They debilitate the plants and reduce yields (Barber et al., 2003; Lilley and Campbell, 1999). Contamination of hop cones reduces their economic value (Neve, 1991; Weihrauch et al., 2012). However, Weihrauch (2005) found that hop plants can tolerate densities of > 1000 active stages of *T. urticae* leaf^{-1} without adversely depressing the yield and brewing quality of cones. Nevertheless, because of the conceived risks posed, pesticides have been used for over a century against *P. humuli* (Parker, 1934), and against *T. urticae* since the 1950s (Cranham, 1974).

Both pests have developed pesticide resistant strains that became dominant under continued selection pressure from frequent pesticide use on such a high value crop (Cranham, 1974; Campbell and Hrdý, 1988; Weichel and Nauen, 2003; Vostřel, 2007). Naturally occurring enemies and introduced predators exploited in an integrated pest management strategy can halt the cycle of pesticide over-use that induces pesticide-resistant strains (Barber et al., 2003; Lilley and Campbell, 1999; Campbell and Lilley, 1999; Jones et al., 2003) and preserve quality (Campbell, 2001; Barber et al., 2003), but are unreliable against *P. humuli* on aphid-susceptible cultivars (Campbell, 1978, 2001; Trouvé et al., 1997; Barber et al., 2003) and against *T. urticae* also (Campbell and Lilley, 1999; Jones et al., 2003; Vostřel, 2013; Jereb and Weihrauch, 2017).

In hop monocultures there is always delay between the first *P. humuli* migrants arriving from primary hosts and their natural enemies

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owing to a lack of alternative prey (Campbell, 1978). Interspersing low trellis hops with companion plants may counteract that problem by combining conservation biological control (CBC) with habitat manipulation (Gurr et al., 2000). The CBC component aims to attract natural enemies into the crop before and after *P. humuli* arrives (Goller et al., 1997; Solomon et al., 1999; Grasswitz and James, 2009; Calderwood et al., 2017) and, by siting companion plants within the crop, maximise the opportunity for spill-over of natural enemies on to the hops (Begg et al., 2017), and conserve them thereafter (Landis et al., 2000). The habitat manipulation component aims to reduce colonisation by *P. humuli* migrants by breaking the visual contrast between plant and soil (Finch and Collier, 2000) and by releasing volatiles that deter landing by *P. humuli* migrants (Campbell and Ridout, 2001). Unlike tall hop cultivars, low trellis hops are harvested *in situ* leaving bines and most leaves in place, thereby providing a more stable habitat for *T. urticae* and its natural enemies to overwinter within the crop.

Up until World War II, hops in England were sometimes interplanted with grass swards to maintain soil structure (Thompson et al., 1955), a practise still followed by at least one commercial grower (Campbell, unpublished). In CBC experiments on hops, Majer (1996) compared grass undersows with bare soil in Slovenia and reported lowered populations of *P. humuli* and elevated populations of *T. urticae* in the undersown plots. Růžička et al. (1986) in Czechia and Goller et al. (1997) in Germany undersowed hops with broad leaved plants with the aim of improving biological control of *P. humuli*. Růžička et al. (1986) reported some success against *P. humuli*, whereas Goller et al. (1997) found that aphid populations were lower in the bare soil plots. In the USA, Grasswitz and James (2009) and Calderwood et al. (2017) sowed flowering plants in hop alleys with the aim of boosting predation of *P. humuli* and *T. urticae* and reported inconsistent effects on *P. humuli*, but lower *T. urticae* densities in plots undersown with a range of broad-leaved herbs. However, control plots in Calderwood et al. (2017) were not bare soil, but a combination of sown red clover and weeds, which they report is a common ground cover treatment for organic hops in Vermont. Similarly in Switzerland, hop plots with broad-leaved weeds had significantly fewer *T. urticae* on the hop plants at harvest-time than did weed-free plots (Schweizer, 1995). Undersown grasses were found to provide hibernation sites for predatory mites in biocontrol experiments against *T. urticae* on hops in Germany (Jereb and Weihrauch, 2017).

The present study assesses the impact of companion planting on aphid-susceptible cultivars First Gold (FGO) and Herald (HER), and on the aphid-resistant, hence more sparsely aphid infested cultivar Boadicea (BOA) (progeny 23/90/08 in Barber et al., 2003) in south-eastern England. The aim was to assess the impact of companion planting on the full range of pest and beneficial arthropods found on low trellis hops grown in the absence of insecticides and acaricides, rather than simply on the two key pests, thereby adopting a landscape approach (Landis et al., 2000; Tscharntke et al., 2007). Owing to the volume of data generated, the impacts on secondary pests and epigaeic beetles will be reported elsewhere (Campbell, unpublished).

2. Material and methods

Arthropods were monitored for a total of six crop cycles in two low trellis hop plantations at NIAB EMR. The plantations comprised parallel rows ca 2.5 m apart of dense hop hedges on 2.5 m high polypropylene net (14 cm square mesh). The young climbing stems (bines) were hand thinned in April/May to *ca* 1 bine on each vertical filament. Surplus bines and foliage below *ca* 0.3 m were defoliated chemically in May–July with repeated sprays of sodium monochloracetate at 10 kg in 1000 l water ha^{-1} to reduce the vertical spread of hop mildews (Neve, 1991). Fertilisers were applied in January [Kieserite (25% MgO + 50% SO_3) at 200 kg ha^{-1} and Sulphate of Potash (K_2SO_4) at 300 kg ha-1], April [Nitram (NH_4NO_3)] at 200 kg ha-1 and May (Nitram at 400 kg ha^{-1}) following normal farm practice.

Table 1
Composition of meadow-mix (treatment 3) sown annually at NIAB EMR in 2002–2006.

Common name	Binomial	%
Meadow Fescue	*Festuca pratensis*	44.0
Promesse Timothy	*Phleum pratense*	14.5
Yarrow	*Achillea millefolia* L.	1.3
Corn Chamomile	*Anthemis arvensis* L.	2.6
Cornflower	*Centaurea cyanus* L.	6.5
Common Knapweed	*C. nigra* L.	1.7
Corn Marigold	*Chrysanthemum segetum* L.	6.5
Wild Carrot	*Daucus carota* L.	1.3
Lady's Bedstraw	*Galium verum* L.	1.3
Oxeye Daisy	*Leucanthemum vulgare* L.	2.6
Musk Mallow	*Malva moschata* L.	4.3
Hoary Plantain	*Plantago media* L.	1.3
Salad Burnet	*Poterium sanguisorba* L.	1.7
Meadow Buttercup	*Ranunculus acris* L.	5.2
Red Campion	*Silene dioica* (L.)	5.2

2.1. Study sites

Site 1, comprised 0.4 ha of FGO and a contiguous 0.4 ha of HER at NIAB EMR planted in February 1996. A plot consisted of 5 × 32.5 m rows of hops. A randomised complete block design (RCBD) was used with four treatments replicated three times on each of the two hop cultivars. The treatments, applied as a one metre wide strip centrally in the drive alleys between the hop rows, were: 1) Grasses, a 3:1 mixture of Meadow Fescue (*Festuca pratensis* Huds.) and Timothy (*Phleum pratense* L.), sown at 25 kg ha^{-1}; 2) Brown Mustard (*Brassica juncea* (L.)) sown at 7.5 kg ha^{-1}; 3) meadow-mix (Table 1) sown at 43 kg ha^{-1}, and 4) bare soil. In year 3 (2004), the grasses treatment 1) was replaced with *Phacelia tanacetifolia* Bentham sown at 10 kg ha^{-1}. Weeds were controlled in bare soil plots using simazine, isoxaben, paraquat, clopyralid and/or glyphosate herbicides applied as necessary. Grass and meadow-mix treatments were mown in July each year to reduce competition with the hops for water. All of the drive alleys between rows of hops were rotovated in winter and vegetated treatments were resown annually in April each year.

Site 2, also at NIAB EMR, comprised 0.8 ha of BOA planted in February 2003. The plot layout, seeding rate of the inter-row spaces and crop management was the same as above with the 4 treatments; 1) *Pha. tanacetifolia*, 2) Brown mustard, 3) meadow-mix, and 4) bare soil. The 4 treatments were replicated six-fold in a RCBD.

2.2. Leaf and hop cone samples

Population densities of leaf-inhabiting arthropods were assessed from samples of foliage taken from the central row in each plot. Samples of 10 fully-expanded main-bine leaves from each plot were examined weekly from May–September at NIAB EMR site 1 in 2002-3, and fortnightly in 2004 and at site 2 in 2004–2006. The numbers of pest arthropods and their natural enemies were counted. All parasitoid mummies on sample leaves were collected individually in gelatine capsules and returned to the laboratory where adults that emerged were identified. Samples of 50 cones per plot were taken annually from plants in the field at harvest time. The fresh cones were dissected under a stereo-microscope and the numbers of arthropods present were recorded. In 2004-6 the cone samples were weighed prior to dissection.

2.3. Beat samples

Mobile arthropods were assessed by jarring them from foliage on to a 90 × 120 cm beating tray. Six beat samples from along the centre row were taken at weekly intervals from each plot in 2002 (Total beats = 1728) and fortnightly in 2003 (Total beats = 864). Owing to a