



Evidence for multi-trophic effects of pesticide seed treatments on non-targeted soil fauna



Lesley W. Atwood^{a,*}, David A. Mortensen^b, Roger T. Koide^c, Richard G. Smith^a

^a Department of Natural Resources and the Environment, University of New Hampshire, Durham, NH, 03824, USA

^b Department of Plant Science, The Pennsylvania State University, University Park, PA, 16802, USA

^c Department of Biology, Brigham Young University, Provo, UT, 84602, USA

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ABSTRACT

The use of pesticide seed treatments containing neonicotinoid insecticides is widespread in large-scale row crop agriculture. Recently, use of pesticide seed treatments has come under scrutiny due to concerns over non-target impacts on beneficial insects (e.g., honey bees) and the environment. Amidst these growing concerns, however, few studies have examined how pesticide seed treatments may impact soil faunal communities across multiple feeding guilds and the soil processes they regulate. We grew corn and soybean with and without pesticide seed treatment for three years and measured the response of the soil faunal detritivore, herbivore, mixed, and predator feeding guilds, nitrogen mineralization, and surface litter decomposition at three time points each year. We found the effects of seed treatment on the soil faunal community varied in direction and magnitude by year and feeding guild and were most apparent in the predator and detritivore guilds. Guild-level effects tended to be strongest soon after planting but remained apparent throughout the crop growing season, particularly in the predator and mixed feeding guilds. We found no evidence that pesticide seed treatment affected the herbivore guild—the intended target of the seed treatment, or nitrogen mineralization, surface litter decomposition, or grain yields. Collectively, these data suggest that pesticide seed treatments can alter the abundance, richness, and diversity of all non-targeted soil faunal guilds. Additional research will be necessary to determine the longer-term significance of pesticide seed treatment-driven changes in non-target soil faunal communities in agroecosystems.

1. Introduction

Seeds of most commodity crops planted in the US are coated with pesticides. These pesticide seed treatments commonly include a mixture of systemic and contact fungicide and systemic neonicotinoid insecticide active ingredients intended to prophylactically protect the crop against soil borne fungal pathogens and soil-inhabiting insect pests during the early stages of plant development (Taylor and Harman, 1990). World-wide, adoption of pesticide seed treatments in row crops such as maize, soybean, wheat and cotton has grown rapidly, resulting in nearly ubiquitous use of seed treatments in some regions (Jeschke et al., 2011; Simon-Delso et al., 2015). In the US, it was estimated that in 2011 up to 44% of soybean and more than 79% of maize hectares were planted with seeds containing seed treatments with neonicotinoid insecticides, almost triple their usage in maize since 2003 (Douglas and Tooker, 2015). This increase in the use of seed treatments is due, in

part, to their purported effectiveness in providing broad-spectrum and systemic control of serious crop pests such as aphids and wireworms, and the perception that seed treatments reduce overall pesticide use and have lower environmental impacts compared to other forms of application of these pesticides (Tomizawa and Casida, 2005; Bonmatin et al., 2015).

Recently, the use of pesticide seed treatments has come under scrutiny because the active ingredients in these mixtures, particularly the neonicotinoids, have been linked to negative impacts on populations of some non-target organisms (Hallmann et al., 2014; Pecenka and Lundgren, 2015; Gibbons et al., 2015; Rundlöf et al., 2015), particularly bees (Girolami et al., 2009; Krupke et al., 2012; Goulson, 2013; Godfray et al., 2014; Godfray et al., 2015; Rundlöf et al., 2015; Mogren and Lundgren, 2016). Neonicotinoids from seed treatments have also increasingly been detected in off-target locations, including waterways (Hladik et al., 2014; Gibbons et al., 2015; Rundlöf et al., 2015).

* Corresponding author. Department of Natural Resources and the Environment, 264 James Hall, 56 College Road, University of New Hampshire, Durham, NH, 03824, USA.

E-mail address: atwood@nceas.ucsb.edu (L.W. Atwood).

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Consequently, their use has been restricted or prohibited in a number of countries (European Commission, 2013; U.S. EPA, 2013; Ministry of the Environment and Climate Change, 2015).

While the non-target effects of pesticide seed treatments on terrestrial faunal populations (e.g., bees) and aquatic ecosystems have received significant scientific and media attention, much less attention has been paid to quantifying the effects of seed treatments on entire soil faunal communities or the ecosystem functions they regulate (Coleman et al., 2004; Bardgett et al., 2005; Seagraves and Lundgren, 2012; Douglas et al., 2015; Pisa et al., 2015). Recent studies focused on individual faunal populations or specific feeding guilds suggest a diversity of non-target soil organisms, particularly surface-active organisms, can be affected by seed treatments (Seagraves and Lundgren, 2012; El-Naggar and Zidan, 2013; Douglas et al., 2015; Nettles et al., 2016; Smith et al., 2016). For example, pesticide seed treatment use has been shown to alter soil microbial community structure (Nettles et al., 2016) and negatively impact populations of predatory arthropods (Moser and Obrycki, 2009; Seagraves and Lundgren, 2012; Douglas et al., 2015; Douglas and Tooker, 2016). Alternatively, there is emerging evidence that some soil inhabiting populations can thrive in the presence of this management practice. For example, collembolan, which are agriculturally important fungivores (Crossley et al., 1992), have been shown to increase in density (El-Naggar and Zidan, 2013) and surface activity when exposed to seed treatments with neonicotinoids (Zaller et al., 2016).

Recent research has also pointed to pesticide seed treatment-driven changes in soil faunal populations having consequences for some ecosystem services important to agriculture, particularly pest population suppression (Seagraves and Lundgren, 2012; Douglas et al., 2015; Douglas and Tooker, 2016). In the field, observed reductions in the biocontrol of invertebrate pests (i.e., slugs; Douglas et al., 2015) and weed seeds (Smith et al., 2016) have also been attributed to observed and suspected pesticide seed treatment-induced reductions in soil predator and plant pathogen abundance. However, the degree to which seed treatments can alter other ecosystem services mediated by soil fauna, such as litter decomposition or nutrient cycling (Bradford et al., 2002), particularly when high levels of functional redundancy within feeding guilds may ameliorate the functional significance of species-specific changes in abundance (Setälä et al., 2005), has not been investigated.

Here we report the results of a three-year field experiment in which we grew maize and soybean in rotation with and without neonicotinoid seed treatment and measured the response of the soil fauna at the whole community and feeding guild levels, surface litter decomposition, plant-available soil nitrogen, and crop yields. We hypothesized that pesticide seed treatment use would alter the composition, diversity, and total abundance of the soil faunal community and that these effects would manifest differently within different soil faunal feeding guilds (detritivore, herbivore, predator, and mixed). Specifically, we expected that neonicotinoid seed treatment would decrease the abundance and diversity of the soil faunal predator guild because this guild is potentially impacted by pesticide seed treatment through both direct (contact with pesticides) and indirect (changes in prey abundance) pathways. Lastly, we hypothesized that changes in soil faunal guild abundance and diversity due to pesticide seed treatment, particularly at the decomposer guild-level would be associated with altered rates of surface litter decomposition and plant-available nitrogen relative to the control treatment in which seed treatment was not used.

2. Materials and methods

2.1. Site description

The field experiment was conducted at the Pennsylvania State University Russell A. Larson Agricultural Research Center in Rock Springs, PA, USA (40°43' N, 77°55' W, 350 m elevation). Soils at the

field site are shallow, well-drained lithic Hapludalf formed from limestone residuum, and the dominant soil type is a Hagerstown silt loam (fine, mixed, semi active, mesic Typic Hapludalf) (Braker, 1981). The soil is characterized by a silt loam surface texture and subsurface textures of silty clay loam and silty clay. In the five years preceding this study, the field was managed under a conventional no-till rotation of maize for grain (2008 and 2009), soybean (2010), spring oats (2011), and barley and wheat (2012). Therefore, no neonicotinoid seed treatments were used at the study site for at least two years.

2.2. Experimental design

The experiment was established in May 2013 and continued for three years. Each year the same genotype of a glyphosate resistant crop (maize in 2013, soybean in 2014, and maize in 2015) was planted either with or without pesticide seed treatment in a completely randomized design with five replications. Each plot was 6 m by 3 m, encompassing four experimental crop rows (76 cm-spaced rows). Treatments were maintained in their respective plots throughout the duration of the experiment. Planting densities and crop management depended on the crop and were based on standard agronomic practices for the region (described below).

2.3. Maize

Maize was planted in 2013 and 2015. Prior to planting in 2013, 1.52 kg ha⁻¹ glyphosate (potassium salt form) and 1.40 kg ha⁻¹ dichlorophenoxyacetic acid (2,4-D) was applied for weed control (26 April). In preparation for planting, the field was then S-tined, disked, and cultimulched (14–15 May 2013). No-till planting practices were implemented for all subsequent planting periods. On 16 May 2013, maize (hybrid TA510-18, TA Seeds, Jersey Shore, PA, USA) was planted at a density of 78,300 seeds ha⁻¹. Urea was applied at a rate of 358 kg ha⁻¹ on 31 May 2013, and a post-emergence application of glyphosate (1.39 kg ha⁻¹) was applied on 20 June 2013. In 2015, a tank mix of 1.53 kg ha⁻¹ glyphosate (potassium salt form) and 1.40 kg ha⁻¹ 2,4-D was applied for weed control on 7 May. Maize (hybrid FC 397 3122, 1st Choice Seeds, Milton, IN, USA) was no-till planted into soybean residue at a density of 78,300 seeds ha⁻¹ on 13 May. Urea was applied at a rate of 312 kg ha⁻¹ on 28 May 2015. For both years, maize seeds used in this study were genetically modified to be glyphosate tolerant. In both 2013 and 2015, maize seeds planted in the pesticide seed treatment treatment were pre-coated with a mixture of the systemic insecticide thiamethoxam (class neonicotinoid, 0.25 mg ai seed⁻¹), the contact fungicide fludioxonil, and the systemic fungicides mefenoxam, azoxystrobin, and thiabendazole (CruiserMaxx[®] Corn 250, Syngenta, Greensboro, NC, USA). Maize seeds planted in the control treatment did not contain the coating.

2.4. Soybean

Soybean was planted in 2014. Prior to planting, 1.52 kg ha⁻¹ glyphosate (in the form of the potassium salt) and 1.40 kg ha⁻¹ 2,4-D was applied for weed control (27 May). On 30 May 2014, soybean (TS2849R2S, TA Seeds, Jersey Shore, PA, USA) was no-till planted into the maize residue at a seed density of 432,250 seeds ha⁻¹. Soybean seeds used in this study were STS stacked (sulfonyleurea-tolerant) and genetically modified to be glyphosate tolerant. The soybean seed planted in the pesticide seed treatment treatment was coated with a pesticide mixture that included the systemic insecticide thiamethoxam (class neonicotinoid, 0.25–0.5 mg ai seed⁻¹), and the contact fungicide fludioxonil, and the systemic fungicides mefenoxam and sedaxane (CruiserMaxx[®] Beans with Vibrance[®], Syngenta). The soybean seeds planted in the control did not contain the coating. On 16 June 2014, a post-emergence application of glyphosate (1.39 kg ha⁻¹) was applied to control emerged weeds.

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