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Citation	Woods, J. L., & Gent, D. H. (2014). Suppression of Hop Looper (Lepidoptera: Noctuidae) by the Fungicide Pyraclostrobin. Journal of Economic Entomology, 107 (2), 875-879. doi:10.1603/EC13546
DOI	10.1603/EC13546
Publisher	Entomological Society of America
Version	Version of Record
Terms of Use	http://cdss.library.oregonstate.edu/sa-termsofuse

SHORT COMMUNICATION

Suppression of Hop Looper (Lepidoptera: Noctuidae) by the Fungicide Pyraclostrobin

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J. Econ. Entomol. 107(2): 875–879 (2014); DOI: http://dx.doi.org/10.1603/EC13546

ABSTRACT The hop looper, *Hypena humuli* Harris, is a reemergent pest of hop that often requires treatment to mitigate crop damage. In 4 yr of field trials, plots treated with fungicides were observed to sustain less hop looper defoliation compared with nontreated plots. Further investigation revealed that abundance of hop looper and associated defoliation were reduced when the fungicide pyraclostrobin was applied in late July to early August. Two other fungicides possessing active ingredients in the same chemical family (quinone outside inhibitor) did not reduce abundance of hop looper or its defoliation. Pyraclostrobin is efficacious against powdery mildew diseases, and the application timing evaluated in these studies corresponds with a period of juvenile susceptibility of hop cones to the disease. Use of fungicides containing pyraclostrobin at this time may have the ancillary benefit of reducing hop looper damage, potentially obviating the need for broad-spectrum insecticides later in the season. Follow-up studies are warranted to determine whether pyraclostrobin may inhibit other lepidopteran species.

KEY WORDS integrated pest management, *Humulus lupulus*, nontarget impact

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The hop looper, *Hypena humuli* Harris (Lepidoptera: Noctuidae) is considered a reemerging pest of hop (*Humulus lupulus* L.; Grasswitz and James 2008). Documented to be a pest species on hop in the eastern United States in the late 19th and early 20th centuries, hop looper likely diminished in pest status during the mid- and late 20th century owing to the application of broad-spectrum organophosphate pesticides for control of hop aphid (*Phorodon humuli* Schrank) and twospotted spider mite (*Tetranychus urticae* Koch; Howard 1897; Holland 1905; Hawley 1918; Grasswitz and James 2008, 2011). With use of more selective pesticides, hop looper has reemerged as a pest that routinely requires applications of insecticides to mitigate crop damage (Grasswitz 2009, Grasswitz and James 2011).

Recent work by Grasswitz and James (2008, 2011) greatly expanded our knowledge of the biology, phenology, and potential for biological control of the hop looper. This pest usually feeds on hop, although larvae have also been found on stinging nettle (*Urtica* spp.; Grimble et al. 1992; Grasswitz and James 2008, 2011). Overwintering behavior is largely unknown, except that adults have been found overwintering in caves (Kikukawa 1982, Godwin 1987, Grasswitz and James 2008). Adults migrate into hop yards in early spring, and three generations occur in central Washington State (Grasswitz and James 2008).

In addition to several arthropod pests, powdery mildew (caused by *Podosphaera macularis* (Wallroth) U. Braun & S. Takamatsu) is a major disease affecting hop in the Northern Hemisphere (Royle 1978; Mahaffee et al. 2003, 2009; Gent et al. 2008). Management required to minimize crop damage from powdery mildew involves the application of multiple fungicide chemistries, each with varying levels of effects on nontarget organisms (James and Coyle 2001; Mahaffee et al. 2003; Gent et al. 2008, 2009; Woods et al. 2012). In previous experiments with powdery mildew, we noticed that defoliation from hop looper was reduced in plots treated with certain fungicides. While this was an unforeseen consequence of fungicide use, the effect on hop looper warranted further investigation. This article documents the suppression of hop looper populations and its associated defoliation by pyraclostrobin, a fungicide commonly used against powdery mildews and other plant diseases.

Materials and Methods

Experimental Plots and Data Collection. Data were collected from experimental plots near Corvallis, OR, during 2010–2013. The hop yard was planted in 2005 to cultivar 'Willamette' with plants arranged on a 2.1-m grid pattern and under a 5-m trellis. The total area of the yard was ≈0.75 ha and was surrounded by mowed grass to the south and east and cereal and

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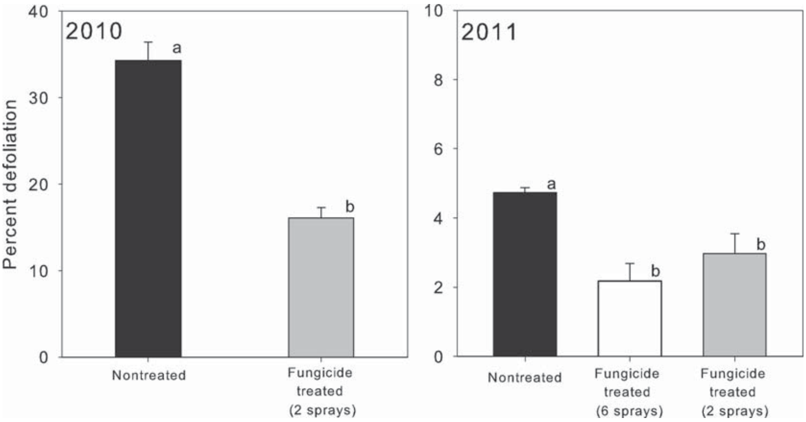

Fig. 1. Percent defoliation of hop leaves (mean ± SE) in relation to fungicide treatment in 2010 and 2011. Means within an experiment that do not share a letter are significantly different ($P < 0.05$) according to a mixed model analysis.

vegetable crops to the north and west. Experimental plots were established in a randomized complete block design with four or five replications of two to six treatments. In all years, individual plots consisted of eight plants separated by at least one row of nontreated plants. Irrigation was supplied by a surface drip system, and herbicides and fertilizers were applied according to standard production practices in western Oregon (Gingrich et al. 2000).

Pymetrozine (0.034 kg a.i./ha, Fulfill, Syngenta Crop Protection, Greensboro, NC), a selective aphicide, was applied in 2011 and 2012 to reduce confounding effects from hop aphid. These applications were made when populations exceeded 90 hop aphids per leaf, as described in Woods et al. (2013). Hop aphids never exceeded 40 aphids per leaf in 2010 or 2013, and an aphicide was not applied in those years. Spider mites did not exceed 34 mites per leaf (Woods et al. 2013), and no other miticides or insecticides were applied to the plots or adjacent plants.

Fungicide treatments varied depending on the objectives of each experiment. In 2010, treatments consisted of—1) a nontreated control and 2) an application of quinoxyfen (0.022 liters a.i./ha, Quintec, Dow AgroSciences, Indianapolis, IN) and pyraclostrobin + boscalid (0.27 kg a.i./ha pyraclostrobin + 0.52 kg a.i./ha boscalid, Pristine, BASF Corp., Research Triangle Park, NC) on 23 July and 5 August, respectively. In 2011, treatments evaluated consisted of—1) a nontreated control; 2) a biweekly rotation of trifloxystrobin (0.15 kg a.i./ha, Flint 50WG, Bayer CropScience, Research Triangle Park, NC), quinoxyfen (0.022 liters a.i./ha), and spiroxamine (0.4 kg a.i./ha, Accrue, Bayer CropScience) beginning 27 May and ending 22 July, followed by an application of pyraclostrobin + boscalid as applied in 2010 (six total applications); and 3) an application of quinoxyfen and pyraclostrobin + boscalid on 22 July and 4 August, respectively, at the rates used in 2010. Based on the results of the 2010 and 2011 experiments and other observations, in 2012 four treatments were used to isolate the components of Pristine fungicide (pyraclostrobin + boscalid) that were suppressive to hop looper—1) a nontreated control; 2) pyraclostrobin + boscalid (0.13 kg a.i./ha pyraclostrobin + 0.26 kg a.i./ha boscalid); 3) boscalid (0.26 kg a.i./ha, Endura, BASF Corp.); and 4) pyraclostrobin (0.13 kg a.i./ha, Cabrio EG, BASF Corp.). Applications were made on 25 July and 8 August. In 2013, an experiment was conducted to determine whether other fungicides in the same chemical family as pyraclostrobin (quinone outside inhibitor; group 11) also suppressed hop looper. Six treatments were evaluated: 1) a nontreated control; 2) pyraclostrobin + boscalid; 3) boscalid; 4) pyraclostrobin (as in the 2012 study); 5) trifloxystrobin (0.15 kg a.i./ha); and 6) famoxadone + cymoxanil (0.296 kg a.i./ha, Tanos, DuPont, Wilmington, DE). Treatments were applied on 25 July and 8 August.

Applications were made with an Eagle BP40 backpack sprayer (Eagle-1 Manufacturing, Monroe, WA) in an application volume of 1,870 liters/ha in 2010, 2012, and 2013. In 2011, as applications were applied from May to August, application volume increased with plant development during the season, ranging between 654 liters/ha to 1,122 liters/ha.

Arthropod Sampling. Abundance of looper larvae was determined in 2012 and 2013 by taking biweekly canopy shake samples from each plot as described in Woods et al. (2013) beginning in mid-July (2012) or mid-June (2013) and continuing until late August. Shake samples were taken from the four plants in the middle of each plot.

Defoliation Ratings. In 2010 and 2011, an assessment of defoliation by hop looper feeding was conducted at the end of the season on 8 September and 2 September, respectively. In 2012 and 2013, defoliation ratings began with a pretreatment assessment in mid-June and continued biweekly until mid to late August. In all years, percent defoliation was visually assessed on each of five randomly selected leaves per plant from each of the eight plants per plot.

Data Analysis. Percent leaf defoliation data from 2010 and 2011 were log-transformed before analysis in a linear mixed model in SAS version 9.2 (SAS Institute, Cary, NC). In 2012 and 2013, percent leaf defoliation

Table 1. Area under the defoliation curve and arthropod days (mean ± SEM) in relation to fungicide treatment in 2012 and 2013

Year	Fungicide treatment	Leaf defoliation[a]	*H. humuli*
2012	Nontreated	1.3 ± 0.2a	310.3 ± 89.3ab
	Pyraclostrobin + boscalid	0.7 ± 0.1b	193.5 ± 44.0bc
	Boscalid	1.7 ± 0.3a	399.0 ± 66.3a
	Pyraclostrobin	0.6 ± 0.1b	146.3 ± 48.8c
2013	Nontreated	8.4 ± 1.3ab	152.7 ± 31.6a
	Pyraclostrobin + boscalid	5.2 ± 0.5d	63.9 ± 22.1b
	Boscalid	7.1 ± 1.0bc	113.8 ± 18.7a
	Pyraclostrobin	6.5 ± 1.7cd	80.5 ± 22.8b
	Trifloxystrobin	9.7 ± 1.8a	125.6 ± 28.7a
	Famoxadone + cymoxanil	8.5 ± 1.0ab	131.7 ± 17.2a

[a] Means within a column that do not share a letter are significantly different ($P < 0.05$) according to mixed model analysis.

data were plotted over time and the area under these curves were calculated for each plot to develop a single composite value for defoliation severity. Looper days were calculated similarly. The area values were log-transformed and analyzed in a linear mixed model, with block considered a random effect in analyses. Denominator degrees of freedom were calculated using the Kenward–Rodger method (Littell et al. 2006).

Results

In all years, leaf defoliation was suppressed when plants were treated with pyraclostrobin. In 2010, the fungicide-treated plots averaged 18% less defoliation than the nontreated plots (F = 127; df = 1, 3; P = 0.0015; Fig. 1). In 2011, there was less defoliation irrespective of whether there were two or six fungicide applications, provided pyraclostrobin was applied in early August (F = 6.36; df = 2, 8; P = 0.0222; Fig. 1). In 2012, the area under the defoliation curve was reduced 49–54% in plots treated with pyraclostrobin or a mixture of pyraclostrobin + boscalid relative to the nontreated plots (F = 11.10; df = 3, 9; P = 0.0022; Table 1 and Fig. 2). In 2013, defoliation was affected by fungicide treatment (F = 5.5; df = 5, 15; P = 0.0045; Table 1 and Fig. 2). Plots treated with pyraclostrobin

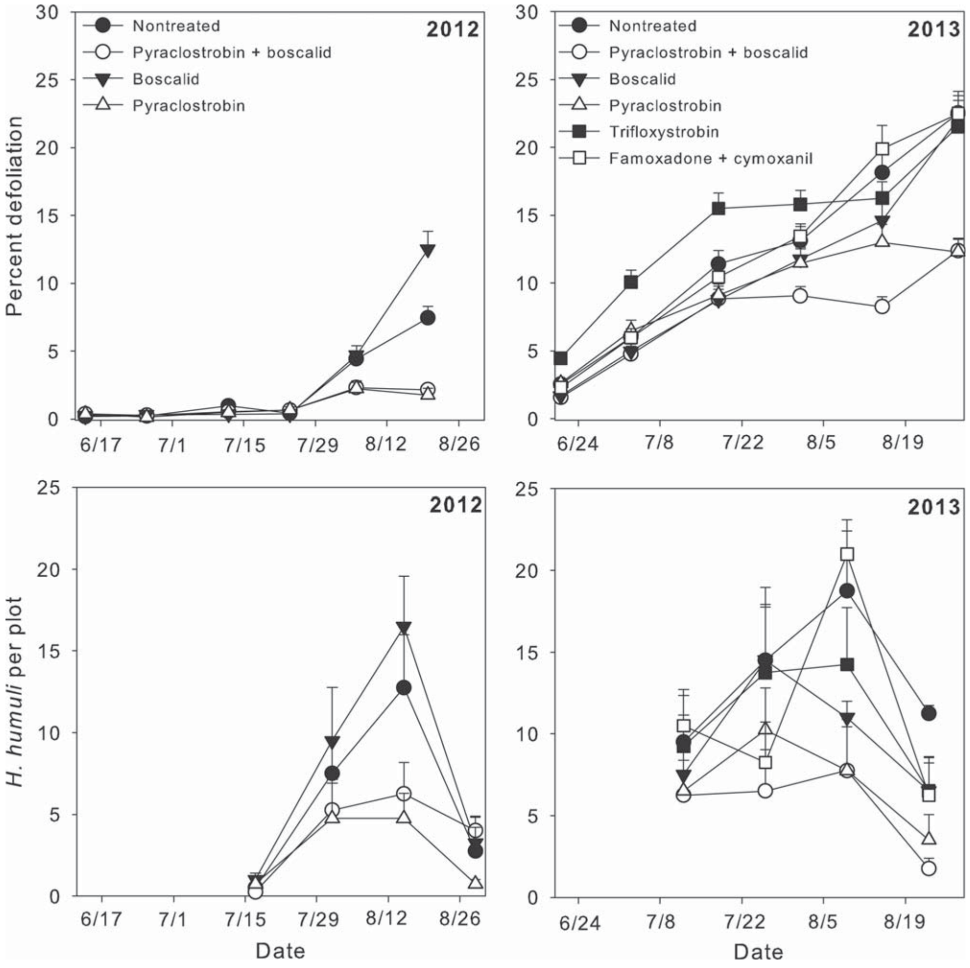

Fig. 2. Percent defoliation of hop leaves (mean ± SE) and abundance of *H. humuli* (mean ± SEM) in relation to fungicide treatment during 2012 and 2013.

or pyraclostrobin + boscalid had significantly less defoliation as compared with the mean looper days of other plots, as indicated by a pairwise contrast ($F = 21.64$; df = 1, 15; $P = 0.0003$).

In 2012, hop looper days varied among fungicide treatments ($F = 6.48$; df = 3, 9; $P = 0.0126$; Table 1 and Fig. 2). Plots treated with pyraclostrobin or pyraclostrobin + boscalid had significantly less mean looper days than other plots (pairwise contrast: $F = 16.28$; df = 1, 9; $P = 0.0030$). In 2013, looper days were reduced 47–58% in plots treated with pyraclostrobin and pyraclostrobin + boscalid relative to nontreated plots ($F = 7.04$; df = 5, 15; $P = 0.0014$; Table 1 and Fig. 2).

Discussion

The use of products containing pyraclostrobin during late July and early August may reduce hop looper larval abundance and feeding damage. In addition to fitting the seasonal phenology of *H. humuli* (Grasswitz and James 2008), the application timings evaluated in this study correspond to a highly important period for protection of hop cones from powdery mildew (Gent et al. 2013). Pyraclostrobin is efficacious against powdery mildew (Nelson and Grove 2007) and often is used for late season management of the disease (Gent et al. 2013). Pristine (pyraclostrobin + boscalid) also possesses some activity against downy mildew (Nelson and Grove 2007). Therefore, the application timing evaluated in this study appears to be a good fit for disease management considerations and also provides the ancillary benefit of suppressing hop looper.

Although there is clear evidence that pyraclostrobin reduces both defoliation by hop loopers and looper abundance, it is unclear whether this is owing to direct mortality of larvae or sublethal effects on either larvae or adults (e.g., repulsion of adult females from treated plants). Bioassays and commercial-scale field trials are needed to determine the underlying mechanism(s).

Using pyraclostrobin as a component of an integrated pest management system for both powdery mildew and hop looper may be a novel approach to avoid the use of broad-spectrum insecticides that can disrupt biological control of hop looper and other pests (Woods et al. 2013). Complete reliance on biological control of hop looper has not been a viable management approach, even though numerous natural enemies of hop looper have been identified (Grasswitz 2009, Grasswitz and James 2011). Commercial management of hop looper often includes the use of pyrethroid insecticides (Grasswitz and James 2008, Grasswitz 2009). Pyrethroid insecticides are nonselective with respect to beneficial arthropods, and resistance to pyrethroids is common in spider mites owing to cross-resistance with abamectin (Van Leeuwen et al. 2010). Grasswitz and James (2008) found that a commercial formulation of the highly selective biopesticide *B. thuringiensis* subsp. *aizawai* provided acceptable control even of late-stage larvae. Use of pyraclostrobin in disease management programs may be complimentary to the use of *B. thuringiensis* and reduce the need for nonselective insecticides for hop looper. Although not reported here, we found no evidence that pyraclostrobin affected natural enemies.

It is unclear how generalizable the findings of this study are to other Lepidoptera. Future studies are planned to determine whether pyraclostrobin can suppress other lepidopteran pests.

Acknowledgments

The authors gratefully acknowledge technical support from Nanci Adair, Kariza King, Suzy Kropf, Kazandra Lewis, Genevieve Martinusen, and Megan Twomey. We also thank Tessa Grasswitz and David James for their review of an earlier draft of the manuscript. Support for these studies was provided by U. S. Department of Agriculture–Agricultural Research Service–Current Research Information System (USDA–ARS–CRIS) Project 5358-21000-046-00D.

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Received 12 December 2013; accepted 1 February 2014.