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Short Communication

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Influence of Nitrogen Fertilizer Rate on Hop Looper

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Abstract

Hop looper, *Hypena humuli* Harris, can cause substantial defoliation and crop damage by feeding on hop leaves and cones. A 4-yr field study conducted in western Oregon evaluated the abundance of hop looper larvae and associated defoliation of leaves on plants fertilized with nitrogen rates ranging from 44.8 to 269 kg/ha. There was annual variation in abundance of hop looper and defoliation, with a tendency for increasing nitrogen rate to increase both abundance of hop looper and defoliation. A mixed model analysis with data combined from 2014 to 2017 found that abundance of hop looper was linearly related to nitrogen fertilizer rate, with a 2.5 increase in hop looper-days per kilogram of nitrogen fertilizer applied. Similarly, based on data from 2015 to 2017, defoliation associated with hop looper increased 0.031 percent with each kilogram of nitrogen fertilizer applied. Therefore, avoiding unduly high rates of nitrogen fertilizer may reduce the abundance and defoliation caused by hop looper. Further studies are needed to understand the mechanisms associated with nitrogen stimulation of hop looper.

Key words: fertilizer, *Humulus lupulus*, *Hypena humuli*, integrated pest management

The hop looper, *Hypena humuli* Harris (Lepidoptera: Noctuidae) is widely distributed across North America, feeding primarily on hop, *Humulus lupulus* L. and nettle (*Urtica* spp.) (Grimble et al. 1992, Grasswitz and James 2008). Hop looper was reported as a pest on hop in eastern North America in the late 1800s, although the importance of the pest diminished during the next century, perhaps owing to ancillary control provided by organophosphate pesticides applied for control of other pests (Howard 1897; Holland 1905; Hawley 1918; Grasswitz and James 2008, 2011). With the transition to more selective insecticides and miticides (James and Coyle 2001, Woods et al. 2014), hop looper has reemerged as a pest on hop (Grasswitz and James 2008, 2011; Grasswitz 2009).

The biology of hop looper has been best studied in central Washington State. In this region, adult moths migrate into yards in early spring and three generations occur during a season, with the last generation typically being the most damaging (Grasswitz and James 2008). The overwintering habitat is uncertain, but could include caves and other protected areas (Kikukawa 1982, Godwin 1987, Grasswitz and James 2008). Hop looper is typically managed with careful timing of insecticides with low toxicity to natural enemies (Grasswitz 2009). Identification of other, nonchemical methods of managing hop looper would be beneficial.

When searching for a suitable host, plant quality can influence arthropod abundance and population growth rate (Rodriguez and Rodriguez 1987). Of the nutrients commonly manipulated in agricultural settings, nitrogen is often reported to influence arthropod fecundity and growth rate (Shanks and Doss 1989). Numerous studies show that the mineral and amino acid content of the host leaf can influence arthropod feeding, ovipositioning, and growth rate (Friend 1958, Vandersant 1958, Ishii 1971, Mattson 1980, Al-Zubaidi and Capinera 1984, Phelan et al. 1996, Chen et al. 2008, Showler and Moran 2014, Showler 2015). Lepidopteran species utilize sensory cues in determining host quality, and leaf color has been shown to be a primary sensory factor associated with host selection (Ramaswamy 1988, Renwick and Radke 1988, Showler and Castro 2010). This short communication presents data from experiments designed to quantify the impact of nitrogen fertility on various aspects of yield, cone quality, and pest levels on hop, and demonstrates that abundance and damage from hop looper are correlated with the level of nitrogen fertilization.

Materials and Methods

Experimental Plots and Data Collection

Data were collected from experimental plots near Corvallis, OR from 2014 to 2017. The hop yard was planted in 2005 to cultivar

'Willamette' with plants arranged on a 2.1-m grid pattern and under a 5.5-m trellis. The total area of the yard was approximately 0.75 ha and was surrounded by mowed grass, cereals, and vegetable crops. Plots were established in a randomized complete block design with four replicates of each of four nitrogen rates. In all years, an individual plot consisted of 24 plants separated by at least one row of plants that did not receive supplemental nitrogen as described below. Irrigation was supplied by a surface drip system, and herbicides were applied according to standard production practices in Oregon (Woods et al. 2014).

The four nitrogen fertilizer treatments were 44.8, 89.6, 179.2, and 269.0 kg/ha. These rates were selected to encompass the range of nitrogen fertilizer that is typically used or recommended for hop (Neve 1991), as well as rates below typical commercial rates to detect potential dose-dependent relationship between nitrogen level and pest levels. In all years, an application of 16-16-16 fertilizer was broadcast-applied to the entire field during mid-April, delivering a total of 44.8 kg/ha of nitrogen, 19.7 kg/ha of P, and 37.2 kg/ha of K. The remaining amounts of nitrogen, 0, 44.8, 134.6, or 224.2 kg/ha, were banded over each hill in two equal applications as either 40-0-0 (2014 experiment) or 46-0-0 (2015–2017 experiments) in mid-May and mid-June. Each plant was irrigated using a garden hose immediately afterward to incorporate the fertilizer into the soil and minimize ammonia volatilization.

The selective aphicide pymetrozine (210 g a.i./ha as Fulfill 50WG, Sygenta Crop Protection, Greensboro, NC) was applied in 2014, 2016, and 2017 to reduce the possibility of confounding effects from *Phorodon humuli* (Schrank) (Hemiptera: Aphididae). These applications were made when populations exceeded approximately 100 hop aphids per leaf, and were not necessary in 2015. In 2017, an application of 22.4 g a.i./ha bifenthrin, (Brigade 2EC, FMC Corporation, Philadelphia, PA) was made to the entire field on 15 May for the purpose of another study. Although bifenthrin is toxic to hop looper, the application made in 2017 was when plants were relatively small (less than 1 m tall) and well before the second and third generations that tend to be most damaging to hop were present in the field (Grasswitz and James 2008). No other miticides or insecticides were applied to the plots or directly adjacent plants.

Arthropod Sampling

Shake samples for hop looper larvae were collected every other week from each plot. In brief, shake samples were collected from the six plants in the middle of each plot by placing a 1-m^2 white cloth under a hop bine and vigorously shaking the bine for 3 s. Dislodged arthropods were identified and counted on the cloth or collected into vials of 70% ethanol for later confirmation or identification in a laboratory (Woods et al. 2014). Sampling began in late June and continued until late August.

Defoliation Ratings

From 2015 to 2017, an assessment of defoliation by hop looper feeding was conducted in late August, the period when defoliation from hop looper is typically most severe (Woods and Gent 2014). Percent defoliation was assessed visually on each of five randomly selected leaves per plant from each of the middle six plants in each plot to estimate a plot-level average.

Data Analysis

The abundance of hop looper larva over time was graphed by replicate plot, treatment, and year, and the area under the population development curve from each sampling unit was expressed as looper-days by calculating the area under the curve. These data and the defoliation severity data were aggregated over years and analyzed in a generalized linear mixed model to regress these variables on nitrogen rate. Nitrogen rate was a continuous fixed effect; and year, block nested within year, and an interaction term for year by nitrogen rate were random effects. Therefore, the analysis was similar to that used for a multiple-location experiment (Littell et al. 2006). When covariance parameter estimates were zero for the random effects, these terms were removed from the model and the model refit. Analyses were conducted using the GLIMMIX procedure in SAS version 9.4 (SAS Institute, Cary, NC). For completeness in data presentation, mean looper-days and defoliation severity also were calculated by treatment in each year and regressed on nitrogen rate per year. Regression models were fit in Sigma Plot version 12 (SigmaPlot, version 12, Systat Software, San Jose, CA).

Results

The abundance of hop looper varied from 2014 to 2017 (Fig. 1), and in each year, there was a tendency for hop looper abundance to increase linearly with nitrogen fertilization rate (Fig. 2). The slope of the regression of looper-days on nitrogen rate varied from 2.181 to 3.325 and was not significantly different than zero in any year ($P \geq 0.0837$). However, in the mixed analysis over years, there was sufficient statistical power to detect a relationship between hop looper abundance and nitrogen rate. Nitrogen rate was significant in the mixed-effect model ($F = 7.24$; df = 1,47; $P = 0.0099$; Fig. 2) and was related to hop looper abundance through the equation: looper-days = 1,219.8 + 2.5369 (kg/ha nitrogen rate). The intercept and slope terms were significantly different than zero (intercept $t = 2.69$; df = 3; $P = 0.0745$; slope $t = 2.69$; df = 47; $P = 0.0099$).

Similarly, percent defoliation from hop looper varied across years, but in every year, there was a relationship between defoliation from hop looper and nitrogen fertilization rate (Fig. 2). The slope of the regression varied from 0.0082 to 0.024 and was significantly different from zero in both 2015 and 2017 ($P = 0.0024$ and 0.0069, respectively). In the mixed-effect model, nitrogen rate was significant ($F = 11.14$; df = 1,35; $P = 0.0020$; Fig. 2) and was related to defoliation from hop looper by the equation: percent defoliation = 13.06 + 0.0307 (kg/ha nitrogen rate). Both the intercept and the slope were significantly different from zero (intercept $t = 6.80$; df = 11; $P < 0.0001$; slope $t = 3.34$; df = 35; $P = 0.0020$).

Discussion

This research establishes that the abundance of and damage from hop looper is positively correlated with the level of nitrogen fertilization. At the whole plant level, nitrogen fertilization typically is associated with an increase in plant growth rate and the amount of juvenile tissue (Huber and Thompson 2007), which may be due to alterations in cell size, cellulose production, and maturity (Poe 1971, Huber 1980, Rotem and Agrawal 2003, Agrios 2005). These factors may in turn influence arthropod feeding, growth and development, and oviposition preference (Vanderzant 1958, Ishii 1971, Mattson 1980, Al-Zubaidi and Capinera 1984, Shanks and Doss 1989).

Annual application of nitrogen is common in hop production, with recommended rates ranging from 150 to 225 kg/ha (Neve 1991). However, excessive nitrogen applications may not increase yield and quality, but rather reduce levels of bittering acids (Keller and Magee 1954, Roberts and Nelson 1961) and increase susceptibility to certain diseases (Burgess 1956, Huber and Watson 1974, Huber 1980, Gent et al. 2015). The present study indicates that

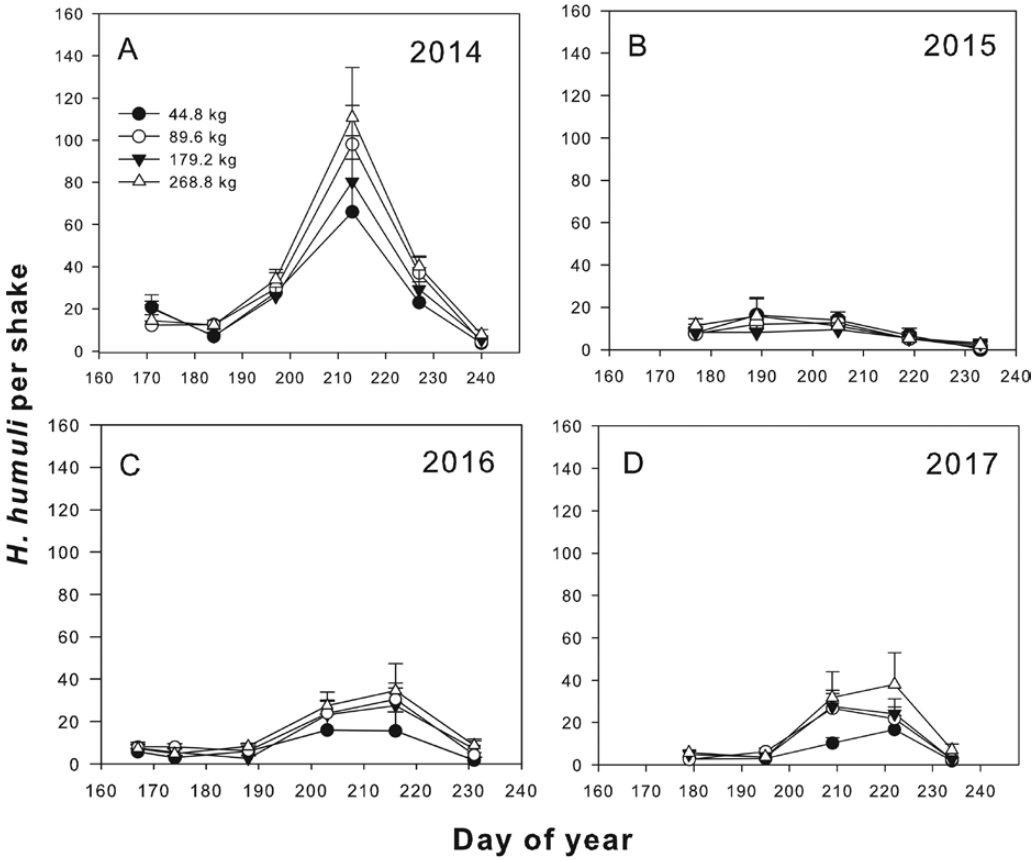

Fig. 1. Abundance of *Hypena humuli* (mean ± SEM) on hop plants in relation to nitrogen fertilization rate during 2014 to 2017.

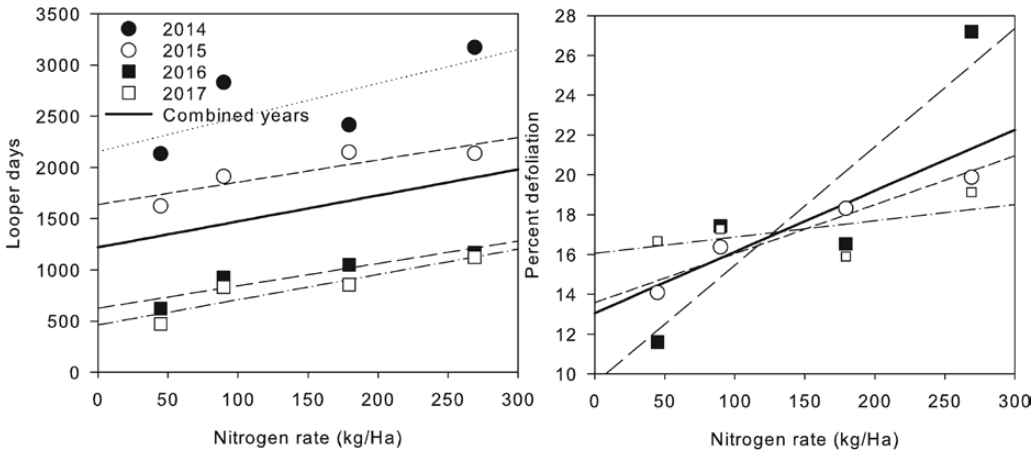

Fig. 2. Relationship between nitrogen fertilization rate and abundance of *Hypena humuli* (left) and associated defoliation (right). Regression lines are fit for each year (2014 to 2017 for looper-days and 2015 to 2017 for defoliation), with the overall relationship based on a generalized linear mixed model fit over all years indicated by the bolded line.

excessive rates of nitrogen also can increase the abundance of hop looper larvae and its concomitant defoliation.

Populations of hop looper may vary considerably from year-to-year (Grasswitz and James 2011, Woods and Gent 2014), and in the present study, we also observed interannual variation in population densities of the pest. Although population levels varied annually, the impact of nitrogen fertilization on abundance of hop looper larvae was relatively consistent over the 4 yr of this study (Fig. 2). The impact on defoliation was less consistent, yet the sign of the relationship was positive in all years. The mixed model analyses conducted explicitly accounts for random variation within and among years, and the parameter estimates provide a good estimate of the fixed effects of nitrogen fertilization rate on the response variables (Little et al. 2006).

The mechanism associated with an increase in hop looper abundance with increased nitrogen fertility has yet to be documented in the literature. Altered host selection, increased nutritional quality of leaves, or lower production of host secondary metabolites with increased nitrogen fertility are known to influence arthropods in other systems (Awmack and Leather 2002, van den Boom et al.

2003, van den Boom et al. 2004). Bioassays and more detailed studies are needed to elucidate the processes responsible for the responses observed herein. Nonetheless, the present study indicates that the overall influence of nitrogen fertilization is to increase abundance of and damage from this pest on hop.

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