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Effects of a pyrethroid and two neonicotinoid insecticides on population dynamics of key pests of soybean and abundance of their natural enemies

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ABSTRACT

Neonicotinoids alone and in combination with pyrethroid insecticides are common in crop production and suppress target herbivores effectively. The goal of this research was to quantify the effects of these insecticides on primary and secondary pests of soybeans and their natural enemies. We examined the effects of neonicotinoids alone applied to soybean seeds (thiamethoxam), neonicotinoids and pyrethroids applied to leaves (imidacloprid + β-cyfluthrin), and a combination of these treatments on arthropod abundance in soybean fields at two locations over two years in eastern South Dakota. Foliar applications of the insecticides suppressed soybean aphids, *Aphis glycines* Matsumara (Hemiptera: Aphididae), while thrips, (Thysanoptera: Thripidae) increased in numbers following exposure to the neonicotinoid insecticides alone or in combination with the pyrethroid in one of the locations and were significantly correlated with their major predators. Spider mites (*Tetranychus urticae* Koch) were not significantly affected by treatments. We also noted suppression of several taxa of predators following exposure to the insecticides. While low abundance of arthropods in the first year of the study limits our inferences, we conclude that both insecticide classes effectively suppress the key pest of soybean, soybean aphids, while their impact on secondary pests and on predators is variable. This research provides important contribution to our understanding of target and non-target impacts of insecticides commonly used in crop protection.

1. Introduction

Soybeans are the second most widely planted field crop in the United States and 30 million hectares of soybeans were planted in 2012, accounting for 23% of the total hectares of field crops cultivated in the United States (National Agricultural Statistics Service, 2013). Until 2005, soybean was scouted for insects and treated with insecticides only sporadically (Ragsdale et al., 2011) owing to infrequent and sparse pest outbreaks. However, following the invasion of the soybean aphids (*Aphis glycines* (Hemiptera: Aphididae), which quickly became the key pest of the crop (Ragsdale et al., 2011), insecticide use in soybean increased rapidly. Particularly, applications of neonicotinoid insecticides, thiamethoxam and imidacloprid, and a pyrethroid insecticide cyfluthin rose significantly since 2005. Combined volume of both neonicotinoids, for example, averaged 0.56 million kilograms annually between 2010 and 2014, while volume of cyfluthrin exceeded 0.022 million kilograms in the same timespan (USGS, 2016). All of these insecticides were applied at a fraction of these volumes between 2005 and 2009, and were virtually absent in soybean prior to 2005 (USGS, 2016).

Pyrethroids and neonicotinoids are frequently applied to soybeans to manage the aphids and provide adequate aphid control (Ohnesorg et al., 2009). Moreover, neonicotinoid insecticides are often applied as a seed coating to control the soybean aphids and bean leaf beetle, *Cerotoma trifurcata* Forster (Coleoptera: Chrysomelidae), vector of bean pod mottle virus (Magalhaes et al., 2009).

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Neonicotinoid insecticides can effectively reduce abundance of the soybean aphid and their efficacy has been reported previously (McCornack and Ragsdale, 2006; Ohnesorg et al., 2009). Soybeans grown from seeds treated with these insecticides, however, have a short window of effectiveness after planting and do not provide long-term suppression of the aphids (Magalhaes et al., 2009; Seagraves and Lundgren, 2012). This was illustrated in greenhouse experiments that reported toxicity of neonicotinoid seed treatments to the aphids in short-term studies, and field studies that indicated inconsistent suppression of *A. glycine* over the growing season using neonicotinoid seed treatments alone (Magalhaes et al., 2009; McCarville and O'Neal, 2013; McCornack and Ragsdale, 2006; Ohnesorg et al., 2009; Seagraves and Lundgren, 2012). Pyrethroids in general and cyfluthrin in particular can effectively suppress key pests of soybean (Ohnesorg et al., 2009), although secondary outbreaks of non-target pests frequently follow pyrethroid applications owing to elimination of insect predators (Penman and Chapman, 1988; Raupp et al., 2010).

While neonicotinoids and pyrethroids suppress target pests effectively, their non-target effects can have significant implications for plant protection and management of insects and mites attacking crops (Desneux et al., 2007). For example, neonicotinoids have been shown to elevate populations of unsusceptible herbivores spider mites (Acari: Tetranychidae). Specifically, eruptive population increases of spider mites following applications of neonicotinoid insecticides were demonstrated in several agricultural plants including hops (*Humulus lupulus* L.) (James and Vogele, 2001), cotton (*Gossypium hirsutum* L.) (Smith et al., 2013; Szczepaniec et al., 2013), corn (*Zea mays* L.), and tomato (*Solanum lycopersicum* L.) (Szczepaniec et al., 2013). Moreover, numerous greenhouse and laboratory studies report that neonicotinoid insecticides are toxic to insect (Douglas et al., 2015; Fogel et al., 2013; James, 2003a; Moser and Obrycki, 2009; Mullin et al., 2005; Rogers et al., 2007; Sclar et al., 1998; Seagraves and Lundgren, 2012; Smith and Krischik, 1999; Stavrinides and Mills, 2009; Szczepaniec et al., 2011) and mite (Bostanian et al., 2009; James, 2003b; Poletti et al., 2007; Stavrinides and Mills, 2009) predators. Pyrethroid insecticides have similar non-target impacts on insect predators and secondary pests. For example, pyrethroids are frequently linked to significant decreases in populations of insect predators through direct toxicity and their applications can cause outbreaks of non-target pests (Penman and Chapman, 1988; Raupp et al., 2010). These unintended consequences of pyrethroids have been implicated in cases of outbreaks of spider mites and thrips (Cordeiro et al., 2013; Gerson and Cohen, 1989; Hardin et al., 1995). It is noteworthy that the majority of literature reporting negative effects of these insecticides on predators is based on greenhouse or laboratory studies. Field research, on the other hand, is more likely to reveal variable consequences of insecticide exposure to natural enemies, such as effective suppression of green peach aphids (*Myzus persicae* Sulzer, Hemiptera: Aphididae) by its parasitoid following applications of a pyrethroid insecticide (Desneux et al., 2005) or lack of consistent reduction in abundance of predators following imidacloprid drenches in elm trees (Szczepaniec et al., 2011).

Thus, the goal of this research was to quantify the impact of commonly used pyrethroid and neonicotinoid insecticides on target and non-target organisms associated with soybean. In field experiments carried out at two locations in eastern South Dakota over two years, we investigated the effects of thiamethoxam seed treatments, imidacloprid + β-cyfluthrin foliar sprays, and combination of the two formulations of these neonicotinoid insecticides on abundance of herbivores (soybean aphid, spider mites, and thrips) and their predators (lady beetles, predatory bugs, predatory flies, and lacewings among others) in soybeans. Our selection of insecticides (two neonicotinoids and a pyrethroid) and their formulations (seed treatments and foliar) was driven by common practices of soybean producers in the region.

2. Materials and methods

2.1. Field locations, planting, and harvest

The field experiments took place at two South Dakota State University Research Farms: Volga (Brookings County, South Dakota) and South Shore (Codington County, South Dakota). *Glycine max* L. (var. S15-L5 and S14-J7 in 2013 and in 2014, respectively, Syngenta Crop Protection, LLC, Greensboro, NC, USA) was planted on 5 June 2013 and 30 May 2014 at Volga, and on 13 June 2013 and 5 June 2014 at South Shore. The experiments were arranged in a randomized complete block design with plots measuring 3 m by 12 m separated by 3 m buffers in both years. Plots were planted to approximately 445,000 seeds per hectare with 0.76 m row spacing. Buffers were planted with soybean (var. 06942 in 2013, Mustang Seeds, Madison, SD, USA; var. S15-L5 in 2014, Syngenta Crop Protection). Glyphosate (Roundup WeatherMAX®, Monsanto Company, St. Louis, MO, USA) was applied to plots at the recommended rate of 2.34 L per hectare at both locations as needed each year to suppress weeds. Plots were harvested on 28 October 2013 and 6 October 2014 at Volga and on 14 October 2013 and 14 October 2014 at South Shore. All plots were harvested using a two-row combine and measurements of weight and moisture of seed were taken. Yield was calculated using a formula to correct for 13% moisture (yield = [100-actual moisture]*test weight × 100.138/plot length/row spacing/number of rows).

2.2. Pesticide treatments

At Volga in 2013, we tested the effects of the following three treatments on the abundance of spider mites, their predators, and other relevant arthropods: untreated seed that received a fungicide seed treatment only ("Untreated"; ApronMaxx®, 2.5 g fludioxonil per 100 kg of seed, 7.5 g mefenoxam per 100 kg of seed, Syngenta); untreated seed with foliar application of imidacloprid and β-cyfluthrin ("Foliar"; fungicide seed treatment + Leverage 360®, 239.68 g imidacloprid per L, 119.84 g β–cyfluthrin per L, Bayer CropScience LP, Research Triangle Park, NC, USA); and thiamethoxam-treated seed ("Seed"; fungicide seed treatment + CruiserMaxx®, 50 g thiamethoxam per 100 kg seed, 2.5 g fludioxonil per 100 kg of seed, 7.5 g mefenoxam per 100 kg of seed, Syngenta). In 2014 at Volga and in both years at South Shore, an additional treatment of thiamethoxam-treated seed combined with foliar imidacloprid+ β-cyfluthrin spray was added ("Seed + Foliar"; fungicide seed treatment + CruiserMaxx®, Leverage 360®, Bayer). Soybean seed is routinely treated with fungicides in eastern South Dakota owing to high incidence of fungal diseases and we omitted the 'naked seed' treatment (i.e., no fungicide) due to high probability of disease development. Moreover, Leverage 360®, a foliar insecticide with two active ingredients (a neonicotinoid and a pyrethroid) was selected based on prevalent farmer practices in the area. Plots assigned to the "Seed" treatment did not receive any foliar insecticide applications. The foliar insecticide was applied at the label rate of 204.52 mL per hectare on 16 August 2013 at Volga and on 23 August 2013 at South Shore using a CO_2 backpack sprayer under 20 psi pressure, with a flat fan nozzle (TeeJet, XR110015) at 0.5 m (20 inch) spacing, delivered at 95 L/ha. In 2014, foliar applications of the insecticide were administered at the label rates on 11 August at Volga and 19 August at South Shore. All of the foliar applications of imidacloprid+ β-cyfluthrin coincided with soybean aphids reaching the established