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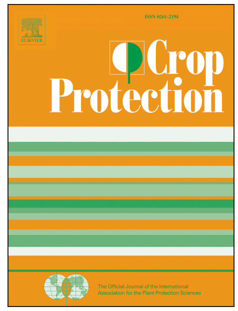

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Corresponding Author
Adrian J. Pekarcik
Department of Entomology
The Ohio State University
1680 Madison Ave.
Wooster, OH 44691
Phone: 440-223-4739
Fax: 330-263-3686
Email: ajpekarc@gmail.com

Active and passive sampling methods for grubs of the Asiatic garden beetle, *Maladera formosae* (Coleoptera: Scarabaeidae), in a corn-soybean rotation

Adrian J. Pekarcik, Amy L. Raudenbush, Eric Richer[1], and Kelley J. Tilmon

Department of Entomology, Ohio Agricultural Research and Development Center, The Ohio State University, 1680 Madison Ave., Wooster, OH 44691; [1]Department of Extension, The Ohio State University, 8770 OH-108, Wauseon, OH 43567

Abstract

Beginning in the mid-2000s, grubs of the Asiatic garden beetle, *Maladera formosae* (Brenske) (syn. *M. castanea* [Arrow]), emerged as significant early-season pests of field corn grown in sandy soils of the Great Lakes region. Overwintered grubs move towards the soil surface in springtime to resume feeding on roots, causing stand losses of up to 40%. Scouting for *M. formosae* is problematic as the grubs are subterranean, and the adults are nocturnal. The objective of this study was to evaluate sampling methods currently in use for other annual white grub species specifically for use with *M. formosae* grubs in corn production systems. In a series of two experiments, we evaluated the ability of the compact cutter, golf hole cup cutter, and wire-mesh bait station to detect *M. formosae* grubs and sense varying population densities. The cup cutter, which takes a deeper but smaller soil volume sample than the compact cutter, sampled more grubs per soil volume and was more sensitive to smaller grub populations. The bait station, a passive sampling technique, and cup cutter were both successful at detecting *M. formosae* before planting. However, the cup cutter is more adequate and economical since it can be used with less equipment in a single trip to the field. Identification of a standardized sampling methods will enable researchers to predict future infestations and ultimately lead to the development of economic threshold levels for *M. formosae* in row crop agroecosystems.

Keywords

Asiatic garden beetle, annual white grub, sampling methods, field crops, Scarabaeidae

Highlights

- Cup cutter is more sensitive to varying grub densities than compact cutter
- Bait station and cup cutter allow for passive pre-plant sampling of grubs in corn
- Cup cutter requires only one trip to the field and less supplies than bait station

1. Introduction

The Asiatic garden beetle, *Maladera formosae* (syn. *M. castanea* [Arrow, 1913]) (Coleoptera: Scarabaeidae: Melolonthinae) (Fig. 1), has been present in North America since 1921 (Hallock, 1929) and is historically a pest of turfgrass (Hallock, 1930), ornamentals (Hallock, 1930), and vegetables (Hallock, 1934). However, the grubs have recently emerged as a significant, annual, early-season pest of field corn (Fig. 2) in northern Indiana (Krupke et al., 2007), southern Michigan (DiFonzo, 2007), and northern Ohio (Hammond, 2013). As with many other annual white grub species (i.e., the entire life cycle is completed in one year), rising springtime temperatures stimulate overwintered second and third instars (Fig. 1B) to move towards the soil surface to resume feeding on roots until they pupate and mature into adults by summer (Tashiro, 1987). The upward migration and resumption of feeding coincides with the planting of corn and other field crops in the Great Lakes region. Grub feeding on fragile corn seedling roots causes plants to stunt, wilt, discolor, and ultimately die (Fig. 2), and plant stand losses in excess of 40% are not uncommon (Hammond, 2013).

It is difficult to scout for and distinguish white grub species since they occur in grub complexes that are comprised of several species, are subterranean, physically similar to the untrained eye, and cause similar feeding damage and symptoms (Potter, 1998; Vittum et al., 1999; Reding and Klein, 2007; Shetlar and Andon, 2012). The adults, which are easier to scout and identify, occur nocturnally during summer after root feeding has concluded and the grubs are no longer present (Hallock, 1932). Current management options are limited and rely primarily on the use of insecticides, yet products labeled for use against white grubs are either largely ineffective (Krupke et al., 2007; DiFonzo 2007; Richer and Michel 2016) or have not yet been evaluated specifically for this species in field cropping systems. It is commonly observed that grubs are not adequately controlled by even high rates of neonicotinoid seed treatments (Krupke et al., 2007; DiFonzo, 2007). Additionally, certain products like imidacloprid, thiamethoxam, and carbaryl used against white grub species in turfgrass have been evaluated under laboratory conditions and showed reduced efficacy against *M. formosae* relative to other white grub species (Koppenhöfer and Fuzy, 2003; Koppenhöfer, 2010; Morales-Rodriguez et al., 2010; Brandenburg and Freeman, 2012).

It is important to have effective sampling procedures to predict infestations prior to planting, to be used in research on economic injury levels and action thresholds, and to ultimately allow for the successful implementation of preventative pest management (Fleming and Baker, 1936; Yates and Finney, 1942; Youngman et al., 1993; McLeod et al., 1999; Youngman and Tiwari, 2004; Jordan et al., 2012). Annual white grubs are typically sampled either using a pre-plant bait station to attract grubs, or by physically sifting grubs from a known volume of soil (Fig. 3) (Youngman et al., 1993; Youngman and Tiwari, 2004; Jordan et al., 2012; Tiwari et al., 2019). The bait station is a pre-plant method used to scout for grubs early season. It works by planting corn on a wire mesh ledge a few weeks before the main crop and checking it after the corn has germinated to identify the ground dwelling species that overwintered in the field (Tiwari et al., 2019). This method provides a small window to identify and implement management tactics in response to infestations.

Another way to sample for grubs is to use active soil sampling methods where the contents of a known volume of soil are sifted and the contents analyzed. Three soil sampling techniques have been evaluated to monitor white grub species including the golf hole cup cutter, 'standard' and 'compact' soil cutter sampling methods. The golf hole cup cutter is primarily used in the turfgrass industry and takes a cylindrical soil core with 10.16 cm diameter and 15.24 cm depth (total volume = 1,236 cm^3) (Koppenhöfer, 2010). The 'standard' and 'compact' soil cutter methods take larger volumes of soil (9,439 and 4,195 cm^3, respectively) from a broader surface area but a shallower depth than the cup cutter (Jordan et al., 2012; Laub et al., 2018). Jordan et al. (2012) determined that the latter two methods sample similar numbers of grubs per soil volume and can predict spring grub population densities from fall sampling efforts in Virginia corn-soybean rotated fields (Tiwari et al., 2019). The golf hole cup cutter has not yet been evaluated for sampling white grubs in field cropping systems.

Prior to now there were no formal evaluations of sampling methods specifically for use with *M. formosae* grubs in field cropping systems. The objective of this study is to identify sampling methods that can both detect and sense varying densities of *M. formosae* grubs in corn-soybean rotated fields in northwest Ohio. In this study we assessed soil sampling methods including the 'compact' soil cutter, golf hole cup cutter, and a pre-plant baited station for *M. formosae* grubs. Identification of sensitive sampling methods for *M. formosae* grubs will enable farmers to prepare for future infestations and allow the best management strategies to be evaluated and implemented.

2. Materials and Methods

Sampling methods for *M. formosae* grubs were evaluated from 2017-2019 in three agricultural fields in northwest Ohio with known histories of *M. formosae* infestation (Table 1). At each field, sampling occurred within 40 plots (30 x 30 m) arranged in an 8 x 5 grid that was established over a 5-acre area where infestations were historically concentrated; the number of plots used varied by experiment. Corn and soybean were grown following commercial recommendations for the region with rows spaced 0.76 m and 0.38 m apart, respectively. Aside from insecticide and fungicide seed treatments that are standard on commercial seed, additional insecticide applications were not made. We compared two active sampling methods including the golf hole cup cutter (Fig. 3A) (hereafter referred to as 'cup cutter'), and compact soil cutter (Fig. 3B) (hereafter referred to as compact cutter). Then, we evaluated the most successful method against the bait station (Fig. 3C-D), a passive sampling method.

2.1 Experiment 1 – Compact Cutter vs. Cup Cutter

The cup cutter takes a cylindrical soil core with 10.16 cm diameter and 15.24 cm depth (total volume = 1,235.56 cm^3) (Koppenhöfer, 2010), while the compact cutter takes a larger volume of 20.32 cm x 20.32 cm x 10.16 cm (total volume = 4,195.09 cm^3) (Jordan et al., 2012). In 2017, all 40 plots were sampled weekly for a total of four times between 18 May and 14 June at the Fulton1 and Henry sites. By 21 June, we only observed pupae in our samples. On each sampling date we took one cup cutter and one compact cutter sample, spaced 3 m apart, within each plot such that each pair of samples was located approximately 30 m away from neighboring pairs. We chose this design based on golf course scouting recommendations for white grubs used to pinpoint areas of infestation (Grant, 1999; Dalthorp et al, 2000). We carefully sifted each soil sample in a tray in the field and counted the number of *M. formosae* grubs per sample. We recorded the number of *M. formosae* grubs (2^{nd} and 3^{rd} instars; Fig. 1B) in each sample. *Maladera formosae* grubs are distinguished from other white grub species by their pronounced maxillary stipes and aggressive behavior (Hallock, 1932)

2.2 Experiment 2 – Bait Station vs. Cup Cutter

The bait station design was adapted from Tiwari et al., (2019). Each station consisted of a 60.96 cm long by 7.62 cm wide wire-mesh (0.64 cm) strip bent medially at a 90-degree angle into a 5.08 cm deep furrow. We placed 20 untreated corn seeds evenly along the bend in the trap, then buried the trap with 2.54 cm soil and marked it with a flag. After two weeks, we evaluated each bait station by pulling it from the soil, sifting the soil contents from within a 7.62 cm radius around each station in a tray, and recording the number of grubs. At the time of bait station removal, we took a paired cup cutter sample approximately 3 m from each station and counted the number of grubs. We evaluated the cup cutter and wire-mesh bait station at the Fulton1, Fulton2, and Henry sites in 2018, and at Fulton1 and Henry in 2019. At each site, we evaluated both methods in 15 plots in 2018 and 10 plots in 2019. We set up all bait stations on 25 April in 2018 and 1 May in 2019. In 2018, the root and shoot lengths of each corn seedling from each bait station, as well as the root-to-shoot length ratio, were recorded to assess feeding damage. Few roots were damaged at each site during bait station removal across all sites; root losses were negligible and did not bias the overall evaluation.

2.3 Statistical Analysis

2.3.1 Experiment 1 - Compact Cutter vs. Cup Cutter

Prior to analysis, we first adjusted the number of grubs sampled with the cup cutter by multiplying by 3.395 to allow for equal comparisons based on soil volume since the two methods sample different volumes of soil [the compact cutter takes a 3.395-times larger soil sample than the cup cutter]. All statistical analyses were conducted using SAS 9.4 (SAS Institute Inc., 2013). We assessed the grub count data per plot (from both the compact cutter and cup cutter) for normality in separate analyses by site using PROC UNIVARIATE, and all datasets were non-normal ($P \leq 0.05$). We performed a square root transformation ($[x + 0.5]^{1/2}$) on the adjusted grub count datasets to account for their Poisson distributions and satisfy normality (Fry, 1999). In separate analyses for Fulton1 and Henry, we compared the transformed number of grubs sampled by the compact cutter to the cup cutter with respect to sampling date, sampling method, and date*method interaction with a repeated measures analysis of variance using PROC MIXED. We nested sampling method within plot, and designated block as a random effect. We performed mean comparisons using Tukey-Kramer's post hoc test with LS means ≤ 0.05.

We then determined whether grub captures from the two sampling methods were correlated (i.e., do both methods reflect the same variations in grub population density). We compared the average transformed capture rates for each compact cutter and adjusted cup cutter sample taken per plot with robust linear regression analysis using PROC ROBUSTREG with an M-estimation and default bisquare weighting function (i.e., non-zero residuals are somewhat downweighted). We chose robust regression to identify and account for influential outliers in the data set. Influential outliers are any data that significantly deviate from the other observations, while leverage points are any datapoints in the X-Y plane that are distant from others but fall within the extrapolated trendline (Chatterjee and Hadi 1986). When left unaccounted for, outliers and leverage points can increase error rates and variance, reduce normality, and skew model estimates (Osbourne and Overbay, 2004). We identified and accounted for zero influential outliers and six leverage points in the Fulton1 dataset, and seven influential outliers and four leverage points in the Henry dataset.

2.3.2 Experiment 2 – Bait Station vs. Cup Cutter

First, we assessed all grub count datasets for normality in separate analyses for each site-year combination as described in Experiment 1. We determined that none of the datasets were normally distributed, so we fit each dataset to various models using PROC GENMOD with a log-link function and determined that the negative binomial model was optimal for both Fulton1 ($X^2 = 42.26$, df = 47, $P = 0.6688$) and Henry ($X^2 = 36.84$, df = 47, $P = 0.8607$) grub data sets. We compared the average number of grubs sampled from the bait station and adjusted cup cutter of each plot using PROC GLIMMIX with a negative binomial distribution and the independent variables site, year, and the site*year interaction designated as fixed effects. We conducted mean comparisons using a simulated LS means at a $P \leq 0.05$ level. Because no grubs were sampled at Fulton2, we did not include it in the analysis. The number of grubs sampled by the bait station and cup cutter was similar among site ($F = 1.80$, df = 1, 96, $P = 0.1830$) and year ($F = 2.16$, df = 1, 96, $P = 0.1449$), so we reran the final model with site and year designated as random effects and sampling method as a fixed effect.

We conducted robust linear regression analysis with PROC ROBUSTREG to determine whether the bait station and the cup cutter attracted/sampled grubs at similar rates. We used the M-estimation and default bisquare weighting function. Prior to analysis, we performed a square root transformation ($[x + 0.5]^{1/2}$) on the grub count dataset to satisfy normality. We aggregated data from both sites since the site variable was previously found to be insignificant. Robust regression analysis identified and accounted for two outliers and six leverage points in the combined dataset.

We then evaluated bait station seedling plant growth characteristics datasets (i.e., root length, shoot length, root-to-shoot length ratio) for normality by site with Box-Cox transformation using PROC TRANSREG. We determined that the shoot length ($F = 7.43$, df = 1, 43, $P = 0.0092$) and root-to-shoot length ratio ($F = 48.00$, df = 1, 43, $P \leq 0.0001$) datasets had estimated lambda values (i.e., an indication of the power to which data should be transformed to satisfy the normality criterion) of zero and were log-transformed before further analysis. Root length data ($F = 36.91$, df = 1, 43, $P \leq 0.0001$) had an estimated lambda of one and were not transformed. We compared the average seedling root length, shoot length, and root-to-shoot length ratio per bait station in separate analyses using PROC GLIMMIX with a gaussian distribution model and site designated as a fixed effect. We conducted mean comparisons using a simulated LS means at a $P \leq 0.05$ level. We included data from Fulton2 in the analyses to act as a type of control (i.e., plants without grub feeding) to allow for a rough comparison. We are hesitant to consider Fulton2 a true control since we did not account for potential site-specific variation of local environmental conditions (e.g., precipitation, temperature, soil properties and health, etc.).

3. Results and Discussion

Maladera formosae emerged as a significant pest of field corn in northern Ohio, northern Indiana, and southern Michigan, within the last two decades (Krupke et al., 2007; DiFonzo, 2007; Hammond, 2013). Before this publication there were no formal evaluations of sampling methods specifically for use with *M. formosae* grubs and adults in field cropping systems.

3.1. *Experiment 1 – Compact Cutter vs. Cup Cutter*

At Fulton1 (Fig. 4A), the number of grubs captured per plot varied significantly over time ($F = 10.67$, df = 3, 308, $P < 0.0001$). We captured the most grubs per sample on 18 May, after which populations significantly declined by 31 May and remained low for the last two sampling dates. The cup cutter and compact method captured significantly different numbers of grubs per soil volume overall (F = 8.41, df = 1, 308, P = 0.0040). Overall, we sampled nearly twice as many grubs per soil volume with the cup cutter method compared to the compact method. We determined that differences in sampling method sensitivity were not dependent on time (F = 1.77, df = 3, 308, P = 0.1527), although multiple comparisons tests indicated that significantly more grubs were captured per soil volume during the week of May 31.

At Henry (Fig. 4B), grub populations were approximately half of that observed at Fulton1. The average number of grubs captured per plot was statistically similar across sampling dates (F = 1.06, df = 3, 148, P = 0.3683), although we sampled numerically more grubs on 18 May than at any other time during the study and observed the fewest grubs per sample on 14 June. Additionally, we sampled similar numbers of grubs per soil volume with the compact cutter and cup cutter throughout the experiment (F = 3.47, df = 1, 148, P = 0.0646). This trend did not vary with time (F = 1.25, df = 3, 148, P = 0.2945).

We observed a significant correlation between the cup cutter and compact cutter at both sites (Fig. 5). The strength of the relationship varied with site. At Fulton1 (Fig. 5A) where sampled grub populations were higher, there was a weaker, albeit significant, relationship between the two methods (R^2 = 0.1, $X2_{(1,40)}$ = 5.70, P = 0.0170). The cup cutter sampled 0.76 grubs per soil volume for every grub sampled by the compact cutter. However, when the compact cutter failed to detect grubs, the cup cutter is expected to sample at least 0.5 grubs. At Henry (Fig. 5B), we identified a strong positive association between the number of grubs sampled per soil volume by the compact cutter and cup cutter (R^2 = 0.5, $X2_{(1,20)}$ = 56.59, P < 0.0001); the cup cutter sampled 1.74 grubs per soil volume for every grub sampled by the compact cutter. These findings indicate that both methods are reflecting the underlying grub populations proportionally to each other, but that the cup cutter may be more sensitive to smaller grub populations than the compact cutter.

The main difference between the two methods aside from sample area is sample depth; the cup cutter samples 15.2 cm below the soil surface, or 5.1 cm deeper than the compact cutter. This is relevant because *M. formosae* grubs are known to occur further below the soil surface than other annual white grub species (Tashiro, 1987). Often, we observed grubs in the soil at the bottom of the hole from a cup cutter, suggesting they are even further down than what we were able to sample (personal observation, ALR, AJP). However, we do not know the relationship between *M. formosae* grub depth and feeding damage to corn seedlings. In turfgrass, *M. formosae* grubs are known to feed on roots lower underground than other grub species, causing less damage, thus warranting a high action threshold of 18-20 grubs per 0.1 m^2 (Vittum et al., 1999, Niemzcyk and Shetlar, 2000, Morales-Rodriguez et al., 2010). Do grubs preferentially feed closer to the surface on corn than they do in other systems like turfgrass? Feeding on nodal roots close to the kernel would eliminate the primary root system and ruin plant development, whereas feeding on lower lateral roots might allow for plant survival. Further work is needed to determine how grub density and depth influences damage to the crop. Additionally, it is unknown whether the cup cutter can be used to predict spring populations from fall sampling. Researchers in Virginia determined that the compact method can predict white grub populations in the spring from fall sampling (Jordan et al., 2012); in that system thresholds have been established for annual white grubs (including *M. formosae*) which can aid in predicting future economic loss.

3.2. *Experiment 2 – Bait Station vs. Cup Cutter*

In the second experiment, we confirmed that both the bait station and cup cutter could detect early-season *M. formosae* grubs, and that the bait station attracted significantly more grubs than the cup cutter was able to sample (F = 4.68, df = 1, 96, *P* = 0.0330). In general, we observed nearly 2.5 times more grubs around the bait station than in our cup cutter samples that were taken alongside bait station (Fig. 6). We also detected a correlation in grubs recovered from paired samples between the bait stations and cup cutters (Fig. 7) ($R^2 = 0.25$, $X2_{(1,50)} = 38.31$, $P < 0.0001$). We observed 1.1 grubs per bait station for every grub sampled with the cup cutter, suggesting that both methods are sensitive to the underlying grub population size.

Despite its ability to attract grubs and detect early-season infestations, the bait station has several inherent disadvantages compared to the cup cutter. The bait station requires more material and is difficult to set up and time consuming as it requires two trips the field for setup and then breakdown and evaluation 1-2-weeks later, depending on growing conditions. It is possible that the bait station attracted grubs from the surrounding soil that would otherwise have been captured by the cup cutter. Regardless, the cup cutter requires just one trip to the field and yields quick results in real-time relative to the bait station. Thus, it may be in the interest of the crop professional (farmer, crop consultant, extension educator, researcher, etc.) to use an active sampling approach that allows for systematic assessments and saves time and effort.

One advantage of the bait station is that it provides additional information with respect to corn seedling growth characteristics/damage in the face of varying grub density. The average corn seedling root length (F = 38.22, df = 2, 42, *P* < 0.0001), shoot length (F = 10.54, df = 2, 42, *P* = 0.0002), and root-to-shoot length ratio (F = 28.43, df = 2, 42, *P* < 0.0001) of each bait station significantly varied among sites (Fig. 8), with the most robust root and shoot growth at the location with the fewest grub (Fulton2). We hesitate to consider Fulton2 a true control since each field experienced different microclimatic variables (e.g., temperature, precipitation, secondary pests, etc.) that were not accounted for during this study. Nonetheless, these findings suggest that in the absence of grubs, seedlings at Fulton2 had longer roots and shoots than at Henry or Fulton1 where the average number of grubs per bait station was 0.7 and 2.9, respectively. The root-to-shoot length ratio was approximately 1 at Fulton2, but less than 1 at Henry and Fulton1 where roots comprised a smaller proportion of the total plant length. Regardless, future research is needed to assess the value of bait stations for evaluating the relationship between plant growth characteristics and grub density. It is also worth noting that the bait station and cup cutter detected other soil-dwelling insect pest species in addition to *M. formosae* including other annual white grub species like *Amphimallon majale* (Razoumowsky), *Anomala orientalis* Waterhouse, *Phyllophaga* sp. Harris, *Popillia japonica* Newman, in addition to wireworms (Coleoptera: Elateridae). It may be worthwhile to set up given the pest history of a given field.

4. Conclusions

This study reports the first evaluations of the compact cutter, cup cutter, and wire-mesh bait station as sampling tools specifically for *M. formosae* grubs in field corn of the Great Lakes region. We confirmed that both active soil sampling and passive bait station methods adequately detect *M. formosae* grub populations. The cup cutter was more sensitive to grub density than the compact cutter method, and requires fewer resources than the bait station. These results are useful because they provide sampling standards for an emerging pest, which will contribute to future studies on population biology, management tools, and economic thresholds – information that is still greatly lacking for this pest (Hammond, 2013). Otherwise, these methods may be beneficial for detecting and monitoring other agronomically relevant species.

5. Author Contributions

Conceptualization, AP, AR, ER, KT; Data curation, AP, AR, ER; Formal analysis, AP; Funding acquisition, ER, KT; Investigation, AP, AR, ER, KT; Methodology, AP, AR, ER, KT; Project administration, AP, KT; Resources, ER, KT; Software, KT; Supervision, AP, AR, ER, KT; Validation, AP, AR, ER, KT; Visualization, AP; Roles/Writing – original draft, AP; Writing – review & editing, AP, AR, ER, KT.

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List of Figures and Tables

Figure 1. Life stages of the Asiatic garden beetle, *Maladera formosae.* Egg and first instar on a penny (A), and second (bottom) and third (top) instars next to a dime (B). Photo credits: (A) Chris DiFonzo, Michigan State University, (B) Adrian Pekarcik, The Ohio State University.

Figure 2. Signs and symptoms of *M. formosae* grub feeding on roots of corn seedlings. Active second and third instar feeding on roots (A) causes plants to wilt and discolor (B), and ultimately die causing corn stand losses sometimes in excess of 40% (C). Photo credits: A-C) Amy Raudenbush, The Ohio State University.

Figure 3. Sampling methods evaluated for *Maladera formosae* grubs. Golf hole cup cutter (A), compact cutter (B), and the wire-mesh bait station set in a 5.2 cm deep furrow with 20 corn seeds placed equidistant from each other during setup, (C) and prior to breakdown after two weeks (D).

Figure 4. Average number of *Maladera formosae* grubs per sampling method (i.e., compact cutter and cup cutter) for each sampling date at Fulton1 site near Wauseon, OH (A) and at Henry site near McClure, OH (B). Uppercase letters represent significant differences ($P < 0.05$) in the total number of grubs sampled by date. Lowercase letters symbolize significant differences between the two methods on that specific date. Samples were not taken during the week of May 25 due to time limitations.

Figure 5. Robust linear regression assessing the relationship between the average number of *Maladera formosae* grubs sampled per soil volume for each cup cutter and compact cutter pair across all sampling periods in 2017 at Fulton1 (A) and Henry (B) sites in northwest Ohio. Fulton1 and Henry were previously planted to soybean and corn, respectively. The relative size of each datapoint corresponds to the number of samples with those values.

Figure 6. Average number of *Maladera formosae* grubs attracted to each bait station and sampled by each cup cutter per plot from Fulton1 and Fulton2 sites in northwest Ohio in 2018 and 2019. Uppercase letters represent significant differences ($P < 0.05$).

Figure 7. The relationship between the number of *Maladera formosae* grubs sampled by or near each cup cutter and bait station pair, respectively, evaluated at Fulton1 (X) and Henry (□) sites in northwest Ohio in spring 2018 and 2019.

Figure 8. Average root (upper green bars) and shoot (lower tan striped bars) lengths per corn seedling from each bait station after two weeks in the field at Fulton1, Fulton2, and Henry sites in northwest Ohio in spring 2018. Uppercase and lowercase letters indicate significant differences ($P < 0.05$) in shoot length and root length, respectively, among sites. The number of grubs sampled per bait station at Fulton1, Fulton2, and Henry sites averaged one, zero, and three, respectively.

Figure 1. Color

Figure 2. Color

Figure 3. Color

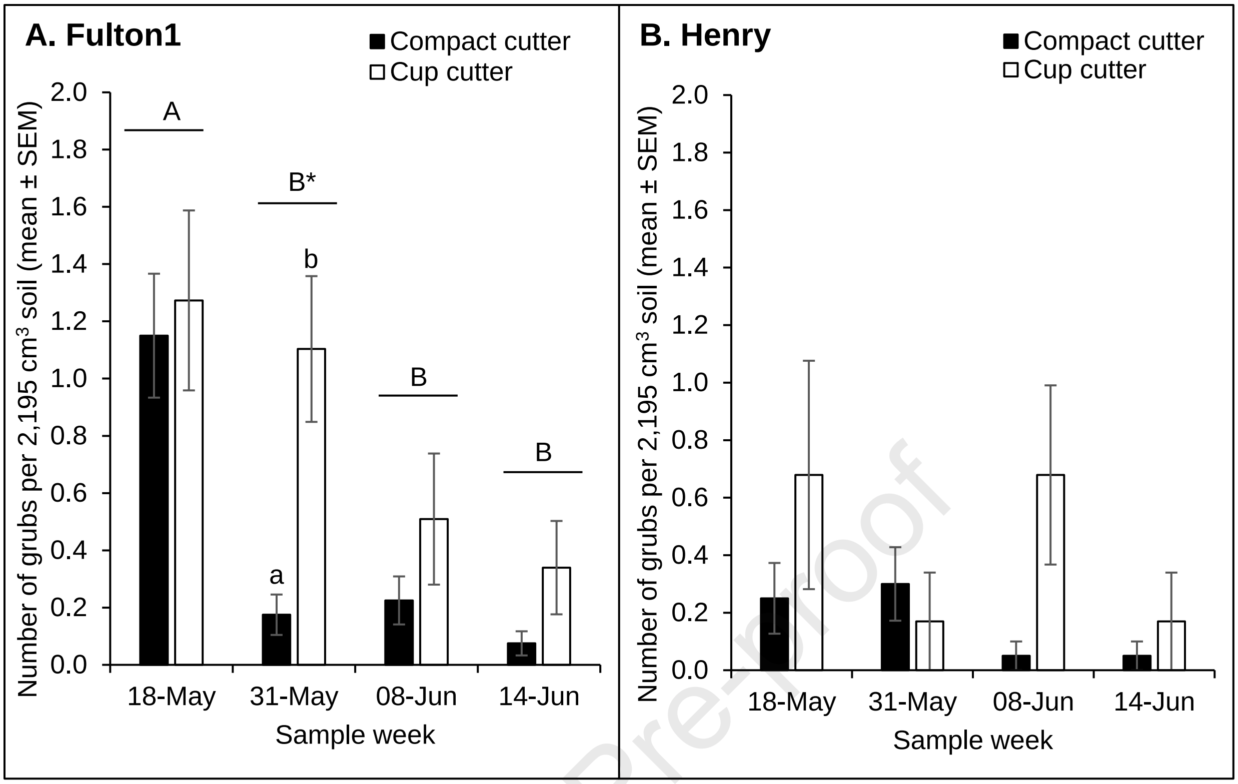

A. Fulton1
Compact cutter
Cup cutter
Number of grubs per 2,195 cm³ soil (mean ± SEM)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
A
B*
B
B
a
b
18-May
31-May
08-Jun
14-Jun
Sample week
B. Henry
Compact cutter
Cup cutter
Number of grubs per 2,195 cm³ soil (mean ± SEM)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
18-May
31-May
08-Jun
14-Jun
Sample week

Figure 4.

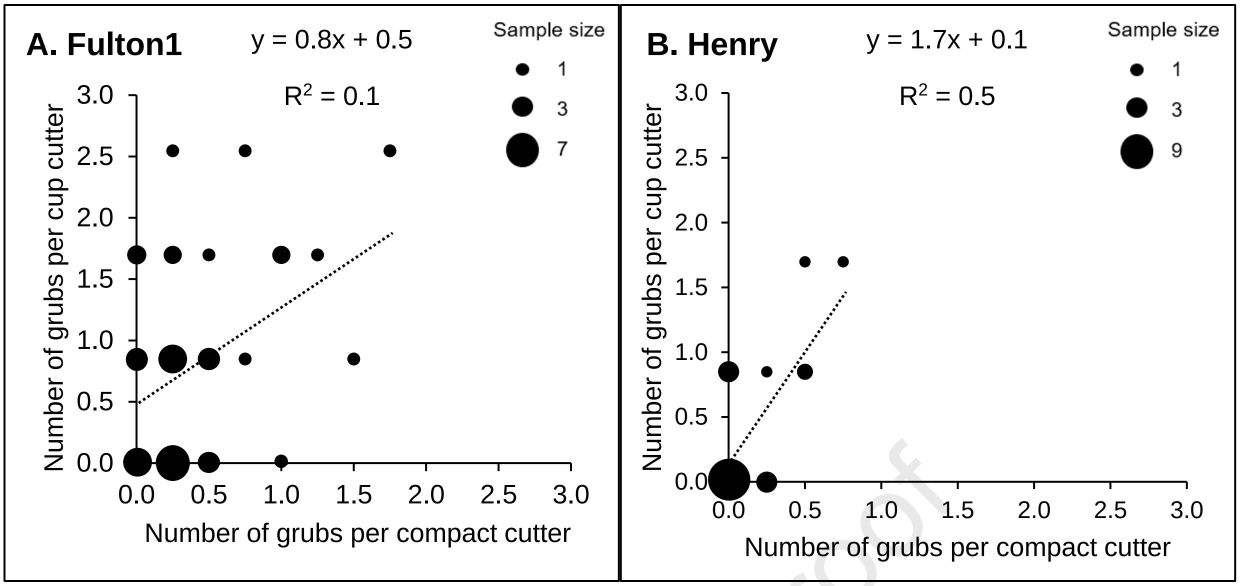
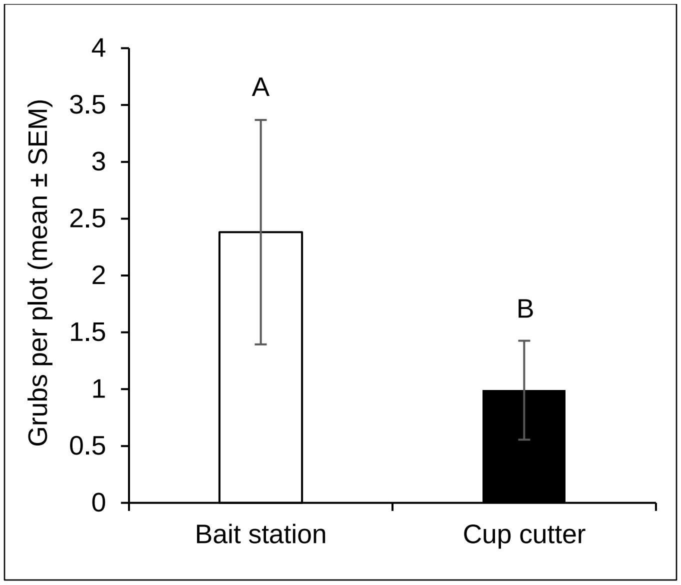
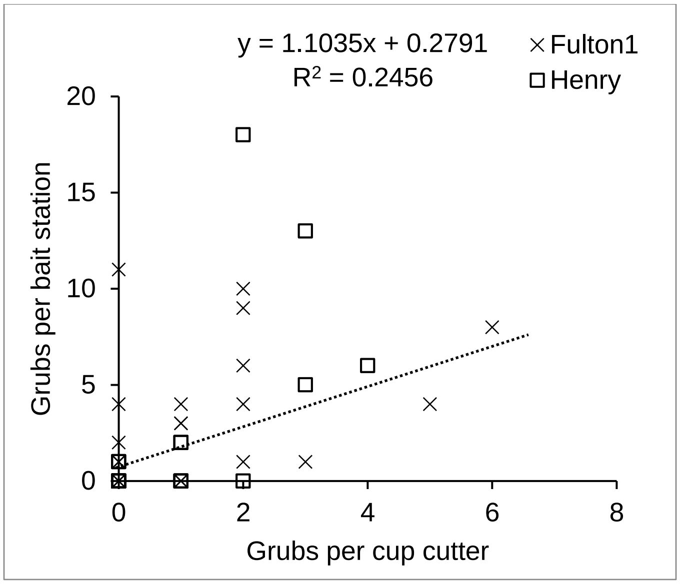

A. Fulton1
y = 0.8x + 0.5
R2 = 0.1
Sample size
1
3
7
Number of grubs per cup cutter
Number of grubs per compact cutter
0.0
0.5
1.0
1.5
2.0
2.5
3.0
B. Henry
y = 1.7x + 0.1
R2 = 0.5
Sample size
1
3
9
Number of grubs per cup cutter
Number of grubs per compact cutter

Figure 5.



442

443 **Figure 6.**

444 

445 **Figure 7.**

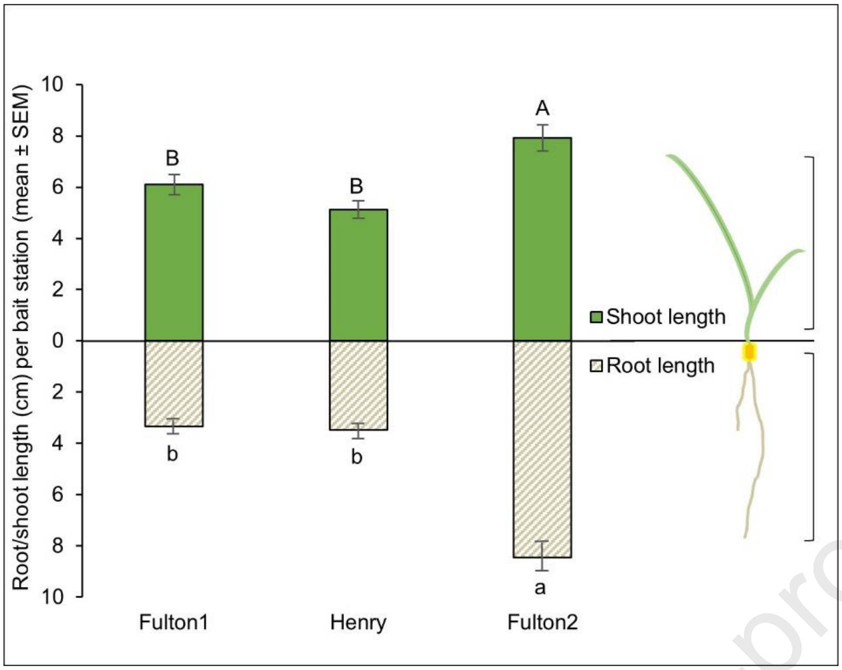


Figure 8. Color

Table 1. Field locations used for *Maladera formosae* grub sampling in northwest Ohio from 2017 to 2019. Sampling method abbreviations are as follows: BS = wire-mesh bait station; CC = golf hole cup cutter; CS = compact soil cutter.

Site name	Latitude, Longitude	Nearest city/town	Year	Previous crop	Crop	Grub sampling methods
Fulton1	41.617739, -84.134506	Wauseon, OH	2017	Soybean	Corn	CM, CC
			2018	Corn	Soybean	CC, BS
			2019	Soybean	Fallow	CC, BS
Fulton2	41.599141, -84.145894	Wauseon, OH	2018	Corn	Fallow	CC, BS
Henry	41.385992, -83.960931	McClure, OH	2017	Soybean	Corn	CM, CC
			2018	Corn	Soybean	CC, BS
			2019	Soybean	Corn	CC, BS

Highlights

- Cup cutter is more sensitive to varying grub densities than compact cutter
- Bait station and cup cutter allow for passive pre-plant sampling of grubs in corn
- Cup cutter requires only one trip to the field and less supplies than bait station

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

All authors have substantially contributed to drafting this manuscript and approve of it for submission as a research article. The authors have no competing interest We confirm that this manuscript has not been previously published and is not currently under consideration by any other journal. Additionally, each author has approved the entire content of this paper and have agreed to Crop Protection's submission policies. No funding was received for conducting this research. To the best of our knowledge, the named authors have no conflict of interest or permissions information, financial or otherwise.

Adrian Pekarcik, Ph.D., on behalf of the coauthors