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Interactions of host-plant resistance and foliar insecticides for soybean aphid management

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ABSTRACT

Soybean aphid, *Aphis glycines* Matsumura (Hemiptera: Aphidae), a major pest of soybean in the Midwest U.S., is primarily controlled with insecticides, but aphid-resistant plants are becoming available for growers. However, aphid populations can still occasionally build to economically damaging levels on resistant plants, which require treatment with insecticides to protect yields. To determine if resistant plants alter soybean aphid susceptibility to foliar insecticides, aphid populations were monitored over two years from 2014 to 2015 in field experiments with near isogenic soybean lines that were either susceptible or resistant to aphids. Field plots of each soybean line were either untreated or treated with an organophosphate (i.e., chlorpyrifos), a pyrethroid (i.e., λ-cyhalothrin), or a mixture of pyrethrum and azadirachtin. Greenhouse bioassays were also conducted with near isogenic lines and two of the insecticides to examine potential interactions under more controlled conditions. In field plots, organophosphate and pyrethroid treatments significantly reduced cumulative aphid days on at least one soybean line each year; additive effects between resistant plants and insecticides were most common. However, significant synergistic interactions between resistant plants and insecticide were found for λ-cyhalothrin in 2015. On chlorpyrifos-treated plants, a synergistic interaction occurred in 2014 and an antagonistic interaction occurred in 2015, but aphid populations did not exceed those of untreated resistant plants. Interactions between aphid-resistant plants and foliar insecticides were variable, but these tactics generally appear compatible for integrated pest management programs. Growers could benefit from additive and synergistic interactions, and the only documented instance of antagonism had a relatively small effect.

1. Introduction

Soybean aphid, *Aphis glycines* Matsumura (Hemiptera: Aphidae), an invasive pest native to Asia, was first discovered in North America in Wisconsin in 2000 and has since spread through much of the soybean production area of the U.S. and Canada (reviewed by Ragsdale et al., 2004; Ragsdale et al., 2011). Soybean aphids feeding on phloem sap can reduce soybean seed size and number (Beckendorf et al., 2008). Soybean aphid is the primary insect pest actively managed by soybean growers in North America (Hurley and Mitchell, 2017). In less than 10 years since detection of soybean aphid in North America, insecticide use in soybean increased 130-fold due to soybean aphid and resulted in increased production costs of U.S.$16 to 33 per ha (Ragsdale et al., 2007, 2011). Unintended environmental or non-target impacts, such as insecticide resistance, pest resurgence, and pest replacement, can result from overreliance on insecticides as a sole control tactic (Pedigo and Rice, 2009; Guedes et al., 2016; Hanson et al., 2017). The invasion of soybean aphid has resulted in U.S. $2.0 to 7.2 billion in lost yield and control costs between its arrival and 2017 (Kim et al., 2008a; Song et al., 2006, Song and Swinton, 2009).

Multiple management tactics have been explored for development of integrated pest management (IPM) programs to reduce soybean aphid population densities. However, foliar insecticides, especially pyrethroids and organophosphates, remain the primary tactic for outbreak suppression (reviewed by Hodgson et al., 2012). Foliar insecticide applications are recommended when aphid populations reach 250 aphids per plant (i.e., economic threshold), which should prevent the population from reaching the economic injury level of 674 aphids per plant (Ragsdale et al., 2007; Koch et al., 2016). Prophylactic neonicotinoid seed treatments are also available, but they are unlikely to provide sufficient control for soybean aphid because insecticide concentrations in the plants generally decrease to negligible levels before aphid populations begin to build (Krupke et al., 2017).

Other factors that can limit soybean aphid population growth include predatory insects, parasitoids, and pathogens. Natural enemies of the soybean aphid include predatory Coccinellidae and Anthocoridae,

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Abbreviations: CAD, cumulative aphid days; CPD, cumulative predator days

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and parasitic Hymenoptera (Ragsdale et al., 2011). The presence of some predators, such as coccinellids, can prevent or suppress aphid outbreaks, but natural enemies do not consistently keep aphids from reaching levels high enough to cause economic damage (Koch and Costamanga, 2017). Furthermore, natural enemies are less common where more insecticides are used (reviewed by Weinzierl, 2009; Hodgson et al., 2012).

Host-plant resistance is a cornerstone of many IPM programs, due to typically high levels of compatibility with other management tactics (Pedigo, 1995). Host-plant resistance is the use of pest-resistant plants to maintain pest populations at low levels or tolerate pest populations normally damaging to susceptible plants (reviewed by Painter, 1958; Smith, 2005). However, the initial incorporation of host-plant resistance into IPM programs is often slow (Stout and Davis, 2009). Aphid-resistant soybean lines containing *Rag* (i.e., Resistance to *Aphis glycines*) genes have been found that repel aphids or reduce aphid population growth (e.g., Hill et al., 2004; Diaz-Montano et al., 2006; Hesler and Dashiell, 2007; Bansal et al., 2013; Bhusal et al., 2013). However, these plants are not completely immune to soybean aphid, and eventually, aphids can reach population sizes large enough to cause damage to the plants and affect yield (Hill et al., 2012; Hesler et al., 2013). In particular, some soybean aphid biotypes are able to overcome the resistance traits (Alt and Ryan-Mahmutagic, 2013; Hesler et al., 2013). The spatial and temporal distribution of these biotypes is variable across the Upper Midwest of the U.S. (Cooper et al., 2015; Crossley and Hogg, 2015).

Integration of host-plant resistance and insecticides can be useful, because insects that feed on resistant plants can potentially become more susceptible to insecticides than those that feed on susceptible plants (e.g., Heinrichs et al., 1984; Tabadkani et al., 2017). This effect has been demonstrated in lepidopteran soybean pests on resistant plants (Kea et al., 1978), but not for soybean aphid with foliar insecticides. Effects of combined management tactics can occur in three ways (reviewed by Eigenbrode and Trumble, 1994; Quisenberry and Schotzko, 1994). An independent effect occurs when two tactics that control a pest do not affect the efficacy of one another (i.e., an additive effect). A synergistic interaction provides more control than expected (e.g., enhanced pesticide efficacy) on insecticide-treated resistant plants than insecticide-treated susceptible plants. Conversely, an antagonistic interaction can reduce the effectiveness of another control tactic to the point that the combined tactics are no more effective than or even worse in efficacy than a single tactic. Both additive and synergistic effects can be beneficial to growers by reducing pest populations more than single tactics alone. Meanwhile, antagonistic effects that reduce efficacy could lead to a pest population being exposed to an insecticide without any economic benefit.

Potential interactions between soybean aphid management tactics need to be understood to advance IPM of this pest. For example, while host-plant resistance is often compatible with natural enemies, many insecticides are not (Desneux et al., 2007; Weinzierl, 2009; Pezzini and Koch, 2015). Maintaining beneficial insect populations after treatment may also suppress soybean aphid population growth and prevent outbreaks of secondary pests. To test whether interactions occur between aphid-resistant soybean plants and foliar insecticides, we examined the effects of these tactics alone and in combination on soybean aphid and its predators under Minnesota field conditions over two years and in controlled greenhouse experiments.

2. Materials and methods

Two near isogenic lines were used in both field and greenhouse experiments: the soybean aphid susceptible IA3027 (i.e., no known *Rag* genes) and the resistant IA3027RA1 (i.e., *Rag1* gene) (Wiarda et al., 2012; McCarville et al., 2014). Three insecticides were used in field experiments, and two in greenhouse bioassays. Insecticides included a formulated mixture of pyrethrins and azadirachtin (Azera®, MGK, Minneapolis, MN), which is available for use by organic and conventional growers, an organophosphate, chlorpyrifos (Lorsban®, Dow Agrosciences, Inc., Indianapolis, IN), and a pyrethroid, λ-cyhalothrin (Warrior II with Zeon Technology®, Syngenta Crop Protection, Inc., Basel, Switzerland), which are both available for conventional growers.

2.1. Field experiment

A field experiment was conducted in 2014 and 2015 near Rosemount, MN to measure effects of combinations of soybean genotype and insecticides on soybean aphids and associated predators. In each year, the experiment consisted of 32 plots arranged in a randomized complete block design with four replications (blocks) of eight treatments. Treatments were a fully-crossed 2 × 4 factorial treatment structure with two soybean genotypes: susceptible IA3027 or resistant IA3027RA1, and four insecticide treatments: untreated, chlorpyrifos, λ-cyhalothrin, and the mixture of pyrethrin and azadirachtin (eight treatments total per replication). Plots were four rows wide by 4.6 m long, planted at 2.5 cm depth, with 76-cm row spacing and 1.5 m alleys between plots. Plots were planted on 13 June 2014 and 27 May 2015 at a rate of approximately 39 seeds per m.

Beginning when plants emerged, plots were sampled weekly by nondestructive, visual whole-plant counts of randomly selected plants for soybean aphids and the two primary taxa of soybean aphid predators, Coccinellidae (Coleoptera) and *Orius insidiosus* Say (Hemiptera: Anthocoridae). The number of plants inspected per plot depended upon percent of plants infested. Twenty plants per plot were inspected until 80% of plants in each plot were infested; then, subsample size was reduced to 10 plants per plot for the remainder of the season (Ragsdale et al., 2007). Insecticides were applied on 8 August 2014 and 11 August 2015 after susceptible plots surpassed the economic threshold of 250 aphids per plant. Applications were made with a CO_2-pressurized backpack sprayer using a 3.05-m boom with eight nozzles (XR-Teejet 8002 flat fan, with no screen) and calibrated to deliver 187.04 L per ha at 275.8 kPa. Chlorpyrifos, λ-cyhalothrin, and the mixture of pyrethrins and azadirachtin were applied at maximum labeled rates (i.e., 2.3, 0.12, and 4.1 L of product per ha, respectively). Aphid and predator sampling continued at 3, 7, and 14 d after treatment. From the day of application to the last sample date, daily high and low temperatures ranged between 28.9 and 10.6 °C in 2014 and 30.6 to 8.9 °C in 2015. Rainfall did not occur in the first week after application, and rain events of approximately 25 mm occurred 9 and 11 d after treatment in 2014 and 2015, respectively.

2.2. Greenhouse bioassays

The greenhouse bioassay was designed to measure susceptibility to insecticides of aphids on resistant and susceptible plants. Separate leaf-dip insecticide bioassays for λ-cyhalothrin and the mixture of pyrethrins and azadirachtin were performed with a fully-crossed factorial treatment structure with two soybean genotypes (susceptible IA3027 and resistant IA3027RA1) and two insecticide treatments (treated or untreated). For each insecticide, the experiment was repeated over three dates with four replications of each treatment per date.

Aphids were sourced from a laboratory colony of biotype 1 soybean aphid (i.e., susceptible to aphid-resistant plants expressing known *Rag* genes) that has not been exposed to insecticides since discovery in North America (Kim et al., 2008b). These aphids were reared at 25 °C with a 14:10 (L:D) h photoperiod at 70% RH on aphid-susceptible Williams 82 soybean. Aphids were transferred to and reared on caged IA3027 and IA3027RA1 soybean in a greenhouse at 25 °C with a 16:8 (L:D) h photoperiod for three days before bioassays to account for potential handling stress and acclimate aphids to these soybean lines.

Preliminary laboratory assays were performed to determine concentrations of λ-cyhalothrin and the mixture of pyrethrins and azadirachtin that would cause approximately 35–50% aphid mortality (data