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Cover crops have neutral effects on predator communities and biological control services in annual cellulosic bioenergy cropping systems

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ABSTRACT

Maize stover is beginning to be used as a cellulosic biofuel feedstock in the Midwestern United States; however, there are concerns that stover removal could result in increased soil erosion and loss of soil organic matter. Use of a winter cover crop following maize harvest has the potential to mitigate these impacts and may have additional benefits by providing continuous living cover in annual crop habitats leading to changes in insect predator communities and increased biocontrol services. However, cover crops may also be harvested in cellulosic biofuel systems, adding a disturbance event that may negatively affect biocontrol. We contrasted insect predator communities and their impacts in four potential bioenergy cropping systems in Michigan and Wisconsin (USA) during the 2013 and 2014 growing seasons. Two annual maize systems were harvested for grain and stover; one maize system included a cereal rye/Austrian winter pea cover crop. Two perennial systems, switchgrass and a mixed prairie grasses and forbs, were harvested in the fall for biomass. Predatory insect abundance and diversity were lower in both annual cropping systems than in the perennial cropping systems and the inclusion of the cover crop did not significantly alter these responses. Similarly, removal of sentinel insect egg prey was also lower in the annual versus perennial cropping systems, with no significant influence of cover crop. We also explored the potential for cover crops to harbor prey populations in the spring that might encourage oviposition by mobile predators and potentially lead to local population sources or sinks of predators depending on the timing and effect of cover crop harvest. We found that existing predator communities in the cover crop treatments effectively suppressed aphid population growth, limiting their attractiveness to mobile predators. While we found no significant positive or negative impacts of this cover crop system on biocontrol services, bioenergy cover cropping systems could be managed to increase multiple ecosystem services by altering cover crop identity, or timing of planting and harvest.

1. Introduction

The sustainability of biofuel production requires balancing the need to produce bioenergy crops efficiently while enhancing water quality, reducing greenhouse gas emissions, and maintaining biodiversity (Meehan et al., 2013; Werling et al., 2014). Biofuel production in the United States is primarily based on ethanol derived from maize grain (first generation biofuels). However, biofuels derived from lignocellulosic feedstocks (second generation biofuels) are beginning to be produced, with several commercial-scale cellulosic ethanol plants starting production in the United States in 2014. Currently, maize stover, the leaves and stalks typically left after grain harvest, is considered one of the most viable and sustainable feedstocks for lignocellulosic bioethanol because it is widely available (US DOE, 2011), does not compete with food production (Thompson and Meyer, 2013), and existing transportation and refining technologies can be adapted for stover more easily than for novel feedstocks (Hess et al., 2009; Janssen et al., 2013). However, removing stover from the field can

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have varying environmental impacts. Stover harvest is projected to decrease nitrate and phosphorous loadings at the watershed level, while greenhouse gas emissions and sediment loadings are projected to increase (Gramig et al., 2013). Other studies indicate that stover harvest has the potential to increase soil carbon loss (Follett et al., 2012; Lugato and Jones, 2014). A potential way to mitigate the negative impacts of stover harvest is to grow winter annual cover crops following maize. Winter annual cover crops can reduce soil carbon loss, erosion, and nutrient runoff from stover harvest (Lugato and Jones, 2014). They can also be harvested as a forage or biofuel feedstock, and can also create habitat for animals during the otherwise fallow winter-spring period. Thus, the widespread planting of cover crops could improve the environmental sustainability of maize stover bioenergy production (Bonner et al., 2014).

One ecosystem service that may be affected by the wide-scale planting of winter annual cover crops is natural pest control. Natural biological control by predators and parasitoids is an important ecosystem service estimated to be worth $4.5 billion per year to United States agriculture (Losey and Vaughan, 2006). Previously, we have shown that predator biomass and diversity, as well as insect prey removal, are lower in continuous maize compared to perennial feedstocks, such as switchgrass and mixed prairie (Werling et al., 2011b). However, it is possible that the addition of winter cover crops to annual systems may introduce some of the benefits of perennial biomass crops by increasing food resources for predators and improving habitat quality. For example, several legume cover crops are known to harbor pea aphid, *Acyrthosiphon pisum* (Harris), and some grass cover crops support bird cherry-oat aphid, *Rhopalosiphum padi* (L.), (Bugg et al., 1991; Tillman et al., 2004); both of which can sustain populations of agronomically important natural enemies (Bugg et al., 1991; Snyder and Ives, 2003). By providing prey and suitable microclimates, cover crops may serve as temporal habitat bridges that help relay natural enemies into subsequent crops (Ruberson et al., 1999).

Natural enemy life history traits affect the way in which they interact with cover crop systems. For many ground-dwelling predators, cover crops may provide prey and suitable habitat that allow them to overwinter and persist into the subsequent crop. Lundgren and Fergen (2010) found increased abundance of ground-dwelling predators and reduced corn rootworm damage in maize planted after a winter cover crop in contrast to plots without cover crop. Similarly, Carmona and Landis (1999) found significant increases in carabid beetle activity-density in maize plots with cover crops, but this effect was not consistent across years. Cover crops can also impact foliar-dwelling predators. For example, aphidophagous Coccinellidae (lady beetles) typically lay their eggs in dense patches of aphids (Evans 2003). If cover crops support aphid build-up in the spring, they may attract oviposition by coccinellids. However, to prevent competition with the subsequent crop, most cover crops are terminated (i.e., killed) prior to planting via herbicides, mowing, cultivation or a combination of these practices, all of which can reduce the number and effect of predatory invertebrates (Landis et al., 2000). Additionally, cover crops can also be harvested for cellulosic biofuel, adding another disturbance event that may negatively affect predatory invertebrates. Flight-capable adult insects can survive such disturbance, but the non-flying larvae and egg stages of these organisms are more susceptible (Hossain et al., 2000). As such, cover crops could act as either source or sink habitats for foliar predators, depending on the timing of cover crop harvest.

Given the growing use of maize stover for cellulosic biomass and the potential soil conservation benefits of coupling winter cover cropping with stover harvest, we investigated the potential impacts of this cropping system on predator communities and biocontrol services. The overall goal of our two-year, two-state study was to determine the effects of a winter cover crop system designed to enhance the agronomic performance of a bioenergy cropping system on predatory invertebrate communities and biocontrol services. Our specific objectives were 1) to determine if winter cover crops altered the abundance and diversity of predator communities, and 2) to assess the impact of the resulting predator communities on rates of predation in the subsequent crop. To do so we sampled predatory arthropod communities and compared sentinel prey removal rates, an index of potential biological control activity (Werling et al., 2011b), in maize grown with and without cover crops, and contrasted the results to switchgrass and mixed prairie, two perennial biofuel feedstocks known to support high numbers of natural enemies. Specifically, we hypothesized greater predator abundance and prey removal in the maize following the cover crop compared to maize grown without cover crops. We also anticipated that cover crops would support aphid populations and attract mobile predators potentially serving as either source or sink habitats for insect predators.

2. Methods

2.1. Study area

Research was conducted during 2013 and 2014 at the two sites of the Great Lakes Bioenergy Research Center (GLBRC) Biofuel Cropping System Experiment, the W.K. Kellogg Biological Station of Michigan State University (MI) (+42°23′42.39″, −85°22′24.77″) and the Arlington Agricultural Research Station of University Wisconsin-Madison (WI) (+43°18′16.00″, −89°19′48.20″). Four of the ten crop treatments in the GLBRC Biofuel Cropping System Experiment (BCSE) were used: continuous no-till maize, continuous no-till maize plus cover crop (hereafter ‘cover crop system’), switchgrass (*Panicum virgatum* L.), and restored prairie. Five replicate plots (40 × 30 m) of each treatment were arranged in a randomized complete block design at both sites.

In the cover crop system, Austrian winter pea (*Pisum sativum* subsp. *arvense* (L.) Poir) and cereal rye (*Secale cereale* L.) (Varieties: MI, 2013: Cougar; MI, 2014: Wheeler; WI, 2013 & 2014: Spooner) were planted in the fall of 2012 and 2013 after maize harvest and stover removal (Table 1). Cover crops emerged in the fall and survived to termination except for those planted in Wisconsin 2013, which did not emerge until the following spring in 2014. In the spring of both experimental years, maize was planted in the continuous maize plots in early May and in the cover crop system in late May to early June (Table 1). Both the continuous maize (glyphosate-tolerant DeKalb 52–59; 102 day maturity) and cover crop system (glyphosate-tolerant Pioneer P8906AM; 89 day maturity) were planted at 75,000 plants ha^{-1}, ~4.5 cm deep, with 76 cm row spacing. The cover crop was harvested as a bioenergy feedstock with a John Deere (Deere and Co., Moline, IL) 7450 forage harvester in late May to early June. After harvest, except for MI 2013, cover crop plots were sprayed with glyphosate herbicide (Roundup PowerMax®, Monsanto Company, St. Louis, MO) at 1260 g A.E. ha^{-1} in late May to early June. Due to low productivity, the 2013 MI cover crop was terminated with a flail mower instead of herbicide and biomass was left in place. Maize grain in continuous maize was harvested in late October and in the cover crop system in late October to early November. Maize stover in continuous maize was harvested in late October and in the cover crop system in late October to early November.

Perennial switchgrass and prairie plots were planted in June, 2008 and were harvested annually in late October. The prairie treatment consisted of six native perennial grasses (including big blue stem (*Andropogon gerardi*), Indiangrass (*Sorghastrum nutans*), and junegrass (*Koeleria cristata*)) and twelve native forbs (including