The impact of cover crop species on natural enemies of slugs in soybean

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Rational and Significance. In Delaware and the mid-Atlantic region, 92% of the no-till soybean growers have experienced significant slug damage, and 82% of the surveyed growers think slugs are the most challenging pest they face (Tooker, et al. 2011). Slugs were particularly challenging during Spring 2017, when they caused some of the most extensive damage experienced in recent years. Despite growing concerns associated with slugs, only 18 peer-reviewed articles have been published today with the keyword "slug AND soybean" and this number drops to 7 only when adding "management OR control". Among these studies, the majority looked at synthetic chemicals. It is therefore of paramount importance to research additional slug control options to add to the toolbox for soybean growers.

One obvious research avenue is to look at slugs within their trophic environment and exploit the ecosystem services provided by their natural enemies. This approach offers alternate and sustainable practices to control slugs in DE soybean crops at no extra cost and has the potential to be highly effective. Lacking to understand how beneficial organisms can be used to manage slug populations in soybean may result in inadvertent depletion of this ecosystem service.

Literature Review. Slugs and snails are voracious mollusk pests having the potential to damage virtually all crops, ranging from vegetables to field crops. Mostly impactful on seedlings, slugs are especially problematic at the establishment of the crop in spring or in fall. *Mollusk outbreaks have become a serious concern for growers* in non-tillage systems (Douglas, et al. 2012, Le Gall, et al. 2017, Tulli, et al. 2009). Slug herbivory can result in a 37% decline of the total biomass of annual crucifer species (Rees, et al. 1992). Generally, slugs tend to be more damaging than snails because of their higher resistance to mechanical disturbance and their lower needs in calcium to build shells (Glen, et al. 2003). In term of population size, slugs have become the most important pest in Western Europe and are an increasing challenge in many parts of the United States (Anderson, et al. 2013, Douglas, et al. 2012). Aside from tillage, the current most widely used slug management practice is the application of the molluscicide metaldehyde or iron phosphate in the form of granular baits. In addition to potential leakage of these chemicals in the groundwater and streams (Kay , et al. 2014), metaldehyde can be toxic for mammals such as dogs (Dolder 2003) or rats (Bailey 2002). In addition, extensive use of these chemicals can potentially result in the evolution of resistance in slugs, as observed with other crop pests (Alyokhin, et al. 2017). Furthermore, insecticidal baits are expensive ($20-25/acre) yet not always effective. However, these active compounds do not seem to be toxic to arthropod predators (Langan, et al. 2004), meaning they can be used with integrated pest management (IPM) or other alternative control methods.

Slug control would undoubtedly benefit from complementary management approaches. Currently the main cultural approach to control slugs is tillage, having important consequences on the erosion of agricultural soils and fertilizer/pesticide run-off. In the mid-Atlantic region, about 70% of the agricultural land is not tilled to prevent erosion and run-off in streams and ocean bays (USDA-NASS 2015), yet favoring the built up of slug population in these no-till setting. One straight, yet largely overlooked, *approach is the use of the ecosystem services provided by slug natural enemies, especially ground beetles* (Lövei, et al. 1996) and mollusk-pathogenic nematodes (Wilson, et al. 2015). If the second has gained some attention over the past years (e.g., Grewal, et al. 2001, Jaworska 1993, Rae, et al. 2010, Ross, et al. 2012, Schley, et al. 2006, Wynne, et al. 2016), commercial products are not yet registered in the United States. On the other end, *the use of predaceous ground beetles has been largely neglected*, whereas several ground beetle species (e.g., *Pterostichus melanarius*, Coleoptera: Carabidae) are considered generalist predators on various species of slugs (e.g., Digweed 1993, Langan, et al. 2001, Lövei, et al. 1996, Mair, et al. 2001, Mundy, et al. 2000).

Objective. We hypothesized that p*roviding or conserving ground beetle habitats will enhance the presence of these natural enemies.* This could eventually have a negative impact on slugs, hence eventually reduce damage on soybean.

We therefore proposed to document:

- how various cover crop species impact ground beetle diversity and abundance.

Experimental methodology.

1) Cover crop species as suitable habitat for ground beetles

Cover Crop Species and Plots

We used the Delaware Cover Demonstration Network (http://www.deccnetwork.com) to assess the impact of cover crop species on the ground beetle diversity and density. This network has been established by the University of Delaware Cooperative Extension service to showcase 13 cover crop species (Tab. 1) throughout the State. We used the plots located in Middletown and Georgetown in order to get a state-wide idea of the impact of the cover crop species on the abundance and biodiversity of the ground beetles. In each location, cover crop species have been established in plots randomly distributed and repeated four times (see plot maps published online http://www.deccnetwork.com).

Table 1. List of the cover crop species to be tested in the laboratory.

Cover crop species	Plant family	Number of replications
Kale	Brassicaceae	10
Winter rape	Brassicaceae	10
Forage radish	Brassicaceae	10
Forage turnip	Brassicaceae	10
Crimson clover	Fabaceae	10
Hairy vetch	Fabaceae	10
Austrian winter pea	Fabaceae	10
Annual ryegrass	Poaceae	10
Cereal rye	Poaceae	10
Winter wheat	Poaceae	10
Winter barley	Poaceae	10
Spring oat	Poaceae	10

Ground beetle abundance and richness

To evaluate the populations of ground beetles, we deployed pitfall traps in each of the plots mentioned above. Captured beetles were brought back to the laboratory in containers with ethanol, counted and identified (to the finest taxonomic level possible). Collections will be conducted weekly from April to June.

To describe the impact of the cover crop species on the ground beetle populations, we will calculate two mathematical indexes commonly used in ecology.

(1) We calculated the species Abundance A hold by each cover crop species where A is simply the total number of individual ground beetled captured in each plot.

(2) We will calculate the species Richness R hold by each cover crop species where richness R is simply the total number of species captured per cover crop species.

$$R = \sum_{i=1}^{i} Sp_i$$

Impact on slugs

In addition, we captured slugs in the experimental plots to evaluate if there were any impact of the abundance of the predatory beetles on the number of slugs.

Results and Discussion. For both indexes, there was a strong difference between the two selected sites. The ground beetle abundance was approximately 20-fold higher in Middletown than in Georgetown ($p < 0.001$) and Middletown was ca. 10-fold richer than Georgetown ($p < 0.001$). This is likely due to the soil characteristics as well as to the differences in farming intensity between both locations, but this still has to be elucidated.

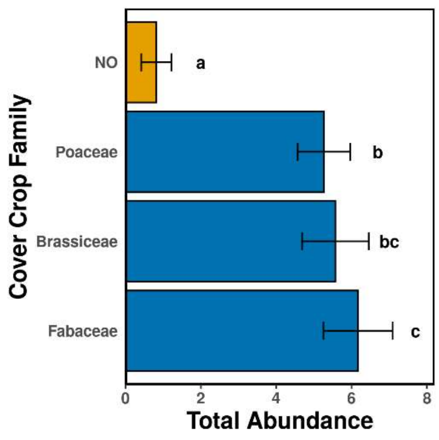

Figure 1. Total abundance of ground beetles per family of cover crop species. Bars indicate SEM and letters significant differences between treatments

As locations were different, we split the data in two and analyzed it separately. In Georgetwon, neither abundance nor richness of carab beetles was significantly different between cover crops families ($p = 0.167$, $p = 0.056$, respectively) and species($p = 0.476$, $p = 0.295$, respectively). In Middletown, there were significant differences in the abundance of carabs between cover crop families ($p < 0.001$, Fig. 1) where Fabaceae were hosting the most beetles. There were also significant differences in the abundance of carab beetles between cover crop species ($p < 0.01$, Fig. 2).

Still in Middletown, richness was not different between cover crop families (Fig. 3) yet significantly influenced by the cover crop species in use (p < 0.001, Fig. 4).

The number of slug captured was negatively correlated with the ground beetle abundance (Fig. 5), indicating a potential strong effect of ground beetle in slug management.

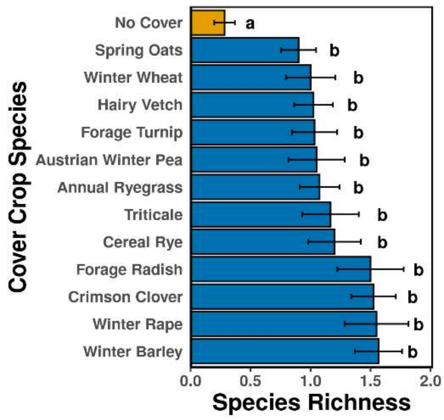

Figure 2. Total abundance of ground beetles per cover crop species. Bars indicate SEM and letters significant differences between treatments.

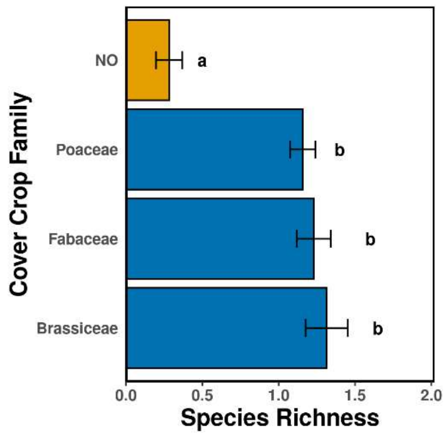

Figure 3. Total species richness of ground beetles per family of cover crop species. Bars indicate SEM and letters significant differences between treatments.

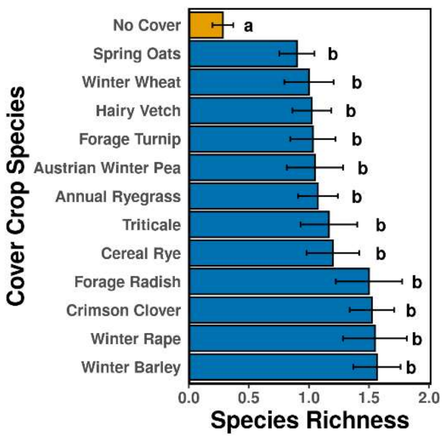

Figure 4. Total species richness of ground beetles per cover crop species. Bars indicate SEM and letters significant differences between treatments.

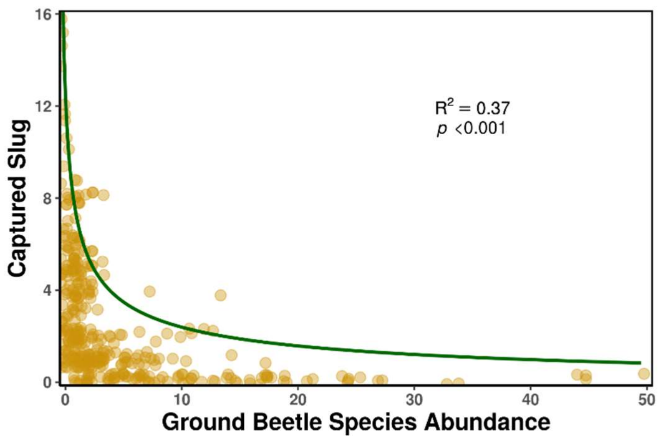

Figure 3. Total species richness of ground beetles per cover crop species. Bars indicate SEM and letters significant differences between treatments.

Conclusions. The use of cover crop impacts the natural occurrence of slug natural enemies with differences between cover crop families and species. Additionally, the more beetle were present, the less slug were captured. It can therefore be concluded that using the appropriate cover crop species could be highly beneficial in terms of functional biodiversity and mollusk pest management.

Outputs. This research was present during the Entomological Society of American annual meeting in St Louis in 2019. IH and BC are still working on the manuscript to publish the data in peer-reviewed journals.

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