

## ABSTRACT

Title of Thesis: INFLUENCE OF A NATIVE INSECTARY  
PLANT, CHAMAECRISTA FASCICULATA  
(MICHX.) ON ORGANIC FIELD CORN AND  
ARTHROPOD COMMUNITIES

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Increasing plant diversity in conventionally monoculture agrosystems has been promoted as a method to enhance beneficial arthropod density and efficacy, suppress herbivory and provide a range of ecosystem services. I investigated the pest suppressive potential and economic impact of plant diversification in organic field corn. The experiment consisted of two treatments, corn grown in monoculture (C) and bordered by strips of partridge pea (PP). Pest and natural enemy populations, corn damage, yield, and profits were compared among treatments. Natural enemy and herbivore arthropod populations were affected by treatment and distance from plot border. Corn damage due to pests was also affected by treatment and location, but did not significantly affect yield. Yield in monoculture plots was generally greater than in PP but did not result in greater profit. Pest and natural enemy arthropod abundances were elevated in partridge

pea treatment borders, but these populations did not consistently diffuse into plot interiors. The potential causes and implications of findings are discussed.

INFLUENCE OF A NATIVE INSECTARY PLANT, CHAMAECRISTA  
FASCICULATA (MICHX.) ON ORGANIC FIELD CORN AND ARTHROPOD  
COMMUNITIES

by

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## Dedication

To my parents and my grandfather, for their support and inspiration, and without whom I could not have accomplished this work.

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# **Chapter 1: Effects of flowering partridge pea *Chamaecrista fasciculata* (Michx.) on stink bugs, grain quality, and yield in organically grown field corn.**

## ***Abstract***

Increasing plant diversification has been advocated as a method to decrease pest colonization and enhance natural enemy density and efficacy. I investigated the pest suppressive potential and economic impact of increased plant diversification in field corn. The experiment consisted of two treatments, corn grown in monoculture (C) and bordered by strips of partridge pea (PP). Stink bug population, egg mass fate, corn damage, yield and profits were compared among treatments. Stink bug numbers were not impacted by treatment, but were influenced by corn stage. The impact of corn stage varied among experimental sites and study years. Stink bug egg mass fate was affected by treatment and distance from plot border. Overall mortality of stink bug eggs was high ( $\approx 85\%$ ). Mortality was higher in monoculture compared to PP plots. Corn damage due to stink bug, sap beetle, European corn borer and corn earworm was affected by treatment and location, but did not significantly affect yield. Stink bug and European corn borer damage was consistently greater at plot borders than plot interiors. However, across all damage types, C plot interiors suffered greater damage in 2/3 of each year/site combinations, compared to PP. At plot borders, damage levels were variable according to treatment. Yield in monoculture was generally greater than in PP but did not

result in greater profit. The potential causes and implications of findings are discussed.

## ***Introduction***

Corn (*Zea mays* L.) is a major component of the agricultural industry in the US. As the world's largest corn producer, 10-20% of the total annual corn produced in the US is exported to the global market (USDA-ERS 2016). US corn acreage has increased more than 5 million acres over the past decade due in part to an increased demand for ethanol and feedstock. This has led to severe changes in agricultural landscapes as well as land-use patterns and practices throughout the US (Malcolm et al. 2009). These changes have prompted concerns regarding the impact of land management practices such as monocropping and agricultural intensification on the environment. In response, consumer demand for organically produced food products has steadily increased over the past decade (Greene 2013). Seen as a more ecofriendly method of farming, certified organic corn has experienced the greatest growth among major field grain crops grown in the US (McBride and Taylor 2015) and has since become a more mainstream commodity.

Fueled by economic incentives and biotechnology advancements, corn is increasingly grown as a monoculture in the US (Wallander et al. 2011; Plourde et al. 2013). The intensification of corn and biofuel production is associated with high-energy inputs, including fertilizer and insecticide (Fausti et al. 2012; Fausti 2015). However, monocultural farming, agriculture intensification and using chemicals across broad agricultural landscapes have regional consequences (Bianchi et al. 2006; Culman et al. 2010). Agroscape simplification is linked to increased pest pressure and insecticide applications (Meehan et al. 2011).

Additionally, widespread use of genetically modified crops creates greater risk for pest outbreaks and pesticide resistance (Altieri 2009). Increasing farmscape complexity by using tactics such as cover cropping, flowering strips, or beetle banks has the potential to help manage arthropod pests in ways that are less disruptive to the environment (Landis et al. 2000; Koji et al. 2007; Pease and Zalom 2010; Nilsson et al. 2012; Hooks et al. 2013). However, studies investigating effects of increased habitat complexity on agroecosystems have focused mainly on their impact on herbivores and natural enemies and few have included an assessment of their impact on profits, crop yield and quality or provided an economic assessment of cost for farmer adoption (Cullen et al. 2008; Jonsson et al. 2010). This is paramount as farmers' willingness to adopt such practices will center on their ability to enhance yields and/or profits.

A multitude of pests can attack organic field corn and result in economic loss including the European corn borer, corn earworm, sap beetle, and stink bug. These pests can cause yield loss, quality reduction and vector mycotoxigenic species to corn, which can also significantly reduce yield quality (Widstrom 1979; Dowd 1995; Ni et al. 2011). Stink bugs frequently damage vegetative and reproductive parts of crops (Zobel et al. 2016), and corn is one of the first crops available for stink bugs to feed upon in the southeast US (Tillman 2010). Exposure to stink bugs can cause termination of and/or reduced growth and quality loss of corn (Apriyanto et al. 1989; Ni et al. 2010; Cissel et al. 2015). Though stink bug pest status in corn is well known (Tillman 2010; Herbert and Toews 2011; Tillman et al. 2014), information regarding their damage to corn

grain is limited (Ni et al. 2010). Stink bugs (Hemiptera: Pentatomidae) have caused millions of dollars in annual losses from reduced yields and increased management costs in major agronomic and vegetable crops (McPherson and McPherson 2000). Invasive stink bugs continue to spread globally, exacerbating damage by native stink bugs in areas where they were of limited concern (Haye et al. 2015). For example, stink bugs have become of greater concern in Mid-Atlantic States since the detection of the invasive brown marmorated stink bug, *Halyomorpha halys* (Stål) in the mid 1990s (Hoebeke and Carter 2003; Leskey et al. 2012).

Egg parasitoids are known to be important stink bug natural enemies (Jones et al. 2014; Koppel et al. 2009; Tillman 2009, 2010; Herlihy et al. 2016) and several generalist predators such as praying mantises, wheel bugs, robber flies and spiders use stink bugs as prey (Stam et al. 1987; van den Berg and Cock 1995; Rice et al. 2014). Various flowering plants have shown promise for utilization in conservation biological control programs (Thomas et al. 1993; Baggen et al. 1999; Hickman and Wratten 1996; Symondson et al. 2002). Flowering borders may be used to increase abundances of parasitoid and predator taxa in grain crops (Zehnder et al. 2007; Jonsson et al. 2010). Furthermore, it was suggested that using conservation biological control to enhance the effectiveness of introduced and indigenous natural enemies may provide the most promising long-term solutions for landscape-level reduction of *H. halys* populations (Leskey et al. 2012). Parasitoid and predaceous arthropod populations were increased by more than 50 and 75% in corn plots bordered with

strips of partridge pea and purple tansy (*Phacelia tanacetifolia*), respectively, compared with monoculture plots (Moore and Dively 2010). Enhanced vegetative diversity increased predator diversity and predation of European corn borer, *Ostrinia nubilalis* (Hubner) and stink bug eggs in sweet corn and tomatoes (Bickerton and Hamilton 2012; Morandin 2014). Nevertheless, limited research has been conducted to specifically increase the density and efficacy of stink bug natural enemies in field crops.

Partridge pea has historically been used in agricultural systems as a leguminous cover crop or honey plant to attract and provide resources for honey bees and serve as a buffer between fields (Atkins and Young 1941, Morris 2012). Partridge pea has been recommended for widespread use by USDA Natural Resources Conservation Service (NRCS) as a conservation plant that can promote soil stabilization, control erosion, serve as food for wildlife and be used as a cover crop (Houck 2006). In Maryland, it is suggested for use in riparian buffer strip plantings (Tjaden and Weber 1998). Partridge pea attracted diverse faunas of predators and parasitoids to nearby soybean fields (Moore and Dively 2010) and has been advocated for usage as an insectary plant (Morris 2012, Portman et al. 2010). Additionally, partridge pea may intercept stink bugs that would otherwise colonize adjacent soybean plantings (Jones and Sullivan 1982). Research suggests that legumes, such as partridge pea, may serve concomitantly as an insectary plant and trap crop by enhancing populations of natural enemies and attracting pests away from nearby cash crops (Jones and Brewer 1987; Panizzi and Slansky 1991; Panizzi 1997). Thus, partridge pea may



be of benefit to field corn producers who are impacted by stink bugs and other arthropod pests.

The objective of this study was to determine the impact of growing a flowering plant on arthropods inhabiting corn fields. I hypothesized that partridge pea would attract beneficial arthropods known to attack stink bug eggs, which would subsequently reduce stink bug populations. This would result in decreased damage to corn ears and greater yield. Specifically, I tested whether bordering field corn with partridge pea would: (i) impact overall pest populations; (ii) influence stink bug egg mortality; and (iii) affect corn grain quality and yield, and to determine if (iv) there is an economic benefit of bordering organic field corn with partridge pea strips.

## ***Methods and Materials***

### **Field experiment sites and layout**

This study took place at the University of Maryland's Western Maryland Research and Education Center at Keedysville (WM, N 39° 30' 34.271", W 77° 44' 0.128") during the 2014 and 2015 growing seasons and at the Central Maryland Research and Education Center at Beltsville (CM, N 39° 0' 44.993", W 76° 49' 33.221") during the 2015 growing season. Fields used at study sites were under organic transition. At each farm site, the study was organized as a randomized complete block design with four replicates. Each block consisted of two treatments: 1) corn with rows of partridge pea planted along their borders (PP), and 2) corn planted as monoculture without partridge pea for control (C) (Fig. 1). Each block ( $\approx 85 \times 14$  m) was separated by a minimum of 180 m.

Individual corn plots of 24 (WM) or 18 (CM) corn rows were no-till drilled (76.2 cm row spacing) into a mowed rye (*Secale cereale* L.) - crimson clover (*Trifolium incarnatum* L.) - hairy vetch (*Vicia villosa* Roth) cover crop mix in 2014, and a mowed rye-crimson clover cover crop mixture in 2015. Within blocks, PP and C plots were separated by a minimum of 60 m of regularly mowed, natural vegetation to reduce interference among treatments. Partridge pea (3 x 13.8 m) was initially drilled into lightly disked soil at a distance of  $\approx$  1 m from outermost corn rows with intra-row spacing of 18 cm. The corresponding field edge of control plots consisted of naturally occurring vegetation that was maintained by regular mowing. Rows of sudangrass (*Sorghum bicolor* x *S. bicolor* var. *sudanese*) (3 x 18 m) were drilled at the center of the bare-ground area between treatment plots to further isolate the two treatments. Each block was bordered by forest on one edge and either conventionally grown soybean or corn along the opposite edge.

Corn and sudangrass were planted 27 May 2014 at WM and 22 and 23 May 2015 at CM and WM, respectively. Partridge pea was planted on 31 May 2014 at WM and 23 May 2015 at CM. The partridge pea was not replanted in 2015 at the WM site as it reseeded itself and completely covered the 3 x 13.8 m ground area by time of corn planting.

At WM, the corn and sudangrass were fertilized with 3:2:3 (N, P<sub>2</sub>O<sub>5</sub>, K<sub>2</sub>O) pelleted organic poultry manure (Perdue Agri-recycle Microstart 60) at a rate of 2767.6 kg/ha on 7 and 8 July 2014 and fertilized with 4:3:2 pelleted organic poultry manure (Crumbled Pellets, Herbruck's Poultry Ranch, Inc.) at a rate of

4447.9 kg/ha on 22 June 2015. At CM, the corn and sudangrass were fertilized with 4:3:2 pelleted organic poultry manure (Crumbled Pellets, Herbruck's Poultry Ranch, Inc.) at a rate of 4472.6 kg/ha on 23 and 26 June 2015.

Weeds were managed in corn plots with the help of cover crop residue that remained on the surface following mowing and push mowers and weed trimmers were used as needed. Partridge pea stands were hand weeded as needed during the initial three weeks after planting prior to canopy closure. Plots were irrigated via natural rainfall events.

### **Stink bug numbers and egg production**

To determine the target pest population species identity, abundance and distribution, stink bug numbers were estimated from a 3 m segment selected randomly from every other corn row. This allowed for weekly assessments of all study sites to be conducted throughout the plot, however, this technique may have underestimated the total stink bug population in the corn fields. Entire corn plants within the 3 m sampling area were visually inspected for stink bugs. Stink bugs were counted and identified to species and classified according to their stage: egg, early nymph (1st instar), mid nymph (2nd - 3rd instar), late nymph (4th - 5th) and adult. Counts were conducted at 7-day intervals beginning when stink bugs were first encountered in plots and ending after the corn reached the hard dough stage which corresponded to when stink bugs were no longer found. On each sampling date, corn stage was recorded to account for effects of varying food suitability at different corn stages (Ni et al. 2010) and to determine if treatment effects differ according to corn stage. Corn developmental stages were

classified as early-middle vegetative (VE-V6), late vegetative (V7-V9), early reproductive (VT-R2, or tassel, silk and blister), and middle-late reproductive stages (R3-R6, or milk, dough, dent, and black layer).

### **Mortality and parasitism of pest egg masses**

All economic pest egg masses were searched for and monitored throughout the season to monitor for differences in successful hatching and/or mortality fates due to treatment.

### **European corn borer**

Corn plants within each row were searched weekly for European corn borer (ECB) eggs. The approximate age (fresh, 1-2 day old, blackhead stage), condition, total number of egg masses found and their locations were recorded similarly to Kuhar et al. (2002). If found, the locality of at least 10 ECB eggs in each plot was marked on the opposite leaf surface with a permanent marker (Kanour and Burbutis 1984). Flagging tape was also placed on the leaf to help identify locations of marked egg masses. Marked egg masses were monitored at  $\approx 3$  day intervals to determine their fate. Eggs were categorized similar to Andow (1990) as hatched, unhatched, killed by a chewing predator, killed by a piercing-sucking predator, or parasitized. Additional categories included unknown mortality (eggs that did not hatch, but showed no signs of predation or parasitism), and missing (egg masses that disappeared from the plant after they were initially found). Black ECB egg masses during development in the field indicated that eggs were parasitized (Flanders 1937). All discolored egg masses were retrieved by cutting around the leaf section bearing the egg mass. Egg

masses were placed into petri dishes and stored in an incubator (27 °C, 70-75% RH, 12:12 LD) in the laboratory until eclosion or emergence of adult parasitoids (Kuhar et al. 2002).

### **Stink bug**

All corn plants were searched weekly for stink bug eggs. When stink bug egg masses were found, their location was marked by circling the mass on the corn leaf with a permanent marker and tying a ribbon around the leaf axial where it attached to the corn stalk. When located, egg mass location was recorded by row. Egg location was converted to distance from plot border to the innermost plot rows (i.e., rows 1-12 (WM) and 1-9 (CM)). Egg masses were monitored weekly until the fate of each egg was determined. Egg fate was classified similarly as described by Tillman (2010): 1) missing - eggs disappeared from leaf surfaces before their fate could be determined, 2) parasitized - mortality due to parasitic wasp, 3) predation - mortality by predator, in which the egg appears shrunk or collapsed or egg chorion is torn, 4) unknown - eggs did not hatch, but showed no evidence of predation or parasitism, and 5) hatched - stink bug nymph successfully emerged from egg via a characteristic exit hole. Eggs fed on by chewing predators were distinguished from those eaten by piercing-sucking predators. During each sampling occasion, if predators or parasitoids were found on or in the vicinity (next to the egg mass) their identity and activity was recorded. A small percentage of eggs that displayed signs of parasitism were removed and brought back to the lab. To determine the species composition of

parasitoids actively parasitizing stink bug eggs, the parasitoids that egressed in the lab were keyed out and identified to species.

### **Corn quality and yield**

To evaluate effects of partridge pea on corn quality and yield, ears were hand harvested at maturity, approximately 2-4 weeks after the corn reached the R6 stage or when kernel moisture content was approximately 15%. These samples allowed for estimates of profit and cost; however, the estimates may be limited in their ability to be extrapolated to conventionally sized fields due to the small plot size.

Given previously reported edge effect patterns of stink bug colonization (Tillman et al. 2014; Venugopal et al. 2014), ears were collected from the edge rows and interior rows and rated separately for damage. Approximately 25 consecutive ears were removed from each of the outer two rows on each side of plots (i.e., four rows total). If there were not enough ears in the two border rows, they were taken from the outer third row. From the interior rows, approximately 20 consecutive ears were collected from each of the innermost six rows. To avoid possible additional edge effects present (perpendicular to rows) in small plots, corn plants located within the initial and final 2 meters of each corn row were not harvested. Ear samples taken from the interior and field edge regions of each plot were used for grain quality analysis.

A total of 1600 harvested ears were inspected each year/site for stink bug, sap beetle, European corn borer and/or corn earworm, and associated damage

(see Appendix A). Corn earworm and European corn borer damage was measured as  $\text{cm}^2$  of kernels consumed, and site of damage (ear tip, upper ear, lower ear) recorded. Sap beetle damage was recorded as number of damaged kernels (kernels opened and hollowed out). To measure stink bug damage, each kernel with distinctive discoloration or scarring caused by stink bug feeding was counted and recorded (Venugopal et al. 2014).

Estimates of grain yield were determined from ear samples from the interior rows. The number of plants was recorded for each inner row length, and the average was expressed as plant density per  $\text{m}^2$ . After damage ratings were completed, a randomized subsample of 10 ears from the interior rows of each plot was weighed, hand shelled (Decker Manufacturing) and measured for moisture content (Dickey John GAC 2100 Grain Moisture Tester) (Lauer 2002). To calculate the yield of grain dry matter, the average kernel weight (g)/ear was multiplied by the average plant density per  $\text{m}^2$  times 1000, and converted to total metric tonnes per hectare, adjusted to 15.5% moisture based on the industry standard.

## **Economic assessment**

Corn grain cost and profit analysis was performed using budgets published by University of Maryland Extension (Beale et al. 2014; 2015), which included gross profit, variable costs, and fixed/overhead costs (Appendix B). This analysis allows for accurate comparison to published profit and costs in Maryland, but is limited in inference to other states and regions. Variable costs

consisted of establishment of cover crop: cover crop, corn and partridge pea (in PP treatment) seeds, fertilizer and lime applications, soil testing, crop insurance, drying fuel and interest on operating capital. Fixed/overhead costs included consist of all variables used in research plots, with some additional costs (e.g., vertical tillage, hauling) that were included to be as accurate as possible (Appendix C). Profits from corn grain yields were calculated using an actual price for organic field corn received by growers in Maryland in 2014. Actual variable costs at each site and year were used in calculations, but fixed/overhead costs were kept constant between treatments to perform a realistic evaluation. Maryland custom rates published by University of Maryland Extension were used as a proxy for all field operation costs for the corresponding year (Dill 2013; 2015). The average rental payment/acre in 2014 for Conservation Reserve Program enrollment in Maryland (\$154.89/acre) (USDA-FSA) was used for both years of the study. A ratio of 0.15:1.0 ha of partridge pea to corn was planted in this study, and the estimated payment was adjusted accordingly. To calculate the net profit, the sum of total variable and fixed costs were subtracted from the gross profit.

### ***Statistical Analyses***

Stink bug abundances were assessed as a generalized linear mixed model (GLMM) with a Poisson distribution (logit link) with treatment and corn growth stage as fixed effects. Block and treatment within block were included as random factors to account for differences among blocks and repeated measures of plots. Model was weighted by number of sampling events included in each



growth stage. Separate models were run on combined stink bugs and individual stink bug species that were present in densities high enough to be statistically relevant. Where there was a significant interaction between treatment and stage, Tukey's HSD (honest significant difference) test was applied to determine differences in mean densities between stages in both levels of treatment. Stink bug nymphal stages were recorded but were pooled for analysis due to low overall density.

Stink bug egg mass fate was modeled as a GLMM with a binomial distribution (logit link) with treatment and distance as fixed effects. The same random effects were included to account for blocks and repeated measures. The response variable was the proportion of 'successes' for each egg mass, weighted by egg mass size. Each fate type, including missing egg masses, was analyzed separately.

Damage to corn ears was modeled as a GLMM with a Poisson distribution (logit link), with damage by stink bug, sap beetle, European corn borer, and corn earworm analyzed separately as a function of treatment and harvest location (i.e., interior or border rows). The same random effects were included to account for blocks and repeated measures.

Differences between estimated yields were modeled as a linear mixed model (LMM) with treatment as a fixed factor. Harvest location was also included as a fixed effect for yield estimates in 2015 but was not measured in 2014. For these analyses, only block was included as a random factor.

The effect of treatment on net profit was modeled with a LMM, with site, year and block included as random effects.

All analyses were conducted using R software v3.2.4 (R Core Team 2016). LMMs and GLMMs were built using the functions *lmer* and *glmer* in the package 'lme4' (Bates et al. 2015). ANOVAs were performed using function *Anova* in the package 'car' (Fox and Weisberg 2011). Tukey's HSD was performed using the function *glht* in the package 'multcomp' (Hothorn et al. 2008). Predicted values were extracted using the function *allEffects* in the package 'effects' (Fox 2003). Data manipulation was performed using the packages 'plyr' (Wickham 2011) and 'reshape2' (Wickham 2007).

## **Results**

### **Stink bug abundance by species**

In 2014, a total of 345 stink bugs were found at WM. They consisted primarily of (68%) brown stink bugs (BSB), *Euschistus servus* (Say), (16%) brown marmorated stink bugs (BMSB), and (13%) spined soldier bugs (SSB), *Podisus maculiventris* (Say). The remaining 3% of stink bug species sampled included red shouldered stink bugs, *Thyanta custator* (Fabricius), rough stink bugs, *Brochymena* spp., green stink bugs, *Chinavia halaris* (Say), and rice stink bugs, *Oebalus pugnax* (Fabricius). In 2015, the 1055 stink bugs found in WM were primarily (92%) BSB, while the remaining included (3%) BMSB, (4%) SSB and (1%) dusky stink bugs, *Euschistus tristigmus* (Say). In 2015, 624 total stink bugs were found at CM. They consisted primarily of (86%) BSB, (7%) SSB, (7%) BMSB, whereas the remaining included rice stink bugs and dusky stink bugs.

Across years and sites, BSB was the only species abundant enough to conduct a separate analysis, and was the primary component of the total population.

### **Treatment effects on stink bug abundances**

There was no main effect for the partridge pea treatment on stink bug abundance at WM or CM during the two year study. However there was an effect of corn growth stage on total stink bug abundance at WM in 2014 ( $\chi^2(3) = 20.9$ ,  $P < 0.001$ ; Fig. 2a). The lowest stink bug density occurred during late vegetative stage (LV), significantly lower than the early-middle vegetative stage (EMV) ( $P < 0.001$ ). Corn growth stage affected populations of BSB ( $\chi^2(3) = 25.1$ ,  $P = 0.01$ ) similarly. Abundances decreased in C and increased in PP as the corn transitioned from vegetative to reproductive stages, but there was no significant interaction.

In 2015, there was an interaction between treatment and corn growth stage on total stink bug abundance at WM ( $\chi^2(3) = 54.8$ ,  $P < 0.001$ ; Fig. 2b). Stink bug densities were lowest at the EMV stage. In PP plots, the population peaked at the LV stage and decreased over the remaining growth stages. In C plots, the population increased steadily, peaking at the MLR stage. Similarly, there was an interaction between treatment and corn growth stage on brown stink bug abundance ( $\chi^2(3) = 41.5$ ,  $P < 0.001$ ).

At CM in 2015, there was no effect of treatment, but corn growth stage impacted total stink bug abundance ( $\chi^2(3) = 46.4$ ,  $P < 0.001$ ; Fig. 2c). Stink bug density peaked at the LV stage and was lowest at the ER stage. Corn growth

stage effects on BSB populations ( $\chi^2(3) = 56.1$ ,  $P < 0.001$ ) were similar to total stink bug population.

### **Herbivore egg masses**

European corn borer (ECB) egg parasitism and predation were observed at each study site during both years. However, numbers of ECB egg masses found were too low to conduct an analysis. At WM in 2014, 27 ECB egg masses were found, 12 in PP and 15 in C. A total of 231 stink bug egg masses (4819 individual eggs) were found. This included 135 (2041 eggs) and 96 (2778 eggs) egg masses found in PP and C treatment plots, respectively. At WM in 2015, 10 ECB egg masses were found, 6 in PP and 4 in C. A total of 165 stink bug egg masses (3533 eggs) were found. Of these, 64 (1881 eggs) and 66 (1652 eggs) were found in PP and C plots, respectively. At CM in 2015, 16 ECB egg masses were found, 10 in PP and 6 in C and a total of 130 stink bug egg masses (2908 eggs) were found. This included 92 (1490 eggs) and 74 (1418 eggs) egg masses in PP and C plots, respectively.

For all sites and years, there was no treatment effect on the proportion of egg masses that disappeared (missing) from corn leaves before their fate could be determined ( $\chi^2(1) = 0.1-3.5$ ,  $P > 0.05$ ). Over the course of the study, 10-35% of egg masses initially found disappeared from corn leaves due to unknown causes and were therefore not included in the analysis.

### **Predation by chewing arthropods**

At WM, there was an interaction between treatment and distance from plot border on the percentage of egg predation by chewing arthropods in 2014 ( $\chi^2(1)$

= 16.6,  $P = 0.031$ ) and 2015 ( $\chi^2(1) = 20.3$ ,  $P = 0.016$ ; Fig. 3). In 2014, chewing predation was not affected by distance from border in PP, but predation was greater in C border rows ( $P < 0.002$ ). There were no differences between treatments within border or interior rows. In 2015 at WM, chewing predation was increased with greater distance from border rows in C ( $P = 0.04$ ), whereas in PP, chewing predation declined with increased distance from border rows ( $P < 0.004$ ). In CM in 2015, there was no treatment effect, however, chewing predation increased with greater distance from border rows ( $\chi^2(1) = 33.4$ ,  $P < 0.001$ ). In 2014 at WM, there were higher rates of chewing predation in PP compared to C border rows ( $P = 0.005$ ), but there was no difference between treatments within interior rows. In 2015 at WM there were higher rates of chewing predation in C compared to PP borders ( $P = 0.02$ ) but no differences existed within interior rows.

### **Predation by sucking arthropods**

There was an interaction between treatment and distance from plot border on levels of predation by sucking arthropods at WM, in 2014 ( $\chi^2(1) = 19.9$ ,  $P = 0.020$ ) and in 2015 ( $\chi^2(1) = 4.0$ ,  $P = 0.045$ ) (Fig. 4). In 2014, sucking predation declined with increased distance from PP border rows ( $P < 0.001$ ) and C ( $P = 0.03$ ). Similarly, in 2015, sucking predation decreased with increased distance from C border rows ( $P < 0.001$ ), but there was no effect of distance in PP plots. There were no treatment effects within interior or border rows. In CM in 2015, the percentage of sucking predation was higher in PP than C plots ( $\chi^2(1) = 4.2$ ,  $P =$

0.04) and rates declined with increased distance from border rows ( $\chi^2(1) = 5.3$ ,  $P = 0.021$ ).

### **Parasitism**

In 2014 at WM, percentage of parasitism was significantly greater in C compared to PP plots ( $\chi^2(1) = 8.8$ ,  $P = 0.003$ ), and overall, parasitism was greater with increased distance from border rows ( $\chi^2(1) = 64.9$ ,  $P < 0.001$ ; Fig. 5). In 2015 at WM, there was an interaction between treatment and distance from plot border on percent parasitism ( $\chi^2(1) = 36.2$ ,  $P < 0.001$ ). Parasitism was greater with increased distance from border rows in PP ( $P < 0.001$ ), but there was no effect of distance in C plots. Parasitism was lower in PP than C at plot borders ( $P = 0.002$ ), but there was no difference in parasitism within interior rows. At CM, percent parasitism was significantly greater in C compared to PP plots ( $\chi^2(1) = 6.1$ ,  $P = 0.01$ ) and overall, parasitism was greater with increased distance from plot border ( $\chi^2(1) = 4.5$ ,  $P = 0.03$ ).

Subsamples of parasitized egg masses were brought back to the lab to identify the species composition that successfully egressed from the egg masses. These parasitoids included: *Telenomus podisi*, *Trissolcus euschisti*, *Trissolcus brochymenae*, and *Trissolcus euschistus* (Hymenoptera: Scelionidae); *Anastatus reduvii*, *Anastatus mirabilis*, *Anastatus pearsalli* (Hymenoptera: Eupelmidae); and *Ooencyrtus* spp. (Hymenoptera: Encyrtidae). Egg masses in both years and across all sites were parasitized by these species.

### **Unknown mortality**

There was an interaction between treatment and distance from plot border on percentage of egg masses with unknown mortality for all years and sites (WM 2014:  $\chi^2(1) = 17.3$ ,  $P = 0.02$ ; WM 2015:  $\chi^2(1) = 22.8$ ,  $P = 0.004$ ; CM 2015:  $\chi^2(1) = 14.1$ ,  $P < 0.001$ ; Fig. 6). At WM in 2014, levels of unknown mortality increased with greater distance from C border rows ( $P = 0.005$ ) and declined with increased distance from PP border rows ( $P = 0.002$ ). Unknown mortality was greater in PP compared to C within border rows but higher in C than PP within interior rows ( $P = 0.03$  and  $P = 0.05$ , respectively). At WM in 2015, levels of unknown mortality increased with greater distance from border rows in C ( $P < 0.001$ ). There was no effect of distance in PP plots. Unknown mortality rates were higher in PP compared to C within border rows ( $P = 0.002$ ), but no differences existed within interior rows. At CM in 2015, levels of unknown mortality declined with increased distance from C and PP border rows ( $P < 0.001$  and  $P = 0.03$ , respectively). Unknown mortality did not differ between treatments within border rows, but was lower in C than in PP plots ( $P = 0.02$ ).

### **Total mortality**

There was an interaction between treatment and distance from plot border on total stink bug egg mortality due to predators, parasitoids and unknown causes for all years and sites (WM 2014:  $\chi^2(1) = 25.8$ ,  $P = 0.003$ ; WM 2015:  $\chi^2(1) = 11.1$ ,  $P < 0.001$ ; CM 2015:  $\chi^2(1) = 20.8$ ,  $P = 0.01$ ) (Fig. 7). At WM in 2014, total mortality rates were enhanced with increased distance from PP border rows ( $P < 0.001$ ), but there was no effect of distance in C plots. Total mortality was higher in C than PP in border rows ( $P < 0.001$ ), but there were no differences within

interior rows. In 2015, total mortality was enhanced with increased distance from PP border rows ( $P = 0.035$ ) and declined with increased distance from C border rows ( $P = 0.01$ ). There were no differences between treatments within border or interior rows. At CM, total mortality rates declined with increased distance from C borders ( $P = 0.02$ ), and improved with increased distance from PP borders ( $P = 0.02$ ). Total egg mortality in C was higher than in PP within border rows ( $P < 0.001$ ), but no differences existed within interior rows.

### **Corn ear damage**

#### **Stink bug damage**

There was an interaction between treatment and row distance from plot border on stink bug damage in 2014 and 2015 at WM and CM (WM 2014:  $\chi^2(1) = 24.0$ ,  $P = 0.009$ ; WM 2015:  $\chi^2(1) = 455.7$ ,  $P < 0.001$ ; CM 2015:  $\chi^2(1) = 26.1$ ,  $P = 0.003$ ; Fig. 8). At WM in 2014, ears in border rows sustained more damage than interior rows in both treatments ( $P = 0.007$ , respectively). There was no difference between treatments at either plot borders or plot interiors. At WM in 2015, damage was greater on ears harvested from borders compared interior rows in both treatments ( $P = 0.002$ , respectively). Damage was greater in C borders compared to PP borders ( $P = 0.005$ ). There was no difference between treatments in plot interiors. At CM in 2015, Ears within borders sustained more stink bug damage than interior rows in both treatments ( $P = 0.002$ , respectively). There was no difference between treatments at plot borders or interiors. Overall, trends were similar across sites for both years.

#### **Sap beetle damage**



There was an interaction between treatment and distance from plot border on sap beetle damage for all years and sites (WM 2014:  $\chi^2(1) = 43.0$ ,  $P < 0.001$ ; WM 2015:  $\chi^2(1) = 60.3$ ,  $P < 0.001$ ; CM 2015:  $\chi^2(1) = 107.1$ ,  $P < 0.001$ ; Fig. 9). At WM in 2014, ears in interior rows suffered more sap beetle damage than border rows in both treatments ( $P = 0.018$  and  $P = 0.018$ , respectively). However, there was no difference between treatments at either plot border or plot interiors. In contrast, at WM in 2015, ears in interior rows suffered less sap beetle damage than border rows in PP and C plots ( $P = 0.018$  and  $P = 0.007$ , respectively). There was no difference between treatments at plot borders or interiors. At CM in 2015, interior rows sustained more sap beetle damage than border rows in C ( $P = 0.007$ ), and border sustained more damage than interior rows in PP ( $P = 0.007$ ). The C sustained greater damage compared to PP treatment within interior rows ( $P = 0.02$ ). However, there was no difference between treatments at plot borders.

### **European corn borer damage**

There were no effects of either treatment or distance at WM in 2014. There was an interaction between the effects of treatment and distance from border on European corn borer damage at WM and CM in 2015 ( $\chi^2(1) = 61.3$ ,  $P < 0.001$  and  $\chi^2(1) = 54.7$ ,  $P < 0.001$ , respectively; Fig. 10). At WM, there were no differences between treatments at plot borders or plot interiors. Damage was greater in C borders compared to plot interiors ( $P = 0.002$ ), but there was no effect of distance from border in PP plots. At CM, European corn borer damage was greater within PP border than interior rows ( $P = 0.002$ ), but there was no

effect of distance from border in C plots. There were no differences between treatments at plot interiors or borders.

### **Corn earworm damage**

There was an interaction between treatment and distance from border on corn earworm damage for all years and sites (WM 2014:  $\chi^2(1) = 5.2$ ,  $P = 0.02$ ; WM 2015:  $\chi^2(1) = 20.8$ ,  $P = 0.012$ ; CM 2015:  $\chi^2(1) = 36.4$ ,  $P < 0.001$ , respectively; Fig. 11). At WM in 2014, C plot interiors sustained greater damage than C border rows ( $P = 0.02$ ). There was no difference between treatments at plot borders or interiors. At WM in 2015, both PP and C border rows sustained greater damage than interior rows ( $P < 0.007$ , respectively). C border and interior sustained more damage than PP interior ( $P = 0.001$  and  $P = 0.011$ , respectively). There were no differences between treatments at plot borders. At CM, corn earworm damage was greater at the plot border than interiors of PP plots ( $P < 0.001$ ), but there were no differences between treatments at plot borders or interiors.

### **Yield and economic assessment**

For all years and sites, there was no treatment effect on yield or profit (Tables 1 and 2, respectively). In 2015, yields from interior rows were greater than border rows ( $\chi^2(1) = 13.3$ ,  $P < 0.001$ ), but this was not measured in 2014.

### **Discussion**

In this study, strips of flowering partridge pea were planted along plots of organic field corn borders to examine how their presence would affect stink bug and European corn borer (ECB) populations as well as grain quality and yield. An

economic assessment was conducted to determine the economic benefits of using partridge pea strips. Overall there was no influence of partridge pea on stinkbug or ECB populations at levels encountered during this study. Generally, their abundance as well as rates of egg mortality was not significantly different between the corn monoculture plots (C) and those bordered by partridge pea (PP). Corn growth stage and row location eventuated as having greater influences on stink bug abundance and egg mortality, respectively. Similarly, though yield was higher in C than PP plots during one study year at one site, row location had the greatest impact on grain quality and yield. As such, there were no short term economic benefits of bordering organic field corn with partridge pea.

Across all years and sites, stink bug numbers never reached levels above one stink bug per ear and remained lower than proposed economic thresholds of greater than three stink bugs per corn ear (Ni et al. 2010). Low stink bug pest pressures may have affected the ability to assertively assess how partridge pea plantings impact their populations. Though stink bug numbers were not high enough to include distance in statistical models, their abundance was comparatively higher within border compared to interior corn rows. This is consistent with the findings that stink bugs are generally found at higher levels along field crop borders (Venugopal et al. 2014; Tillman et al. 2014).

Though there were no treatment effects on stink bug populations, their numbers were affected by corn growth stage throughout the season. Generally population increased during late vegetative stages and again during middle-late

reproductive stages. These results corresponded with previous studies (Apriyanto et al. 1989, Rice et al. 2014), which found that the late vegetative (tasseling) and middle-late reproductive stages (milk and dough) are the most preferred stages for stink bug colonization and injury. However, in 2014, there was a decline in stink bug numbers during late vegetative stages, but through casual observation it was noted that stink bugs were late to colonize corn fields at the WM study site.

Stink bug egg mortality was affected by the presence of partridge pea, but findings were inconsistent. Generally, mortality caused by chewing and sucking predation and parasitism, as well as overall mortality were higher in border rows of control plots compared to corn plots with partridge pea. This contributed to hatch rates or percentage of eggs reaching the 1<sup>st</sup> instar stage being higher within PP border rows. Hatch rates were 12-15% higher in PP compared to C borders during the two year study. An exception to this occurred in 2015 when there were higher rates of chewing (WM) and sucking (CM) predation, and unknown mortality (WM) in border rows of PP plots. Although total mortality was consistently lower within PP border rows, as distance increased from border towards interior rows, rates of mortality in PP reached similar levels or exceeded those in C plots. This would suggest that partridge pea has a greater impact on mortality within interior rows, and that PP may act as a predator sink along border rows, by detracting beneficial arthropods away from exerting control.

It was hypothesized that planting floral resources along field borders would attract more natural enemies (Landis et al. 2000) to border rows, and

subsequently causing greater egg mortality, given stink bug propensity to colonize crop field borders (Tillman et al. 2014). However, the presence of partridge pea along field corn borders seems to promote an increase in egg survivorship along the field border. This suggests that total stink bug survival may be enhanced by the presence of partridge pea strips. Partridge pea may have caused greater egg survivorship within border rows by behaving as a natural enemy sink. Other studies have shown that, provided refuge, predators may not move into the adjacent field and promote biocontrol (Denys and Tscharntke 2002; Koji et al. 2007). Given the potential suitability of partridge pea as a stink bug resource (Panizzi and Slansky 1991), oviposition in field corn neighboring partridge pea may enhance nymphal survivorship. Inconsistencies in egg mortality among years, treatments and row locations encountered during this study suggest that a combination of factors impacted stink bug egg fate, and that causes cannot be elucidated confidently.

Among all damage types assessed, stink bugs inflicted the greatest qualitative kernel damage. Overall, ears harvested from border rows had higher levels of stink bug damage compared to interior rows. This finding was similar to previous observations, which showed stink bug tendency to colonize and exert greater damage at the perimeter of crop fields (Venugopal et al. 2014; Tillman 2014). However this tendency was not consistent. For example, in 2014, ears collected from interior rows had slightly more damage in CM. Variation in findings at WM may be explained by a delayed treatment effect. In 2015, unlike CM, the

partridge pea stand at WM developed from a natural reseeding of the planting from 2014.

The control plots generally had higher yields compared to PP plots, though yields were statistically equivalent between treatments. In 2015, ears harvested from border rows at WM yielded lower than interior rows. This was consistent with higher levels of damage in border rows. Considering the variable patterns in damage, this result suggests that some of the damage measured had a greater impact on grain quality than yield. It has been shown that 1-2 stink bugs per ear may impact grain quality without influencing yield (Ni et al. 2010). This would suggest that the number of stink bugs feeding on corn ears remained below this threshold. However, quality-reducing damage to grain corn can increase concentrations of mycotoxins and reduce nutritive value (Teller 2012).

It is acknowledged that the size of research plots limits direct application of findings to conventionally scaled fields (Swift et al. 2004). Each plot in the current study system functioned similarly as an 'edge' of conventionally sized corn fields. Therefore, edge effects obtained in terms of yield should be considered a partial fragment of the study design. Although differences in yield between border and interior rows were expected, differences were variable and this may have been partially due to low stink bug numbers. If stink bugs were at higher densities these differences may have been more pronounced and consistent across study sites and years. PP had slightly lower yield across all years and sites compared to C plots. This may be partially explained by partridge

pea acting as a potential sink for beneficial arthropods, which indirectly impacted yield of border rows.

Planting 0.15 ha of partridge pea and one ha of organic field corn did not affect profit or production cost compared to control in this study. However, any additional ecosystem services provided by partridge pea were not included in monetary assessments. Economic implications are critical aspects of farmers adopting more ecological production practices, but cost considerations in agroecological literature remains limited (Cullen et al 2008; Jonsson et al 2010). Though not an explicit objective of this study, the cost/profit of conventional corn grown for production were analyzed for comparison to organic treatment plots. Across treatments, organically produced corn had on average, 15-20% greater profit value in Maryland during 2014-2015 than the average value of conventionally produced corn (USDA-NASS). The economic analysis highlights the profitability of organic field corn and demonstrates that premium market prices adds significantly to profit potential. If organic crops are produced in tandem with state sponsor incentive programs such as Conservation Reserve Program (CRP) or cover crop cost share payment programs, profit potential may increase further.

## ***Conclusions***

Contrasting results encountered during this study highlight the difficulty in linking flowering insectary plants or increased habitat diversification to pest suppression (Schelhorn et al. 2014) crop damage and yield. This reiterates that future research should be designed to carefully measure these interactions and

results be more representative of findings that would occur within large commercial fields (Thies & Tscharrntke 1999). Implementing tactics such as flowering borders requires careful planning and is more knowledge-intensive than other pest management tactics. If implemented properly, this technique can be economically feasible and complementary to other production aspects of cropping systems (Fiedler et al. 2008). Given the vast diversity of plants, and the limited number of studies evaluating the impact of floral diversity on ecosystem services, it may be difficult for a grower to earnestly consider implementing this tactic.

Partridge pea, native to large regions of the US, has potential to provide multiple benefits to agroecosystems and can be used in several compensatory conservation programs. Partridge pea is recommended for usage in CRP programs nationwide as the USDA NRCS provides recommendations for multiple cultivars for region-specific plantings (Houck 2006; DuPue and Englert 2015). In Maryland, the Department of Natural Resources promotes planting native warm-season grasses and flowering plants, including partridge pea, to hinder declining habitat diversity. In the 2014 fiscal year, over 25 million acres were enrolled into CRP programs countrywide, providing payments to growers that were over 1.5 billion USD. In Maryland alone, farmers participating in this program received over 10.5 million USD in 2014, with 70 thousand acres registered (USDA-FSA). Growers can enroll land in conservation enrichment programs and utilize a variety of techniques including buffers, flowering strips and restoration practices that would be best suited for their land. Thus, if it can be shown that flowering



borders can be used to help suppress pest populations at a reduced cost, this will serve as an additional incentive for farmers to adopt such practices.

## **Chapter 2: Influence of a native insectary plant, *Chamaecrista fasciculata* (Michx.), on arthropod populations in organic field corn**

### ***Abstract***

Provisioning agricultural ecosystems with floral resources has been promoted as a technique to increase natural enemy densities and suppress pest outbreaks in cropping systems. I investigated the potential of partridge pea to increase the abundance of natural enemies and diversity of target parasitoids while suppressing herbivore abundance in organic corn plots adjacent to partridge pea plantings. The experiment consisted of two treatments, corn grown in monoculture (C) and bordered by strips of partridge pea (PP). Arthropod populations were categorized and quantified by functional feeding guild and compared between treatments. Visual assessments, sticky card traps and vacuum samples were used to measure and compare abundances of detritivore, fungivore, herbivore, parasitoid, predator and pollinator arthropod functional feeding groups. Both beneficial and herbivorous taxa were more abundant in partridge pea compared to areas of managed vegetation. Within corn plots, effects of distance from border rows on arthropod abundance depended on the presence of floral resources as well other factors, including year and site location. The potential causes and implications of findings are discussed.

### ***Introduction***

Declining global biodiversity, or the variability and abundance of living

organisms, has caused tangible disruptions to a multitude of ecosystem services (Barnosky 2011; Bennett et al. 2015). In conventional agricultural systems, these losses are remedially replenished by high-energy inputs and expanded crop acreage (Altieri 1999; Gurr et al. 2003; Bommarco et al. 2013). Increased biodiversity has been touted for its potential to improve environmental health and lower agricultural production cost (Griffiths et al. 2008). Planting supplemental resources in uncultivated land neighboring the production system can increase biodiversity and concomitantly reduce impediments caused by agricultural intensification. This should subsequently reduce the need for mechanical and/or chemical inputs (van Emden 1965; Nicholls and Altieri 2013). It has been suggested that a departure from a nondiverse or monoculture production system can have a positive impact on ecosystem services, such as enhancing biological control (Baggen and Gurr 1998; Letourneau et al. 2011). It is unclear whether enhancing habitat diversity on a small scale can support ecosystem services while effectively increasing biological control and crop yields. However, a recent meta-analysis revealed a strong correlation of generalist predator abundance with plant diversity, with little effect of scale (Dassou and Tixier 2016). While these considerations remain, it is also critical to determine which plant species are suitable for managing pests in different systems (Fiedler et al. 2008). Further, the risk of arthropod pests benefitting from enhanced vegetation diversity, potential competition with other predators or intraguild predation must be considered when selecting resource plants (Landis et al. 2000; Straub et al. 2008).

Plants with flowers and/or extrafloral nectaries are considered critical for increasing the longevity, searching efficiency and fecundity of biological control agents, such as parasitic Hymenoptera (Baggen and Gurr 1998; Tylianakis et al. 2004; Balzan et al. 2014). The successful utilization of plant-derived provisioning to enhance biological control of pests has been well documented (Géneau et al. 2012; Balmer et al. 2014; see review by Lu et al. 2014; Tschumi et al. 2015). Often, these resources can be used to target specific biological control agents, but can simultaneously provide other ecosystem services, such as supporting pollinator health and contributing to soil, water and weed management (Gurr et al. 2003; Cullen et al. 2008; Wratten et al. 2012).

Historically, partridge pea, *Chamaecrista fasciculata* (Michx.), has been utilized in the US as a cover crop for improving soil health (Atkins and Young 1941) and cultivated as a green manure globally (Morris 2012). Recently, it has been advocated for its potential to serve as an insectary plant to enhance beneficial species biodiversity and subsequently reduce the need for chemical interventions to abate pest problems (Fiedler et al. 2008; Portman et al. 2010). Partridge pea may provide beneficial arthropods with greater nutritive supplements from within the flowers or by extrafloral nectaries (Stapel et al. 1997; Röse et al. 2006).

The purpose of this project was to determine the potential use of partridge pea as an insectary plant in field corn systems. The following three questions were addressed: 1. Can partridge pea increase natural enemy abundance and diversity within organic field corn plantings? 2. Are herbivorous populations

impacted by partridge pea presence? and 3. Are key parasitoids more prevalent in corn plots bordered by partridge pea?

## ***Methods and Materials***

### **Field experiment sites and layout**

This study took place at the University of Maryland's Western Maryland Research and Education Center (WM, N 39° 30' 34.271", W 77° 44' 0.128") during the 2014 and 2015 growing seasons and at the Central Maryland Research and Education Center (CM, N 39° 0' 44.993", W 76° 49' 33.221") - Beltsville Facility during the 2015 growing season. Fields used at study sites were under organic transition. At each farm site, the study was organized as a randomized complete block design with four replicates. Each block consisted of two treatments: 1) corn with rows of partridge pea planted along their borders (PP), and 2) corn planted as monoculture/control (C) (Fig. 1). Each block ( $\approx 85 \times 14$  m) was separated by a minimum of 180 m. Individual corn plots of 24 (WM) or 18 (CM) corn rows were no-till drilled (76.2 cm row spacing) into a mowed rye (*Secale cereale* L.) - crimson clover (*Trifolium incarnatum* L.) - hairy vetch (*Vicia villosa* Roth) cover crop mix in 2014, and a mowed rye-crimson clover cover crop mixture in 2015. Within blocks, PP and C plots were separated by a minimum of 60 m of regularly mowed, natural vegetation to reduce interference among treatments. Partridge pea (3 x 13.8 m) was initially drilled into lightly disked soil at a distance of  $\approx 1$  m from outermost corn rows with intra-row spacing of 18 cm. The corresponding field edge of control plots consisted of naturally occurring vegetation that was maintained by regular mowing. Rows of sudangrass

(*Sorghum bicolor* x *S. bicolor* var. *sudanese*) (3 x 18 m) were drilled at the center of the bare-ground area between treatment plots to further isolate the two treatments. Each block was bordered by forest on one edge and either conventionally grown soybean or corn along the opposite edge.

Corn and sudangrass were planted 27 May 2014 at WM and 22 and 23 May 2015 at CM and WM, respectively. Partridge pea was planted on 31 May 2014 at WM and 23 May 2015 at CM. The partridge pea was not replanted in 2015 at the WM site as it reseeded itself and completely covered the 3 x 13.8 m ground area by time of corn planting. At WM, the corn and sudangrass were fertilized with 3:2:3 (N, P<sub>2</sub>O<sub>5</sub>, K<sub>2</sub>O) pelleted organic poultry manure (Perdue Agri-recycle Microstart 60) at a rate of 2767.6 kg/ha on 7 and 8 July 2014 and fertilized with 4:3:2 pelleted organic poultry manure (Crumbled Pellets, Herbruck's Poultry Ranch, Inc.) at a rate of 4447.9 kg/ha on 22 June 2015. At CM, the corn and sudangrass were fertilized with 4:3:2 pelleted organic poultry manure (Crumbled Pellets, Herbruck's Poultry Ranch, Inc.) at a rate of 4472.6 kg/ha on 23 and 26 June 2015.

Weeds were managed in corn plots with the help of cover crop residue that remained on the surface following mowing and push mowers and weed trimmers were used as needed. Partridge pea stands were hand weeded as needed during the initial three weeks after planting prior to canopy closure. Plots were irrigated via natural rainfall events.

### **Plant inspections**

Plant assessments were initiated 4 weeks after corn planting and

continued weekly thereafter to determine the community composition, density and distribution of arthropods in each replicate plot of corn. During each sampling event, one plant in every other row within each plot, 12 and 9 plants per plot in WM and CM, respectively, were searched thoroughly in every other corn row. Plants were chosen at random while traversing through plots in a zigzag transect. All arthropods found were identified to the lowest taxonomic level and recorded by stage (e.g., larva, nymph, adult).

### **Sticky card sampling**

Yellow sticky cards (7.6 x 12.7 cm, Olson Products Inc., Medina, Ohio) were used to assess the aerial community of arthropods. They were secured to bamboo poles (2014) or wooden dowels (2015) with wooden clothespins. One card was placed at the center of the partridge pea strip (6.8 m from the strip end) on each side of the PP plots (1.8 m from each outermost corn row) and at the same position in the natural vegetation areas in C treatment plots.

Additional cards were positioned at three locations within each corn plot to determine arthropod distribution within each treatment plot. A card was placed between rows 6 and 7, 12 and 13 (center), and 18 and 19 (5 cards total per plot). Each card was attached to the pole in a parallel orientation to corn rows, at approximately 2/3 the height of corn plants until stage VT was reached. Thereafter, cards were raised to and remained at ear height. One side of the sticky card was left perpendicularly exposed to face the nearest plot perimeter; the center row had the exposed edge facing either plot perimeter. Cards were initially set up at the V6 corn stage, then collected and replaced weekly until

stage R5. Upon collection, cards were placed in clear plastic re-sealable zipper bags, frozen and, later, agronomical important arthropods were identified, counted and recorded (Musser et al., 2004).

### **Vacuum sampling**

To further determine treatment impact on the arthropod community, vacuum samples were taken weekly within the partridge pea stands and natural vegetation regions adjacent to PP and C corn plots, respectively, between the hours of 10 AM and 11 AM. The vacuum sampling apparatus consisted of a converted leaf blower with a labeled 150 micron polyester multifilament elastic-top paint strainer bag affixed to the inside of the nozzle. A sample was collected by directing the blower nozzle in a back-and-forth motion over the top of the partridge pea stand and the mowed natural vegetation area while walking across a randomly selected 3 m segment of each area, demarcated by field tape. In the PP treatment plots, the vacuum samples were collected from the top portion ( $\approx 15$  cm) of the plant, where the majority of the floral blooms were located. In the C treatment plots, samples were collected in the natural vegetation stand  $\approx 15$  cm above the mowed region. Once the collection was completed, the mesh bag was quickly removed and tied. Collected arthropods were immediately placed into a cooler, until they were transferred to the lab where they remained frozen until later identified to the lowest possible taxonomic level.

### ***Statistical Analyses***

All arthropods observed and collected by each sampling method were assigned to a functional feeding guild (detritivore, fungivore, herbivore,



parasitoid, predator, pollinator) based on the primary ecological function of the majority of the taxonomic group. When arthropod feeding guild classification was unknown, arthropods were grouped into an indeterminate category but were not analyzed. All sampling methods were conducted and recorded weekly.

Functional groups of arthropods detected through visual assessments were modeled as a generalized linear mixed model (GLMM) with a Poisson distribution (logit link) and with treatment (PP and C) and distance (or row) from plot border as fixed effects. Densities of each group were pooled across sampling weeks and summed as the dependent variable in the model. Block and treatment within block were included as random factors to account for differences among blocks. Blocks and distance within treatment by block were adjusted for autocorrelation due to repeated measures of plots. Separate models were run on feeding guild categories present in densities high enough to be statistically relevant.

Accumulation curves were modeled for visual assessments to determine if the samples were robust enough to accurately characterize the identity of the community (Appendix D). The Chao2 and abundance-based coverage estimator (ACE) were also used to estimate the total species richness using the functions *rarefy* and *specpool* in the package 'vegan' (Oksanen et al. 2016).

Functional groups of arthropods collected on sticky card traps were modeled as a GLMM with a Poisson distribution (logit link) and analyzed separately as a function of treatment and card location (i.e., interior or within partridge pea stand/vegetation area). Densities of each group and location were pooled across sampling weeks and averaged as the dependent variable in the

model. Where there was a significant interaction between treatment and location, Tukey's HSD (honest significant difference) test was applied to determine differences in abundances between locations in both levels of treatment. The same random effects were included to account for blocks and repeated measures.

Functional groups of arthropods collected in vacuum samples were modeled as a GLMM with a Poisson distribution (logit link) and analyzed separately as a function of treatment with random effects for blocks and repeated measures. Parasitoid community compositions collected in vacuum samples from partridge pea and natural vegetation areas were also analyzed using partial redundancy analysis (RDA) and ANOVA.

All analyses were conducted using R software v3.2.4 (R Core Team 2016) and Canoco (Canoco v5.0 2013) was used to run the RDA multivariate procedures. GLMMs were built using the *glmer* function in the package 'lme4' (Bates et al. 2015). ANOVAs were performed using function *Anova* in the package 'car' (Fox and Weisberg 2011). Tukey's HSD was performed using the function *glht* in the package 'multcomp' (Hothorn et al. 2008). Predicted values were extracted using the function *allEffects* in the package 'effects' (Fox 2003). Data manipulation was performed using the packages 'plyr' (Wickham 2011) and 'reshape2' (Wickham 2007).

## **Results**

Arthropods observed during visual assessments, trapped on sticky cards, and collected from vacuum samples were classified into detritivore, fungivore,

herbivore, parasitoid and predator guilds (Table 3). Pollinators were categorized also, but were not found in high enough abundance to analyze.

A total of 7,562 arthropods were visually assessed on corn plants over the duration of the study. In 2014 at WM, 12 arthropod orders were observed and recorded, which included 14 suborders and families. In 2015, 10 orders and one arthropod class were observed and recorded, which included 23 suborders and families. In 2015 at CM, 14 orders and one class were observed and recorded, which included 26 suborders and families.

A total of 86,533 arthropods were assessed with sticky card traps in transects through the corn fields and within the partridge pea or mowed natural vegetation areas over the course of the study. In 2014 at WM, 16 arthropod orders were identified on sticky cards, which included 78 suborders, superfamilies and families. In 2015, 12 orders were identified on sticky cards, which included 73 suborders, superfamilies and families. In 2015 at CM, 12 orders were identified on sticky cards, which included 71 suborders, superfamilies and families.

A total of 18,255 arthropods were collected from vacuum samples of the partridge pea and natural vegetation border areas over the course of the study. In 2014 at WM, 13 arthropod orders were collected, which included 70 suborders, superfamilies and families. In 2015, 11 orders were identified on sticky cards, which included 57 suborders, superfamilies and families. In 2015 at CM, 12 orders were identified on sticky cards, which included 57 suborders, superfamilies and families.

## **Visual assessment**

Visual assessments were performed to assess the arthropod community within the corn plots along a spatial gradient with respect to the floral resource. These assessments were designed to detect the communities endemic to organic field corn, with and without partridge pea nearby. However, this sampling technique was unable to capture minute and aerial arthropod abundances. At WM in 2014, the total arthropod community that was visually assessed on corn plants consisted of 3,099 individuals. They primarily consisted of (62%) herbivores, (27%) predators, (8%) detritivores. The remaining 3% of arthropods observed were grouped into the indeterminate category and the parasitoid guild. In 2015, the total community consisted of 2,457 arthropods at the WM site. They consisted of (61%) herbivores, (32%) predators, (3%) detritivores and (2%) parasitoids. The remaining 2% of arthropods were grouped into the fungivore guild and the indeterminate category. The total community visually assessed in 2015 at CM consisted of 2,006 individuals. These consisted of (54%) herbivores, (17%) predators, (14%) indeterminate arthropods, (9%) detritivores, (3%) fungivores and (3%) parasitoids.

Rarefaction curves showed that visual assessments of corn plants were able to accurately detect the community assembly, by reaching an asymptote at each site/year replicate. Additionally, the Chao2 estimator of species richness and ACE abundance-based coverage estimator showed that visual assessment samples of the corn plots achieved close approximations of the total species richness as predicted by these estimators.

**Detritivore**

At WM in 2014, detritivore abundance increased with increased distance from plot borders ( $\chi^2(1) = 4.4$ ,  $P = 0.035$ ), but there was no effect of treatment (Fig. 12a). At WM in 2015, detritivore abundance was not affected by treatment or distance from plot borders (Fig. 12b). At CM in 2015, detritivore abundance was greater in PP compared to C plots ( $\chi^2(1) = 10.6$ ,  $P = 0.001$ ), but there was no effect of distance from plot borders (Fig. 12c).

**Fungivore**

At WM in 2014, no fungivores were detected through visual counts. At WM in 2015, fungivore abundance was greater in C compared to PP ( $\chi^2(1) = 3.8$ ,  $P = 0.05$ ) (Fig. 13a), but there was no effect of distance from plot borders. At CM in 2015, fungivore abundance decreased with an increase in distance from plot borders ( $\chi^2(1) = 5.3$ ,  $P = 0.02$ ) (Fig. 13b).

**Herbivore**

At WM in 2014, herbivore abundance increased with distance from plot borders ( $\chi^2(1) = 45.5$ ,  $P < 0.001$ ), but there was no effect of treatment (Fig. 14a). In 2015, there was an interaction between treatment and distance from plot borders ( $\chi^2(1) = 8.4$ ,  $P = 0.004$ ) (Fig. 14b). At plot borders, PP had higher herbivore abundances than C ( $P > 0.001$ ) plots and herbivore abundance declined with distance from plot borders. However, there was no treatment effect at plot interiors. In CM 2015, there was no effect of treatment or distance from plot borders (Fig. 14c).

**Parasitoid**

In 2014 and 2015 at WM and CM, there was no effect of treatment or distance from plot borders on parasitic populations (Fig. 15a-c).

### **Predator**

At WM in 2014, predator abundance increased with increased distance from plot borders ( $\chi^2(1) = 3.9$ ,  $P = 0.048$ ), but there was no effect of treatment (Fig. 16a). At WM in 2015, there was no effect of distance from plot border, but predator abundance was higher in PP compared to C plots ( $\chi^2(1) = 8.6$ ,  $P = 0.003$ ) (Fig. 16b). At CM in 2015, predator abundance decreased with distance from plot borders ( $\chi^2(1) = 14.7$ ,  $P < 0.001$ ), but there was no effect of treatment (Fig. 16c).

### **Sticky card samples**

Sticky card traps were placed in a gradient from within the partridge pea or natural vegetation areas to the plot centers, to assess changes in the arthropod community at different locations within the plots. The community collected using this sampling technique mainly consisted of small, aerial arthropods, including the parasitoid wasps. The sticky cards generally were unable to trap larger arthropods or ground-dwelling arthropods. The arthropod community assessed with sticky card traps consisted of 27,553 individuals in 2014 at WM. They consisted of (60%) herbivores, (17%) parasitoids, (8%) predators, (6%) detritivores, (5%) indeterminate arthropods and (4%) fungivores. In 2015, a total of 34,006 arthropods were collected from sticky card traps at WM. They consisted of (60%) herbivores, (24%) parasitoids, (6%) predators, (4%) detritivores, (3%) indeterminate arthropods and (2%) fungivores. At CM in 2015, a total of 24,974 arthropods were collected. They consisted of (56%) herbivores, (24%) parasitoids, (9%) predators, (7%) fungivores, (3%) detritivores, and (1%) indeterminate arthropods.

**Detritivore**

At WM in 2014, there was a greater abundance of detritivores in PP compared to C plots ( $\chi^2(1) = 4.9$ ,  $P = 0.027$ ), but there was no effect of distance (Fig. 17a).

At WM and CM in 2015, there was no effect of treatment or distance on detritivore abundance (Fig. 17b-c).

**Fungivore**

Across all years and sites, there were no effects of treatment or distance on fungivore abundance (Fig. 18a-c).

**Herbivore**

At WM in 2014, there was an interaction between treatment and distance from border on herbivorous arthropod abundance ( $\chi^2(1) = 4.6$ ,  $P = 0.03$ ) (Fig. 19a). Herbivorous taxa were more abundant in PP borders compared to PP interior rows ( $P = 0.001$ ), but there was no difference in abundance between locations in C plots. At plot borders, herbivorous taxa were more numerous in PP than C ( $P = 0.002$ ), but there was no difference between treatments at plot interiors.

At WM in 2015, there was an interaction between treatment and distance from border on herbivorous abundance ( $\chi^2(1) = 7.3$ ,  $P = 0.034$ ) (Fig. 19b). Herbivorous taxa were more abundant in PP borders compared to C borders ( $P = 0.004$ ), but there was no difference between treatments at plot interiors.

At CM in 2015, herbivores were more abundant in PP compared to C plots ( $\chi^2(1) = 11.4$ ,  $P < 0.001$ ) (Fig. 19c). Herbivorous taxa were more numerous in plot borders compared to plot interiors ( $\chi^2(1) = 5.7$ ,  $P = 0.02$ ).

## **Parasitoid**

At WM in 2014 (Fig. 20a) and at CM in 2015 (Fig. 20c), there was no effect of treatment or distance from plot borders on parasitoid populations.

At WM in 2015, parasitoid taxa were more abundant in borders than interior rows ( $\chi^2(1) = 16.7$ ,  $P < 0.001$ ) (Fig. 20b). However, there are no differences between treatments at either plot border or interiors.

## **Predator**

Across all years and sites, there were no effects of treatment or distance from plot borders on predator populations (Fig. 21a-c).

## **Vacuum samples**

Vacuum samples were collected from the partridge pea stands and the natural vegetation adjacent to the corn plots. These samples were used to determine the identity of the arthropod community that was attracted to partridge pea compared to the natural vegetation areas. The vacuum samples could capture small arthropods visiting the floral resources and foraging in the grassy areas. However, vacuuming method could not capture larger arthropods or agile fliers as readily. Ground-dwelling arthropods were more difficult to detect in partridge pea areas due to greater biomass between the vacuum and the ground. At WM in 2014, the total arthropod community that was collected from vacuum samples consisted of 7,282 individuals. They primarily consisted of (62%) herbivores, (17%) detritivores, (12%) predators, (5%) parasitoids and (2%) indeterminate arthropods. The remaining 2% of arthropods collected were fungivores and pollinators. In 2015, the total community consisted of 6,650



arthropods at the WM site. They consisted of (62%) herbivores, (28%) detritivores, (4%) predators and (2%) parasitoids, (2%) indeterminate arthropods. The remaining 2% of arthropods collected were fungivores and pollinators. The total community visually assessed in 2015 at CM consisted of 4,323 arthropods. These consisted of (77%) herbivores, (10%) predators, (8%) detritivores, and (2%) parasitoids. The remaining 3% of arthropods collected were fungivores, indeterminate arthropods and pollinators.

### **Detritivore**

At WM, detritivore abundances were higher in PP compared to C (2014:  $\chi^2(1) = 6.5$ ,  $P = 0.01$ ; 2015:  $\chi^2(1) = 14.2$ ,  $P < 0.001$ ). At CM in 2015, there were no effects of treatment on detritivore abundances.

### **Fungivore**

There was no effect of treatment on fungivore populations at either WM or CM in 2014 and 2015.

### **Herbivore**

Herbivorous arthropod abundance was higher in PP compared to C in all years and sites (WM 2014:  $\chi^2(1) = 95.8$ ,  $P < 0.001$ ; WM 2015:  $\chi^2(1) = 16.0$ ,  $P < 0.001$ ; CM 2015:  $\chi^2(1) = 98.0$ ,  $P < 0.001$ ).

### **Parasitoid**

Parasitic arthropod abundance were higher in PP compared to C in all years and sites (WM 2014:  $\chi^2(1) = 81.2$ ,  $P < 0.001$ ; WM 2015:  $\chi^2(1) = 8.7$ ,  $P = 0.003$ ; CM 2015:  $\chi^2(1) = 20.6$ ,  $P < 0.001$ ).

## **Predator**

Predatory arthropod abundance was higher in PP compared to C in all years and sites (WM 2014:  $\chi^2(1) = 238.7$ ,  $P < 0.001$ ; WM 2015:  $\chi^2(1) = 49.3$ ,  $P < 0.001$ ; CM 2015:  $\chi^2(1) = 8.3$ ,  $P = 0.004$ ).

## **Parasitic taxa in vacuum samples**

Redundancy analysis was performed and biplot graphs were rendered to determine how the target natural enemies (i.e., parasitoid) communities were affected by treatment. In these biplots, the direction of the arrows indicate the greatest change in taxa abundance for the corresponding parasitoid family, relative to the location of the treatment (PP or C) in the plot. The length of the arrow represents the variance of the taxa.

### **WM 2014**

Treatment accounted for 17.6% of the partial variation in the taxonomic groupings of parasitoids (Fig. 22). The first two ordination axes explained 39.0% of the variation in the parasitic taxa data due to treatment. There were significant differences in parasitic taxa composition due to treatment ( $P = 0.002$ ). Variation in abundances of mymarids, pteromalids, scelionids, braconids, and cynipids were most positively influenced by PP treatment.

### **WM 2015**

Treatment accounted for 3.9% of the partial variation in the taxonomic groupings of parasitoids (Fig. 23). The first two ordination axes explained 56.6% of the variation in the parasitic taxa data due to treatment. There was no difference in parasitic taxa composition due to treatment.

## **CM 2015**

Treatment accounted for only 9.7% of the partial variation in the taxonomic groupings of the parasitoids (Fig. 24). The first two ordination axes explained 50.2% of the variation in the parasitic taxa data due to treatment. There were no differences in parasitic taxa composition due to treatment.

## ***Discussion***

This study was conducted to determine the effects of using partridge pea as an insectary plant in organic field corn cropping systems. I hypothesized that partridge pea can increase the abundance of natural enemies and diversity of target parasitoids and decrease the abundance of herbivores in corn plots adjacent to partridge pea plantings. Findings of this study suggest that partridge pea may be used to attract beneficial arthropods (i.e., predatory and parasitic) to enhance biological control in field corn but may similarly attract pests (i.e., herbivorous arthropods). These results agree with other studies that found both natural enemy and herbivorous arthropods colonized flowering strips planted adjacent to cropping systems in greater abundances, compared to vegetative or non-floral areas adjacent to cropping systems (Rebek et al. 2005; Fiedler and Landis 2007; Walton and Isaacs 2011). I found that the location where arthropods were detected, from border rows to plot centers, differed depending on the presence of floral resources as well other factors, including year and site location. Overall, beneficial and pest taxa were in higher abundances in PP stands compared to control vegetative areas. The flowering partridge pea likely attracted beneficial taxa through the provision of additional pollen and nectar

resources, similar to previous research, which showed that natural enemies were attracted to flowering stands (Baggen and Gurr 1998; Röse et al. 2006; Tylanakis et al. 2004; Généau et al. 2012).

Sticky card results showed that parasitic and predatory populations were more numerous in border rows of corn plots next to partridge pea (PP) at one of three study site/years replicates. However, there was no treatment effect on beneficial arthropod abundances at corn plot interiors. Herbivorous taxa on sticky cards were consistently more numerous in all field borders with partridge pea plantings, compared to monocultures (C). There was no treatment effect on pest abundance at plot interiors at two of three study site/years. However, in 2015 at CM, there was higher pest abundance in PP corn plot interiors. Visual assessments revealed no treatment effects on parasitic arthropod abundances, and only in 2015 at WM did partridge pea have a positive impact on predatory arthropod abundance. Pest arthropods appeared to be more attracted to PP corn plot borders in 2015 at WM, with no significant treatment effect for any other year or site. These findings highlight the importance of habitat specificity for beneficial arthropods, which exclude resource provisioning for pest species. The increase in herbivorous taxa in PP corn plots suggests that some herbivores favored a system with floral resources. Though, the attraction of herbivorous arthropods to PP corn plot borders may also indicate edge colonization behavior, irrespective of any effect of floral plantings at crop edges.

Predatory and parasitic arthropods captured on sticky traps were in greater abundances within the partridge pea stands adjacent to corn, but they did

not disperse into the corn plots beyond the border rows. This may be explained by satiation from resource consumption (pollen and/or nectar) that reduces the need to consume additional resources (such as the target pest), and may ultimately result in lower rates of biological control (Spellman et al. 2006; Brown and Mathews 2007; Robinson et al. 2008). Alternatively, these findings may be explained partially by a positive prey-prey interaction, in which the presence of one prey attracts the majority of predator control and frees the second prey from attack (Koss and Snyder 2005). In this study, predators may have been attracted to and satisfied by the availability of alternative prey within the partridge pea and as such, did not enter the crop in search of prey. This would result in greater number of beneficial arthropods within the agroecosystem but without the added benefit of greater pest suppression within the corn crop itself.

Total beneficial taxa (i.e., parasitic and predatory) abundance in the corn plots without PP either increased or showed no change in abundance within the interior rows at two of three study site/years. In PP, these populations decreased from border to plot interiors at two of three site/years. This disparity between treatments suggests that partridge pea may be so attractive to natural enemies that it acts as a natural enemy trap, whereby there is less demand by parasitoids and predators to search for respective reproductive hosts or alternative food sources within the crop. Previous studies examining effects of flowering native plants on arthropods in blueberry and tomato systems found a similar decrease in natural enemy abundance within the crop with increased distance from the flowering source (Walton and Isaacs 2011; Morandin et al. 2014),

Herbivorous arthropods were consistently found in greater abundance within partridge pea plants compared to control borders, which consisted of natural vegetation, echoing results of Walton and Isaacs (2011). Even if herbivores gain nutritive value from partridge pea, it may inhibit herbivores from colonizing field interiors and reduce the risk of damaging the crop. Thus, the partridge pea may act as a trap crop for some herbivorous taxa, subsequently reducing the diffusion of herbivores into corn plots. By attracting both herbivorous and beneficial arthropods, partridge pea may be classified as a non-selective food plant, or a food plant that provides resources to beneficial arthropods while also positively affecting pest populations. Non-selectivity places limitations on application of this technique, by potentially increasing fitness of the herbivore community (Lavandero et al. 2006).

One goal of vacuum sampling was to compare parasitic arthropod composition and diversity within partridge pea strips and vegetative control areas. In WM in 2014, many of the parasitic families were strongly influenced by the presence of partridge pea including wasps in the families Mymaridae, Pteromalidae and Scelionidae, all of which are considered important biological control agents. It is not clear why this treatment effect did not extend to both years and sites; however, it is apparent that there were additional factors that impacted the community composition of parasitic taxa categorized during this study. It has been documented that some parasitic taxa require wooded or permanent vegetative overwintering habitat sites to complete their life cycle (Corbett and Rosenheim 1996). Variation in the quantity or quality of such

habitats between seasons of the study's duration may have altered the community of parasitoids that were available for biological control. Knowledge of all beneficial and herbivorous arthropod life histories that are associated with the cash crop is imperative for successful implementation of biological control.

It is important to consider landscape structure and composition when designing local diversification strategies, such as conservation biological control, within otherwise homogenous farming systems (Thies and Tscharntke 1999; Schmidt et al. 2005; Woltz et al. 2012; Jonsson et al. 2015). This may include establishing a complex of neighboring fields on a larger scale than the plot size used in this study. However, large-scale conservation practices may not be easily researched or implemented, even if found to be highly predictable and favorable with respect to pest regulation. Thus, more localized habitat manipulation techniques such as the use of insectary plant borders may prove more pragmatic for implementation.

## ***Conclusions***

Future testing of insectary plants in organic corn should be conducted when target pest populations are at or above economic thresholds, allowing for accurate detection of treatment effects that may result in reduction of yield loss or damage. When effective pest control is shown with insectary border plantings, a common uncertainty is the area and distance at which insectary plants should be established in the system to obtain predictable pest suppression benefits throughout the crop. Flowering resource strips could provide beneficial organisms with much needed resource supplementation across an agroscape

(Alteri 1999). However, further research must be conducted with varying ratios of manipulated habitat and distances from critical production areas to determine optimal combinations for desired outcomes.

Research should also strive to quantify the effects of different ratios of reproductive host: floral resource availability on natural enemy efficacy. Under different pest pressures, field sizes, and local landscapes, natural enemies' access to both reproductive hosts and food is subjected to spatiotemporal variability. The extent to which a change in resource availability to one functional group influences the abundance of another requires further research.

Fluxes in availability of reproductive hosts may trigger territorial behaviors in key natural enemies such as parasitoid wasps, who have shown behaviors such as guarding, attacking and retreating when host eggs are limited. Changes in availability of floral resources may alter the population of parasitoids and affect inter- and intraspecific competition that the parasitoids are exposed to. Finally, small-scale research operating at the plot level should identify natural and agricultural resources found in the surrounding landscape, which may be utilized by multiple key players in the cropping ecosystem. Identifying and including such landscape characteristics as a part of future studies may be relevant to both the local system, as well as prospective meta-analyses, which may utilize this information and thereby increase the long-term value of the research.



## Appendices

Appendix A. Photos showing indicative visual symptoms of damage types due to field corn arthropods. European corn borer damage and corn earworm damage was measured in  $\text{cm}^2/\text{ear}$ . Sap beetle and stink bug damaged was measured in number of kernels.

Appendix B. Sample budget tables used to determine profit/unit for PP and C treatments. Assumptions listed were the same for both treatments. Calculations were made for each yield estimate per replicate for 2014 and 2015 using actual yields and inputs listed in Appendix C.

Appendix C. Table of inputs used in economic analysis. Actual variable costs were used. Fixed cost values were obtained from the custom work charge rates published by the University of Maryland Extension in 2013 and 2015. Average operation costs were used to determine total variable and fixed costs and net income for the corresponding field seasons.

Appendix D. Rarefaction curves modeled to determine robustness of visual assessment samplings. The Chao2 and abundance-based coverage estimator (ACE) estimate the total species richness. Curve asymptotes indicate sufficiency of samples to accurately characterize communities in (a) WM in 2014, (b) WM in 2015 and (c) CM in 2015.

## Tables and Figures

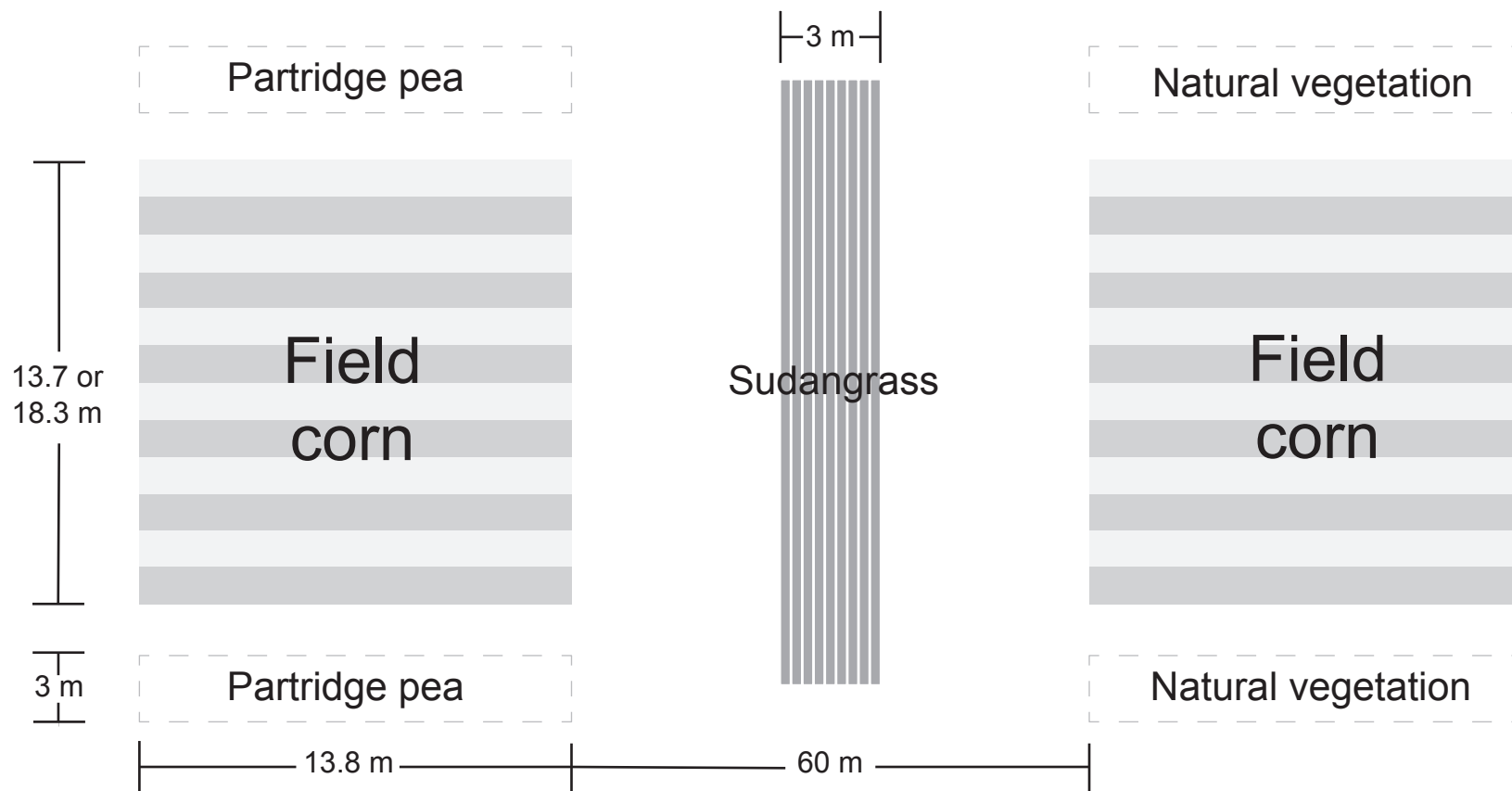


Fig. 1. Illustration of an experimental replicate consisting of corn monoculture/control (C) and corn bordered by partridge pea (PP). Width of experimental plots at CM and WM sites were 13.7 m (18 corn rows) and 18.3 m (24 corn rows), respectively. Natural vegetation in C treatment plots remained mowed.

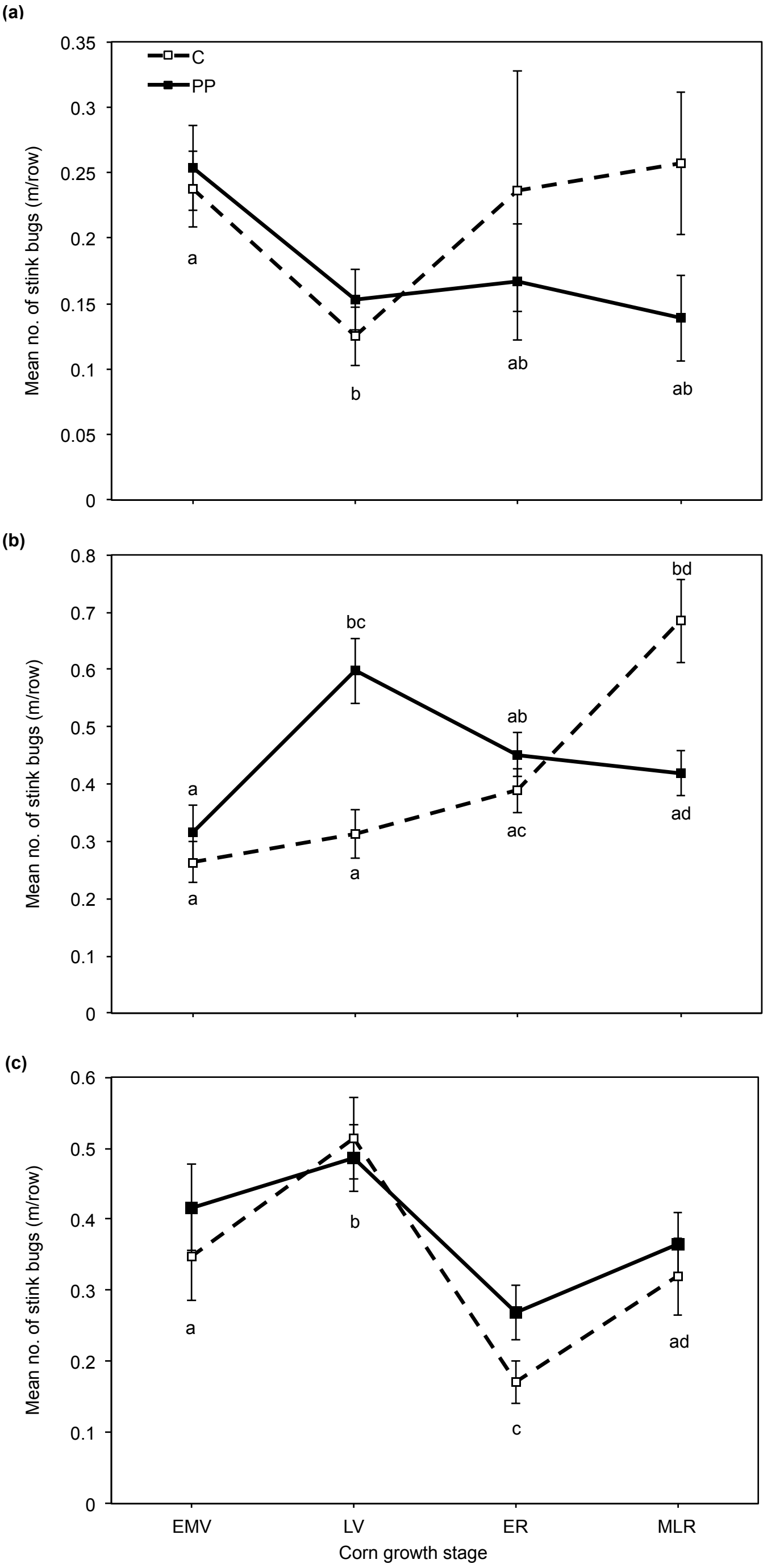


Fig. 2. Mean density ( $\pm$  SEM) of stink bugs per meter of row in corn plots flanked with partridge pea (PP) as an insectary plant compared to monoculture/control (C) corn plots in (a) 2014 at WM, (b) 2015 at WM (b) and (c) 2015 at CM. Weekly samples were grouped into corn growth stages: early-middle vegetative (EMV), late vegetative (LV), early reproductive (ER), and middle-late reproductive (MLR). Letter notation indicates significant main effects of corn growth stages (Figs. 2a and 2c) and simple effects (Fig. 2b), determined from Tukey HSD tests following generalized linear mixed models.

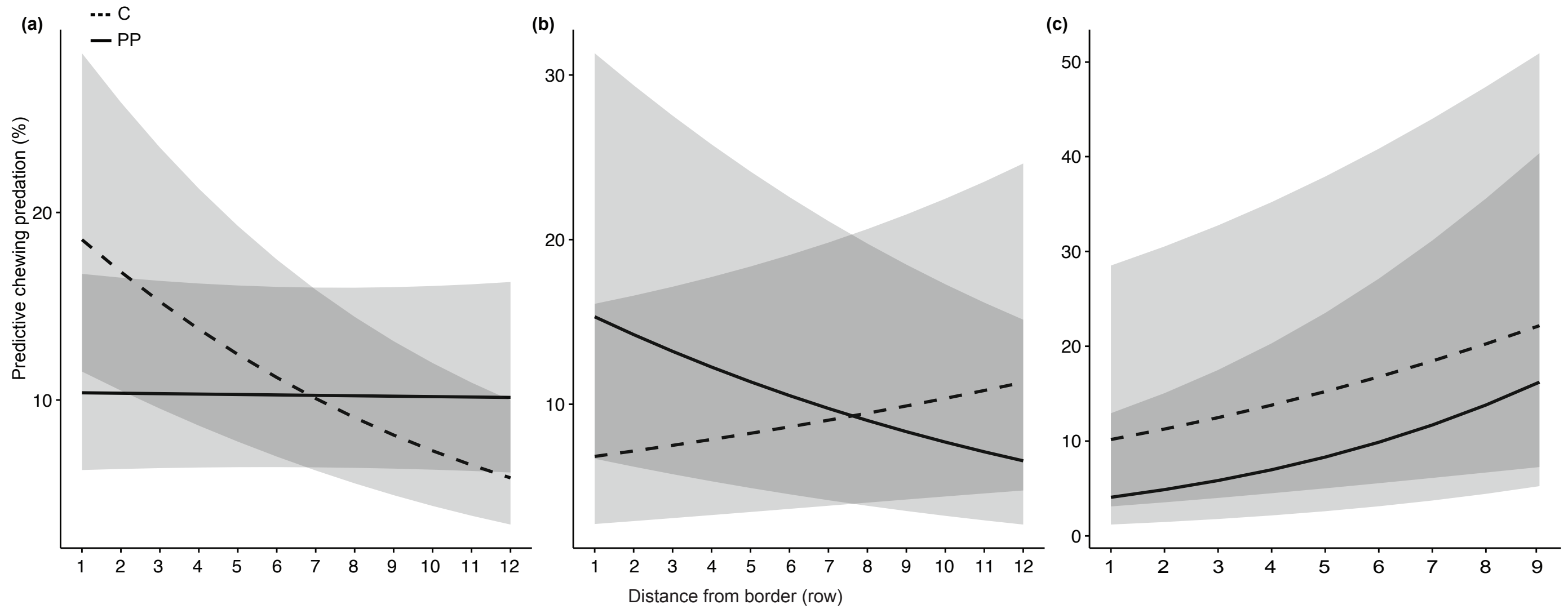


Fig. 3. Predicted probability of chewing predation per egg mass in field corn plots at WM in (a) 2014, (b) 2015 and in (c) CM in 2015. Shaded areas represent 95% confidence interval bands. Distance is measured in row interval from plot border (1) to plot interior (12 or 9, in WM and CM, respectively).

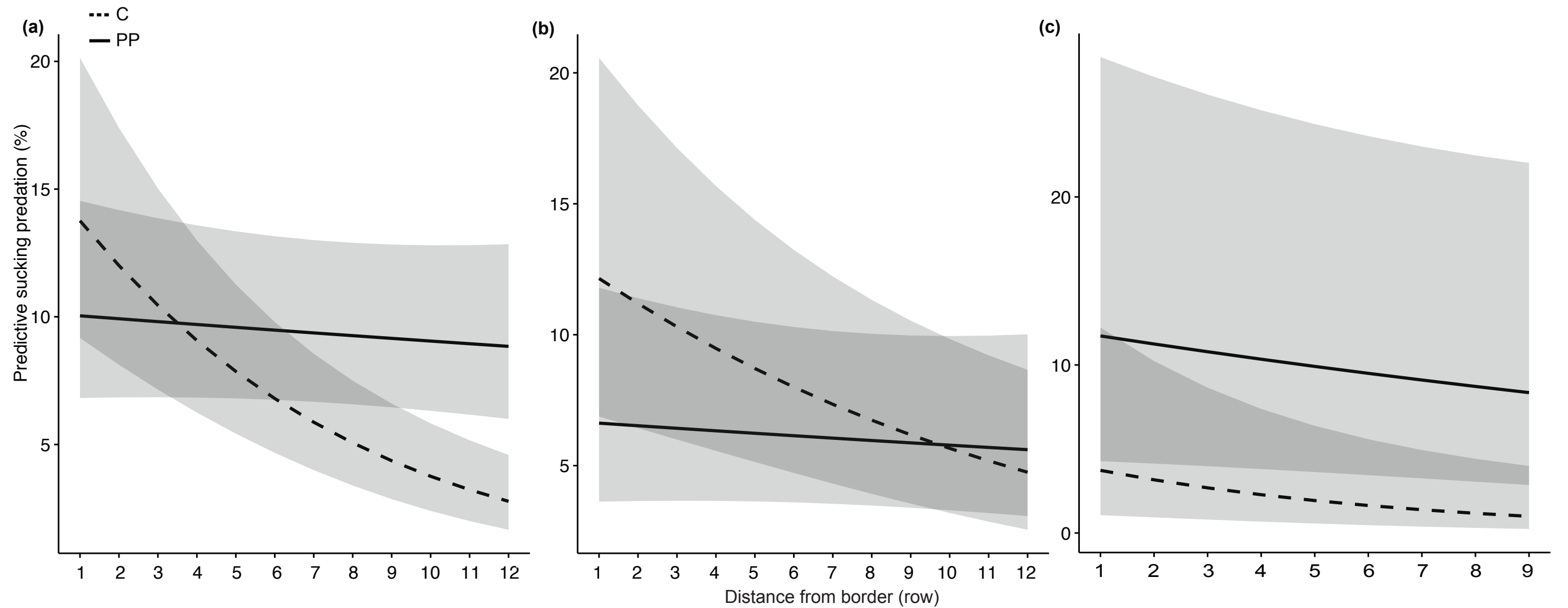


Fig. 4. Predicted probability of sucking predation per egg mass in field corn plots at WM in (a) 2014, (b) 2015 and in (c) CM in 2015. Shaded areas represent 95% confidence interval bands. Distance is measured in row interval from plot border (1) to plot interior (12 or 9, in WM and CM, respectively).

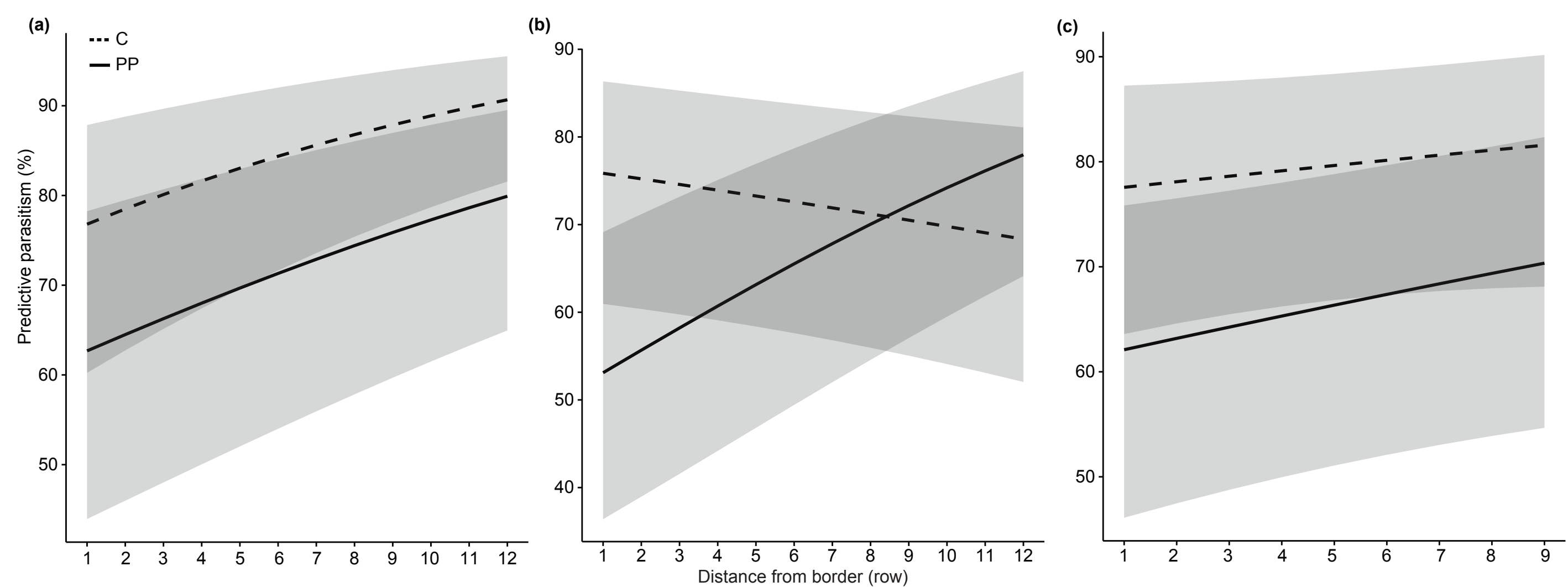


Fig. 5. Predicted probability of egg mass parasitism (%) in field corn plots at WM in (a) 2014, (b) 2015 and in (c) CM in 2015. Shaded areas represent 95% confidence interval bands. Distance is measured in row interval from plot border (1) to plot interior (12 or 9, in WM and CM, respectively).

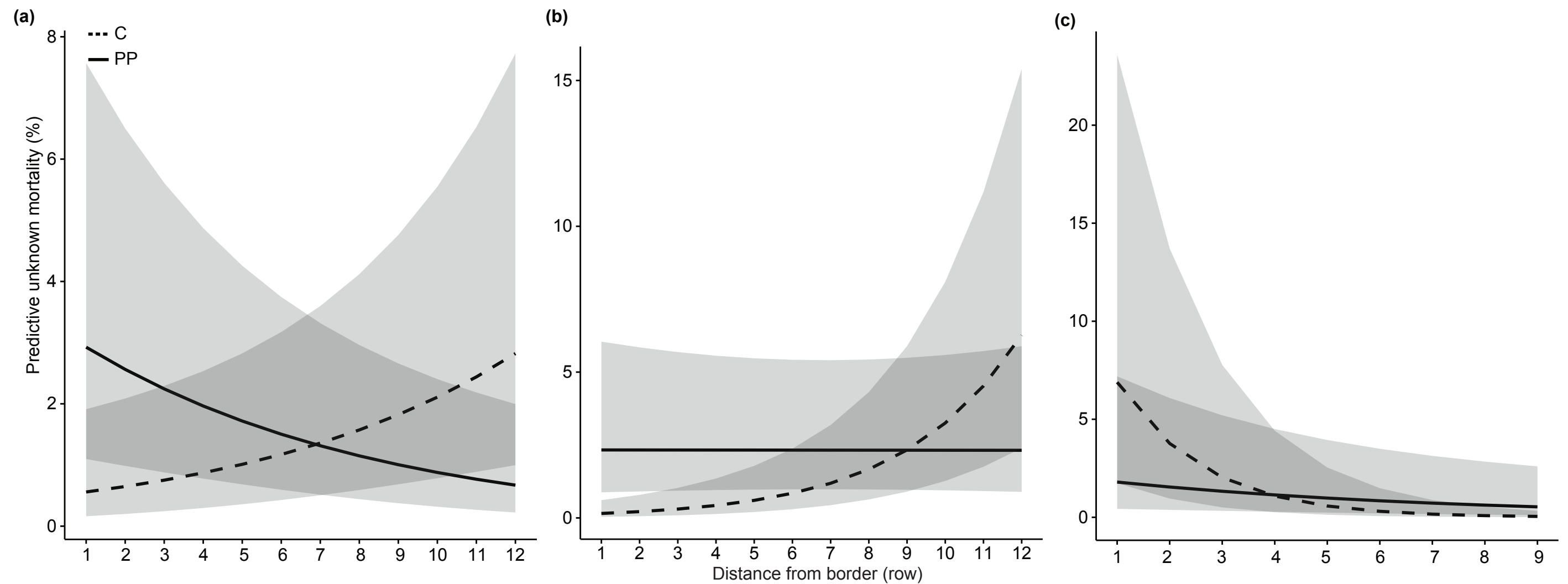


Fig. 6. Predicted probability of egg mass mortality (%) due to unknown causes in field corn plots at WM in (a) 2014, (b) 2015 and in (c) CM in 2015. Shaded areas represent 95% confidence interval bands. Distance is measured in row interval from plot border (1) to plot interior (12 or 9, in WM and CM, respectively).

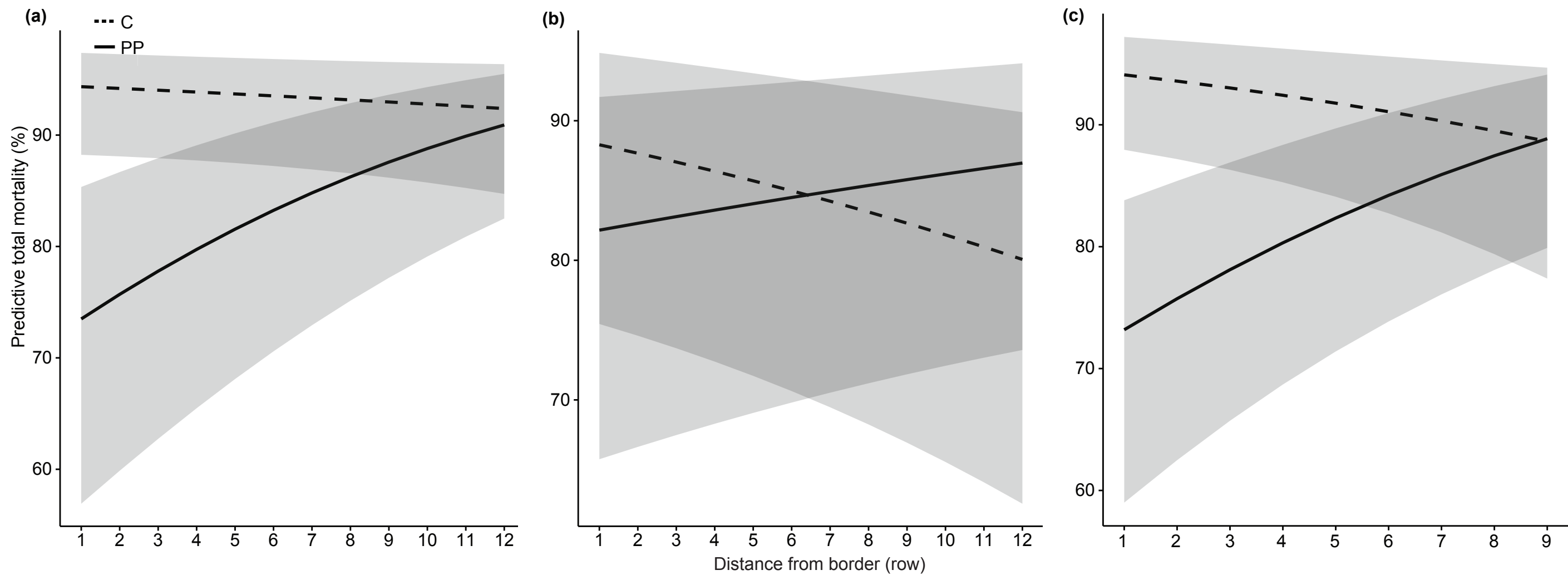


Fig. 7. Predicted probability of total mortality per egg mass in field corn plots at WM in (a) 2014, (b) 2015 and in (c) CM in 2015. Shaded areas represent 95% confidence interval bands. Distance is measured in row interval from plot border (1) to plot interior (12 or 9, in WM and CM, respectively).

Table 1. Mean yield ( $\pm$  SEM) of field corn bordered by partridge pea (PP) and grown in monoculture/control (C) plots at WM in 2014 and 2015, and CM in 2015. Yield is measured in metric tonnes per hectare.

	WM		CM
	2014	2015	2015
Partridge pea	8.6 $\pm$ 0.4	7.8 $\pm$ 0.8	7.6 $\pm$ 0.0
Control	8.8 $\pm$ 0.8	8.5 $\pm$ 0.7	7.8 $\pm$ 0.8

Table 2. Cost and return (USD\$) of organic field corn yield bordered by partridge pea (PP) and grown in monoculture/control (C) plots at WM in 2014 and 2015, and CM in 2015.

	WM				CM	
	2014		2015		2015	
	C	PP	C	PP	C	PP
Cost per acre	8.60	9.16	8.14	9.53	10.11	9.42
Profit per acre	4.73	4.44	5.21	4.14	3.32	4.24



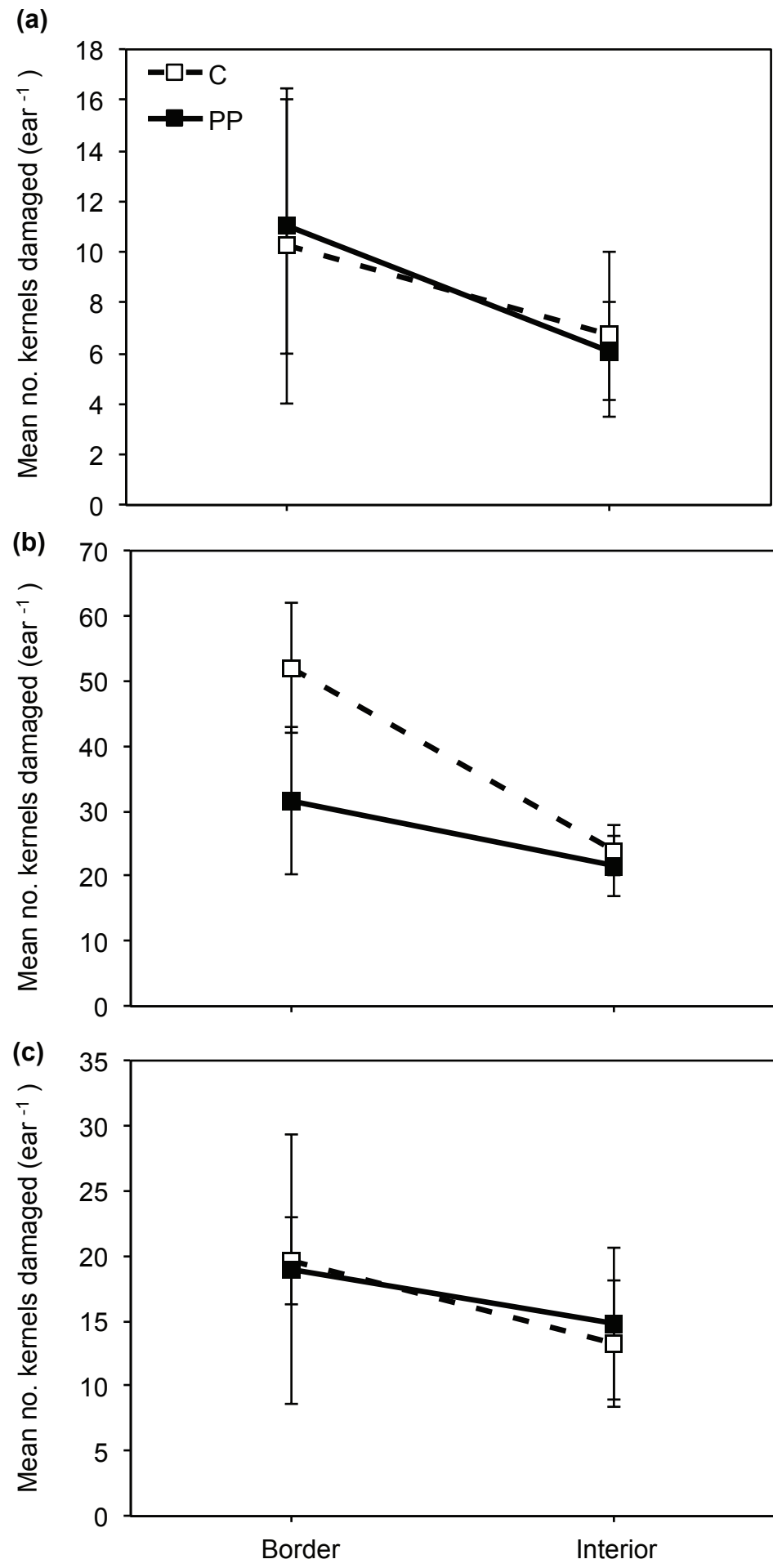


Fig. 8. Mean ( $\pm$  SEM) number of field corn kernels per ear damaged by stink bugs at WM in 2014 (a), WM in 2015 (b) and CM in 2015 (c) in plot border and interior regions.

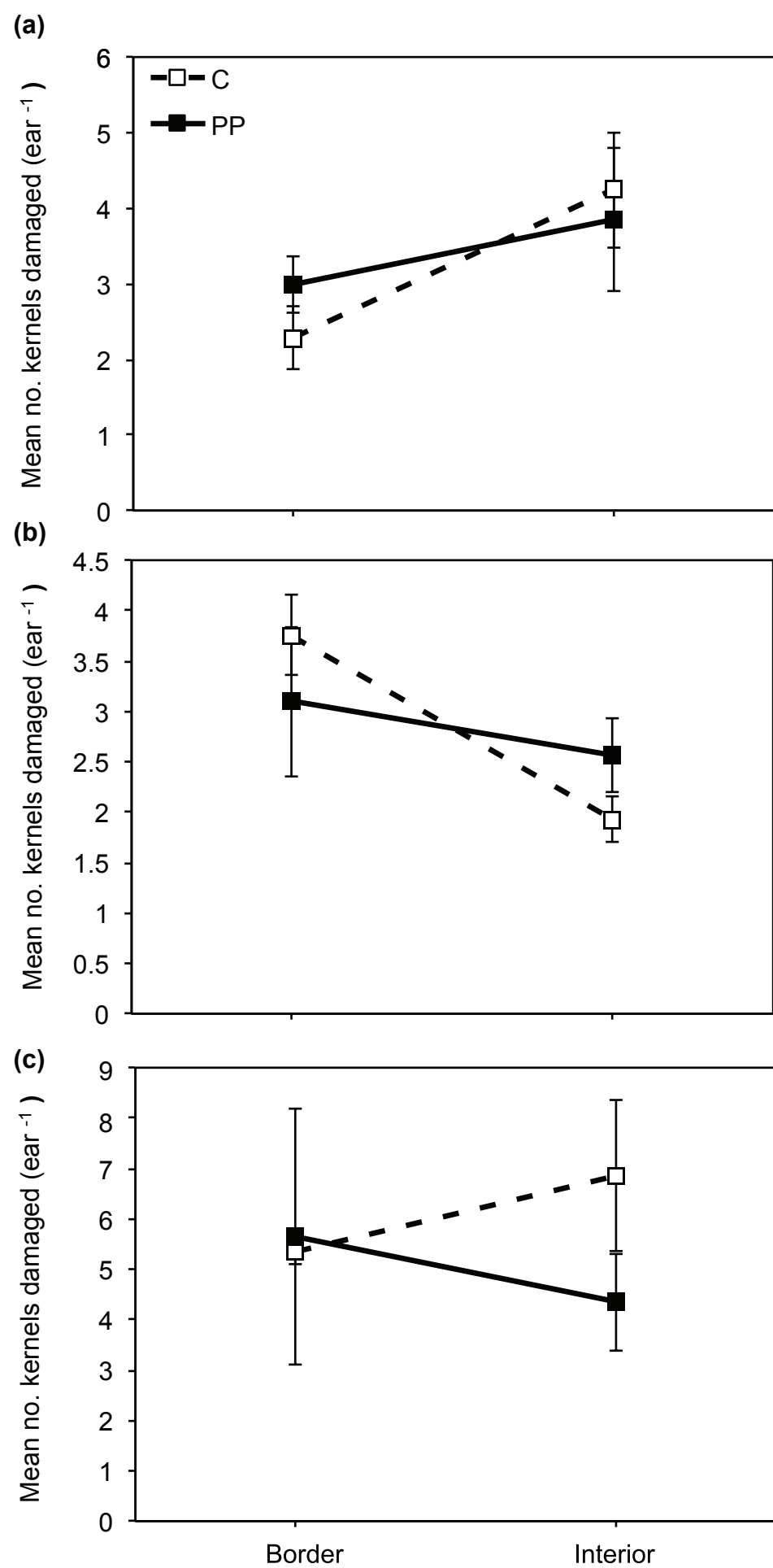


Figure 9. Mean ( $\pm$  SEM) number of field corn kernels per ear damaged by sap beetles at WM in 2014 (a), WM in 2015 (b) and CM in 2015 (c) in plot border and interior regions.

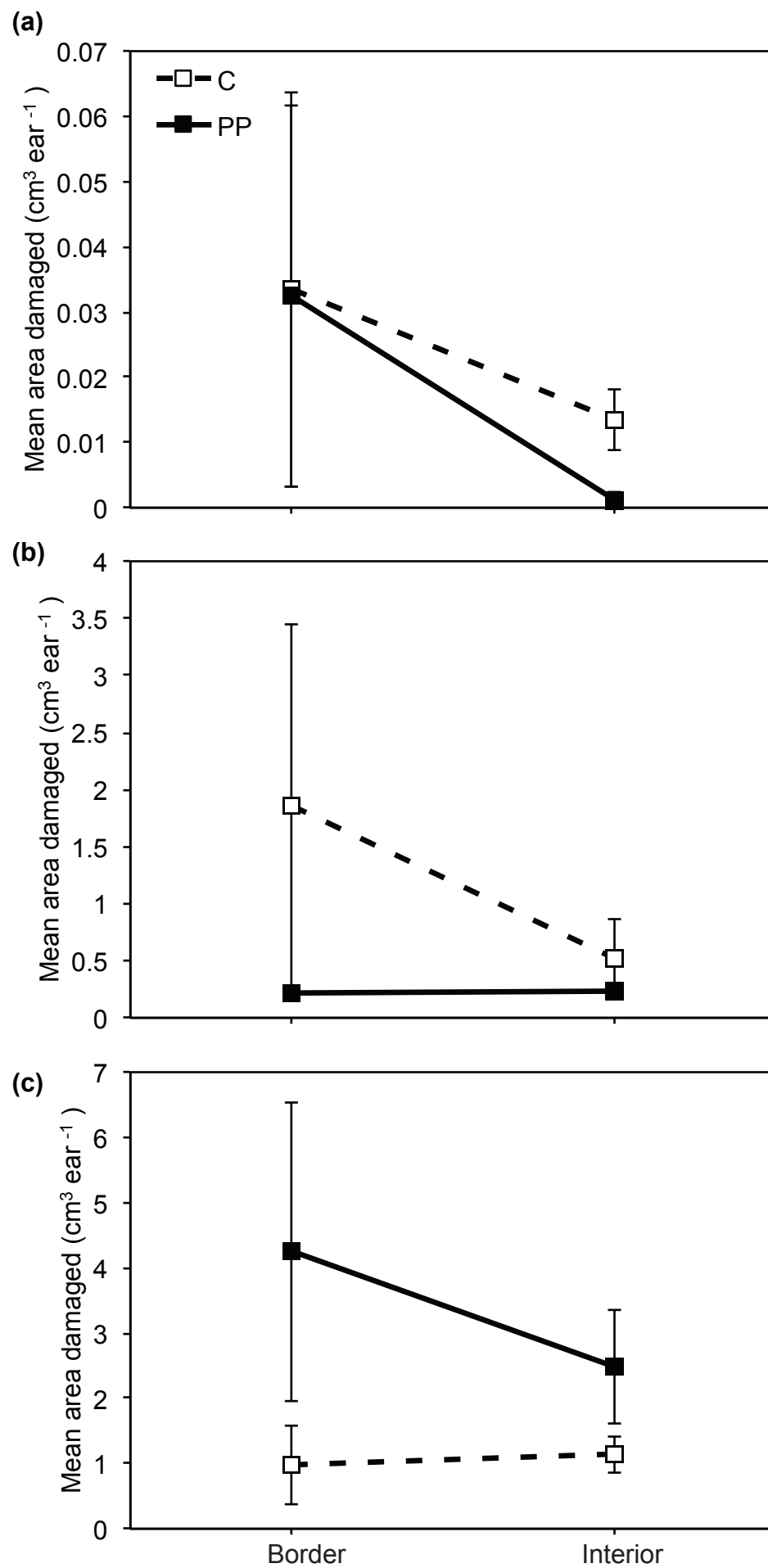


Figure 10. Mean ( $\pm$  SEM) area of field corn ear damaged by European corn borers at WM in 2014 (a), WM in 2015 (b) and CM in 2015 (c) in plot border and interior regions.

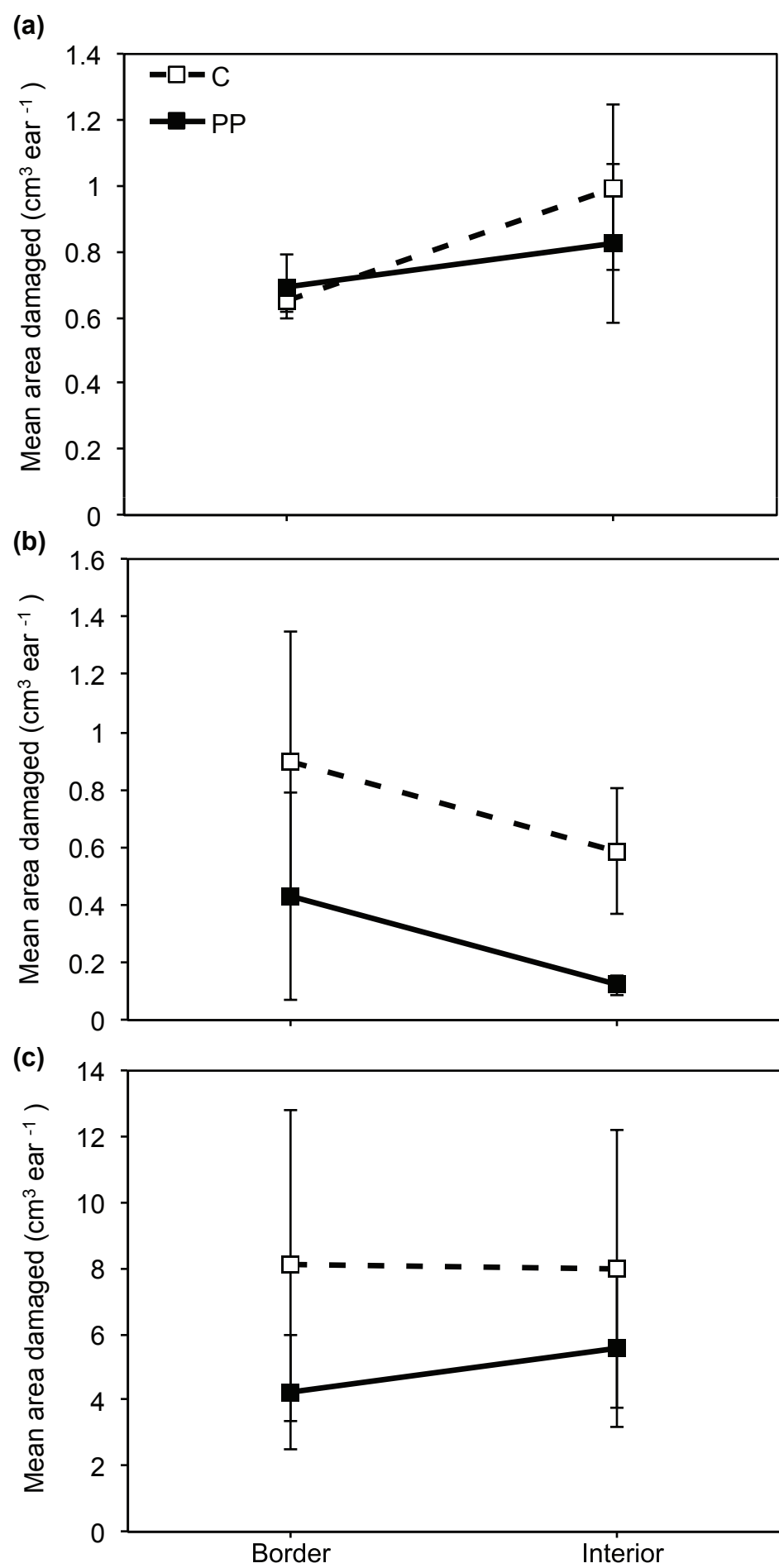


Figure 11. Mean ( $\pm$  SEM) area of field corn ear damaged by corn earworms at WM in 2014 (a), WM in 2015 (b) and CM in 2015 (c) in plot border and interior regions.

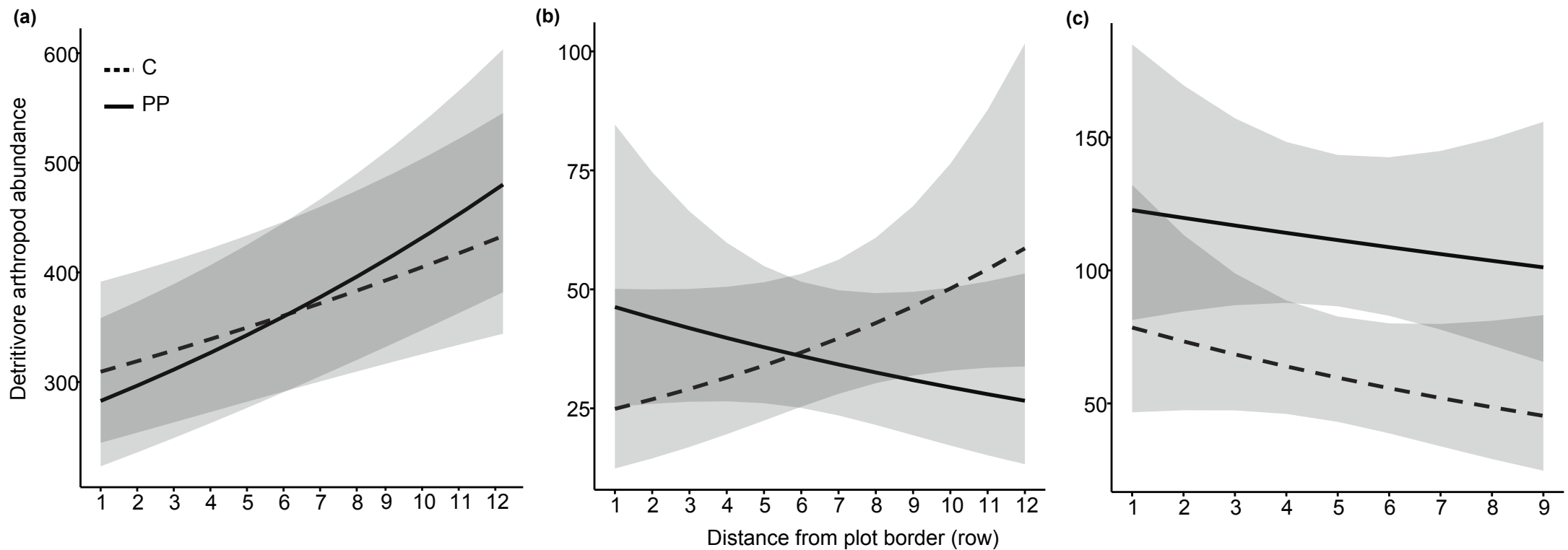


Fig. 12. Total detritivore arthropod community observed in visual assessments in field corn plots at WM in (a) 2014, (b) 2015 and in (c) CM in 2015. Shaded areas represent 95% confidence interval bands. Distance is measured in row interval from plot border (1) to plot interior (12 or 9, in WM and CM, respectively).

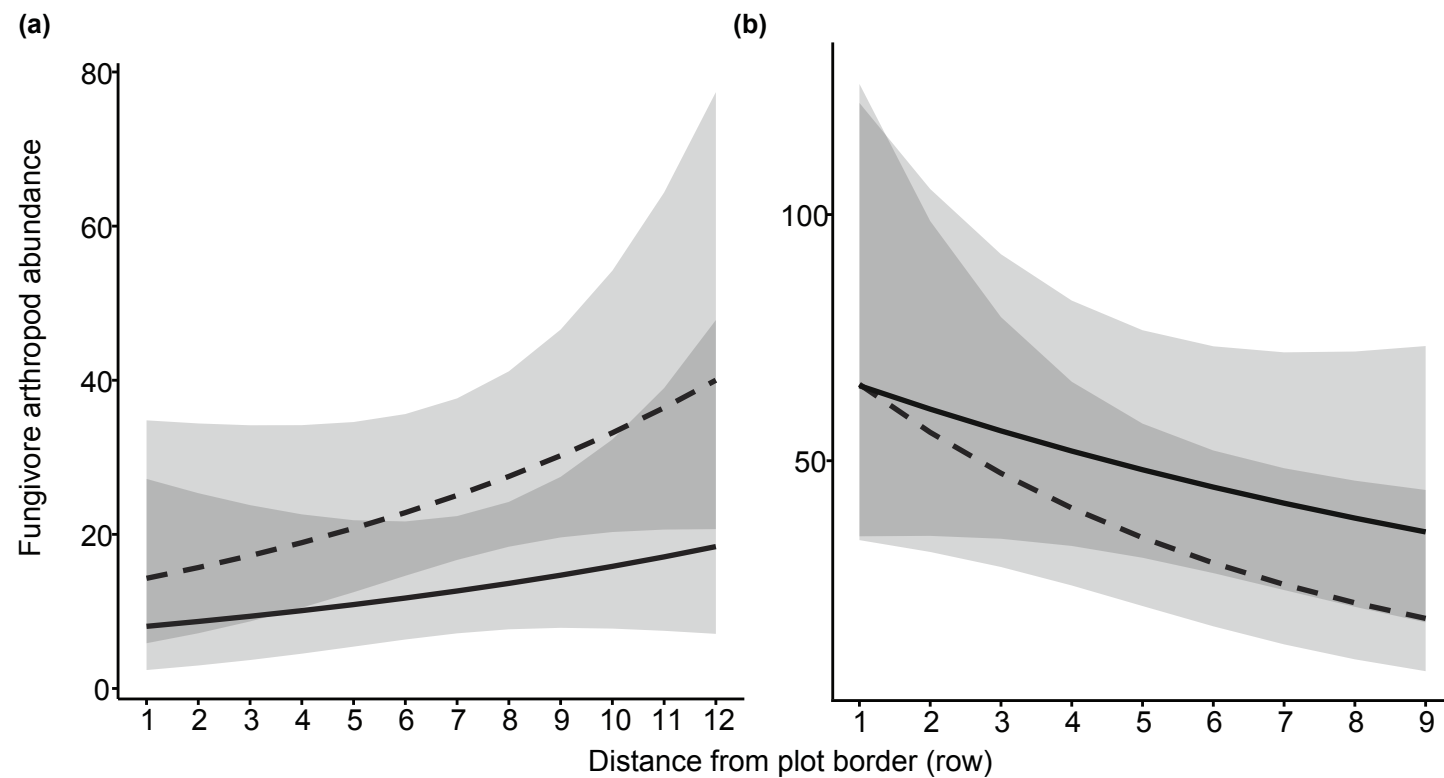


Fig.13. Total fungivore arthropod community observed in visual assessments in field corn plots at (a) WM and (b) CM in 2015. No fungivorous taxa were detected at WM in 2014. Shaded areas represent 95% confidence interval bands. Distance is measured in row interval from plot border (1) to plot interior (12 or 9, in WM and CM, respectively).

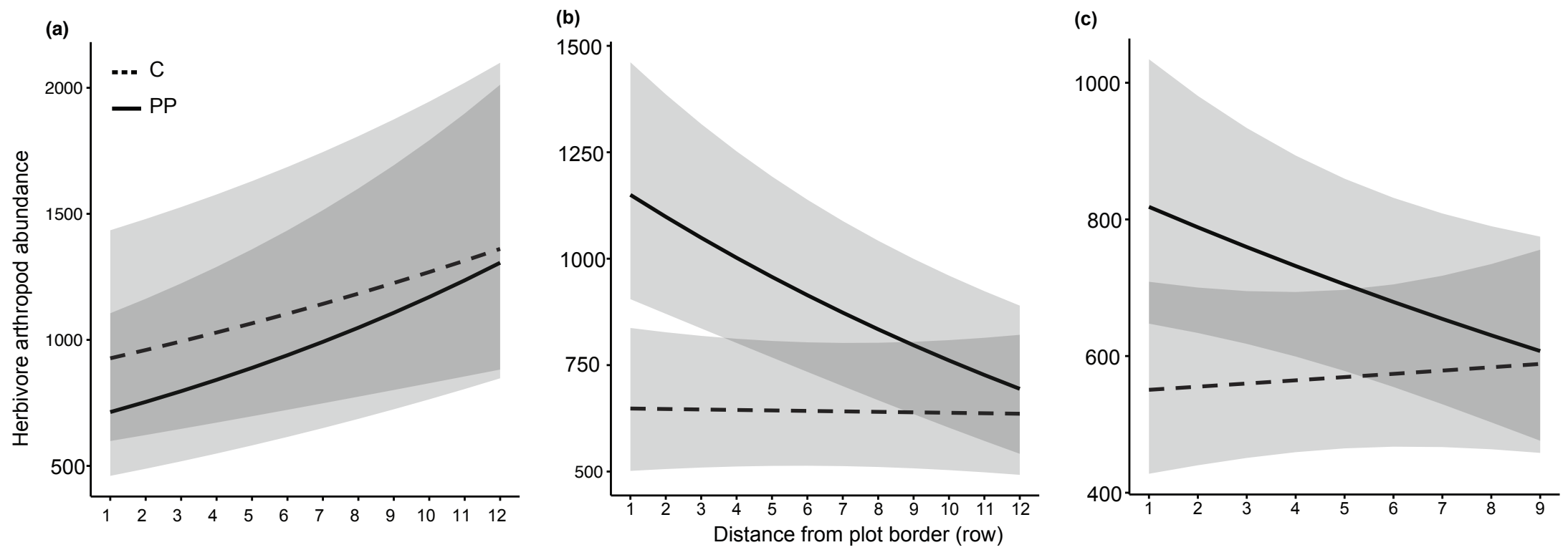


Figure 14. Total herbivore arthropod community observed in visual assessments in field corn plots at WM in (a) 2014, (b) 2015 and in (c) CM in 2015. Shaded areas represent 95% confidence interval bands. Distance is measured in row interval from plot border (1) to plot interior (12 or 9, in WM and CM, respectively).

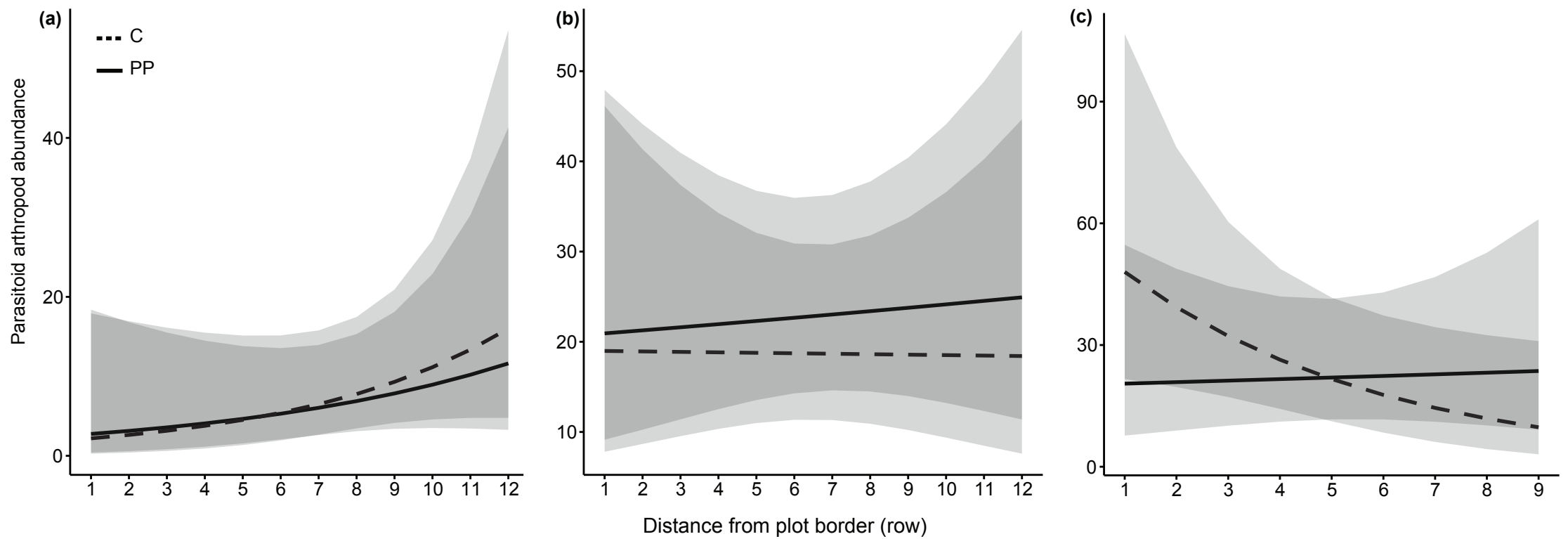


Fig. 15. Total parasitoid arthropod community observed in visual assessments in field corn plots at WM in (a) 2014, (b) 2015 and in (c) CM in 2015. Shaded areas represent 95% confidence interval bands. Distance is measured in row interval from plot border (1) to plot interior (12 or 9, in WM and CM, respectively).

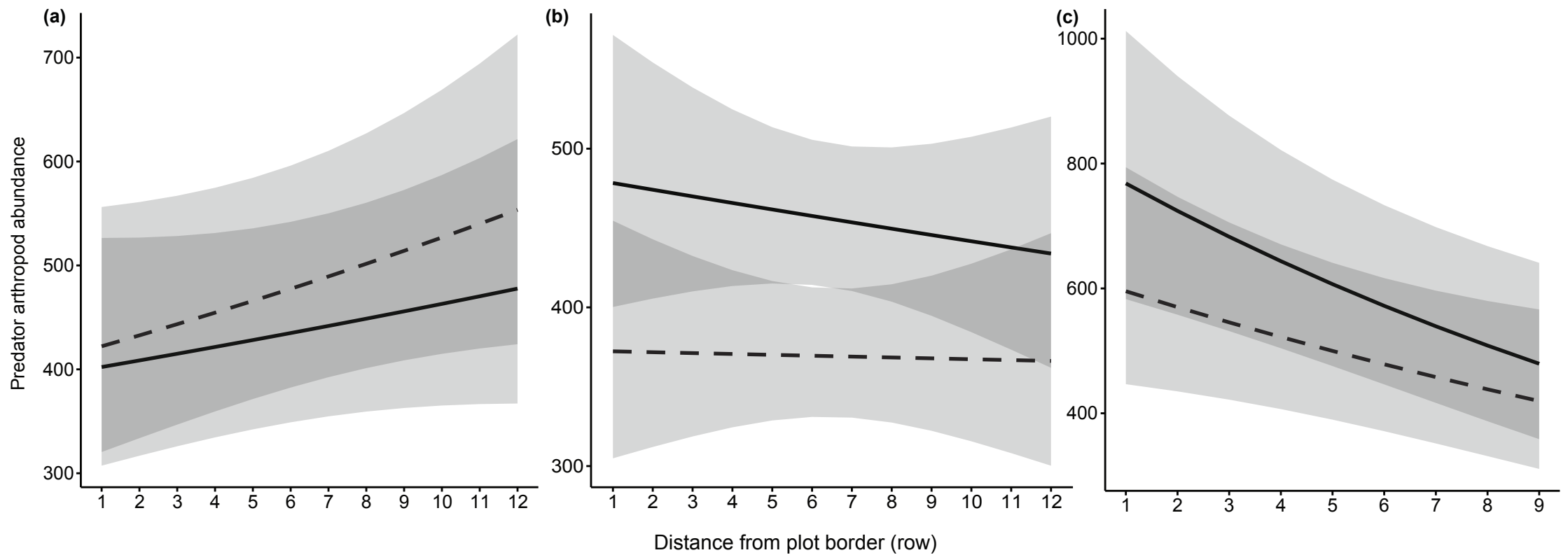


Fig. 16. Total predator arthropod community observed in visual assessments in field corn plots at WM in (a) 2014, (b) 2015 and in (c) CM in 2015. Shaded areas represent 95% confidence interval bands. Distance is measured in row interval from plot border (1) to plot interior (12 or 9, in WM and CM, respectively).

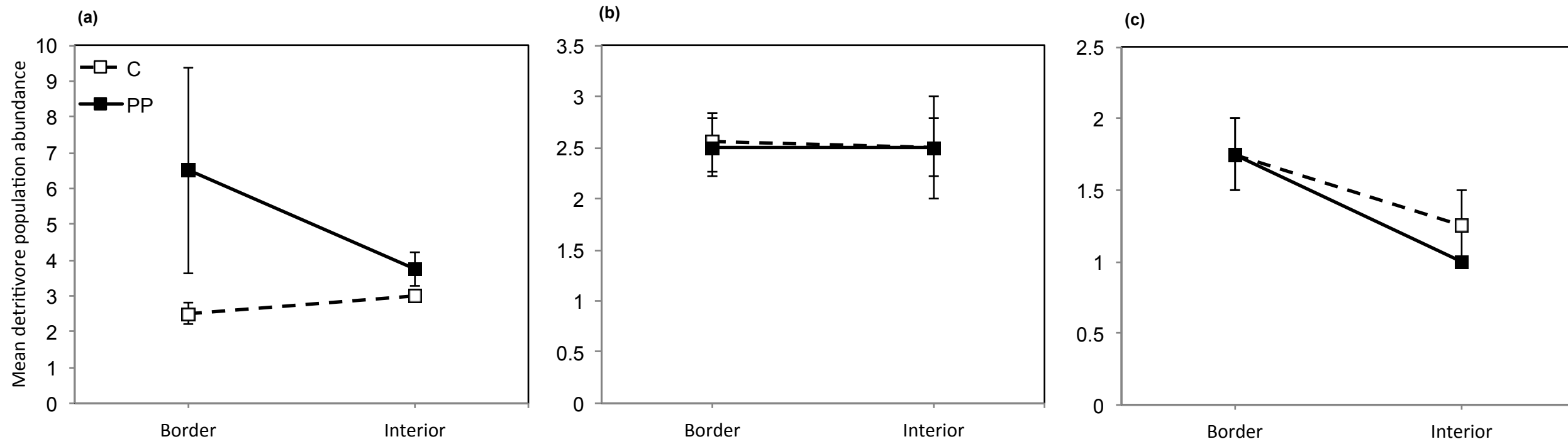


Fig. 17. Mean detritivore arthropod community (per plot) collected on sticky cards in field corn plots at (a) WM in 2014, (b) WM in 2015 and (c) CM in 2015. Abundances were pooled across weeks averaged by replicate, treatment and location. One sticky card was placed within the partridge pea stand (PP) or the natural vegetation area (C) adjacent to each border of each treatment plot. Plot interiors had 3 sticky card traps following an equidistant linear transect through the plot.

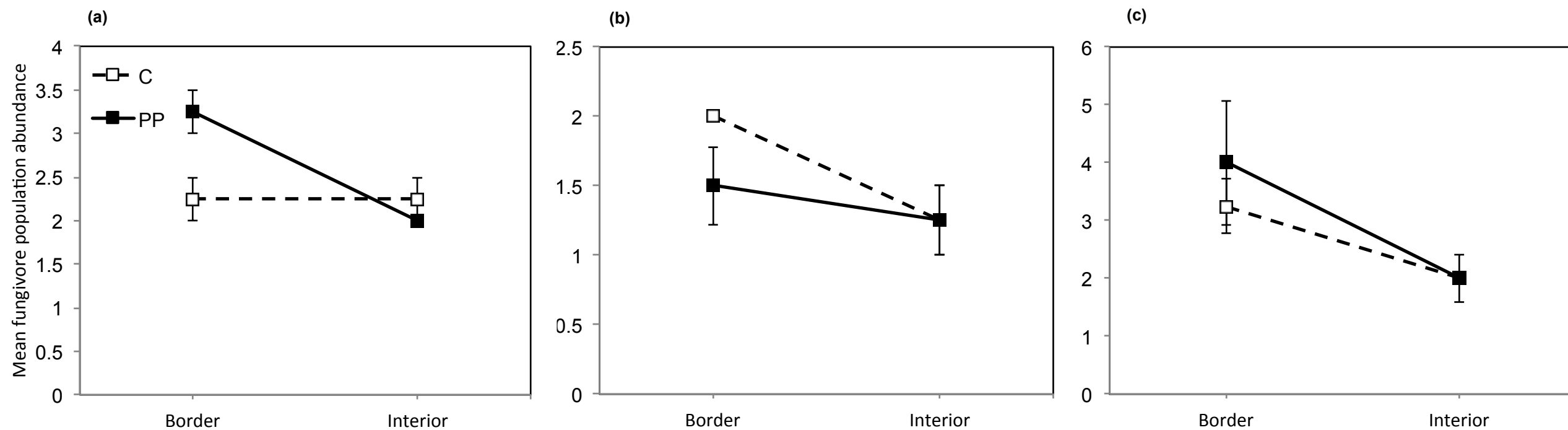


Fig. 18. Mean fungivore arthropod community (per plot) collected on sticky cards in field corn plots at (a) WM in 2014, (b) WM in 2015 and (c) CM in 2015. Abundances were pooled across weeks averaged by replicate, treatment and location. One sticky card was placed within the partridge pea stand (PP) or the natural vegetation area (C) adjacent to each border of each treatment plot. Plot interiors had 3 sticky card traps following an equidistant linear transect through the plot.



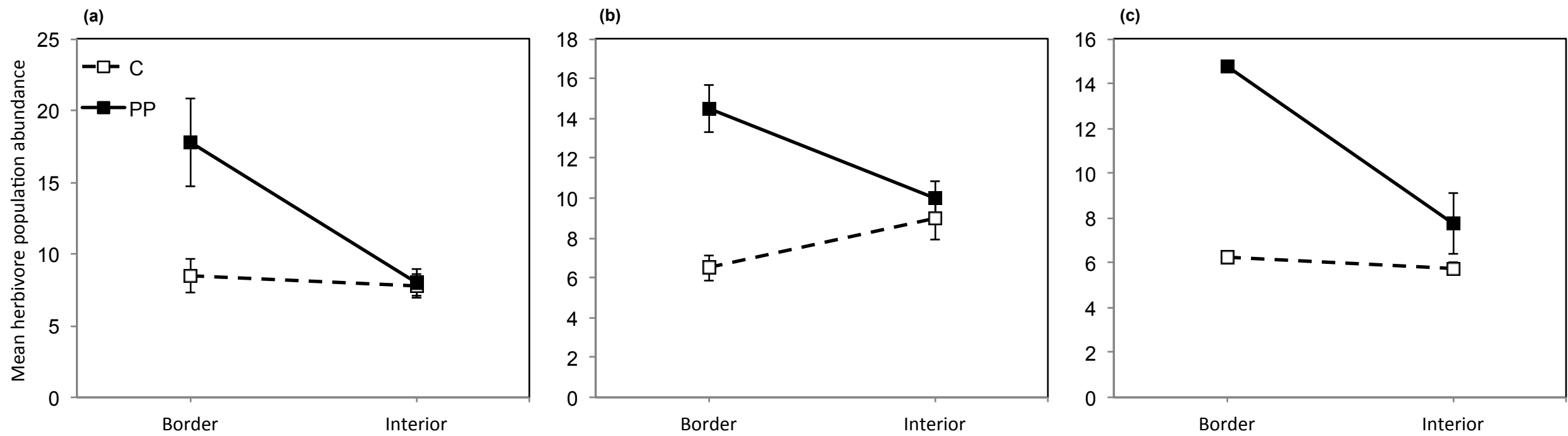


Fig. 19. Mean herbivore arthropod community (per plot) collected on sticky cards in field corn plots at (a) WM in 2014, (b) WM in 2015 and (c) CM in 2015. Abundances were pooled across weeks and averaged by replicate, treatment and location. One sticky card was placed within the partridge pea stand (PP) or the natural vegetation area (C) adjacent to each border of each treatment plot. Plot interiors had 3 sticky card traps following an equidistant linear transect through the plot.

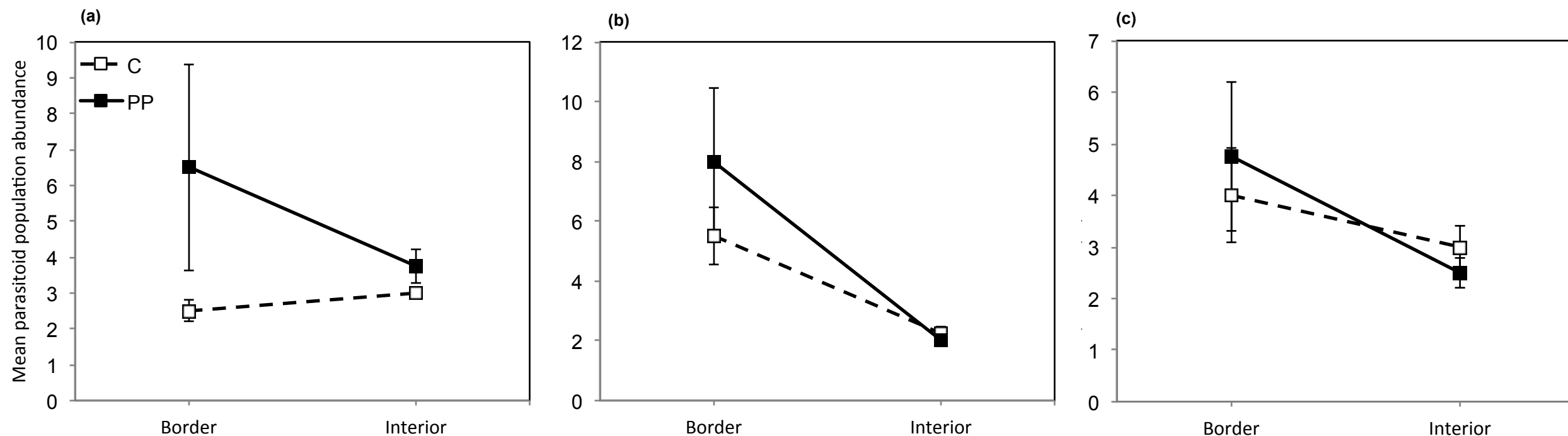


Fig. 20. Mean parasitoid arthropod community collected on sticky cards (per plot) in field corn plots at (a) WM in 2014, (b) WM in 2015 and (c) CM in 2015. Abundances were pooled across weeks averaged by replicate, treatment and location. One sticky card was placed within the partridge pea stand (PP) or the natural vegetation area (C) adjacent to each border of each treatment plot. Plot interiors had 3 sticky card traps following an equidistant linear transect through the plot.

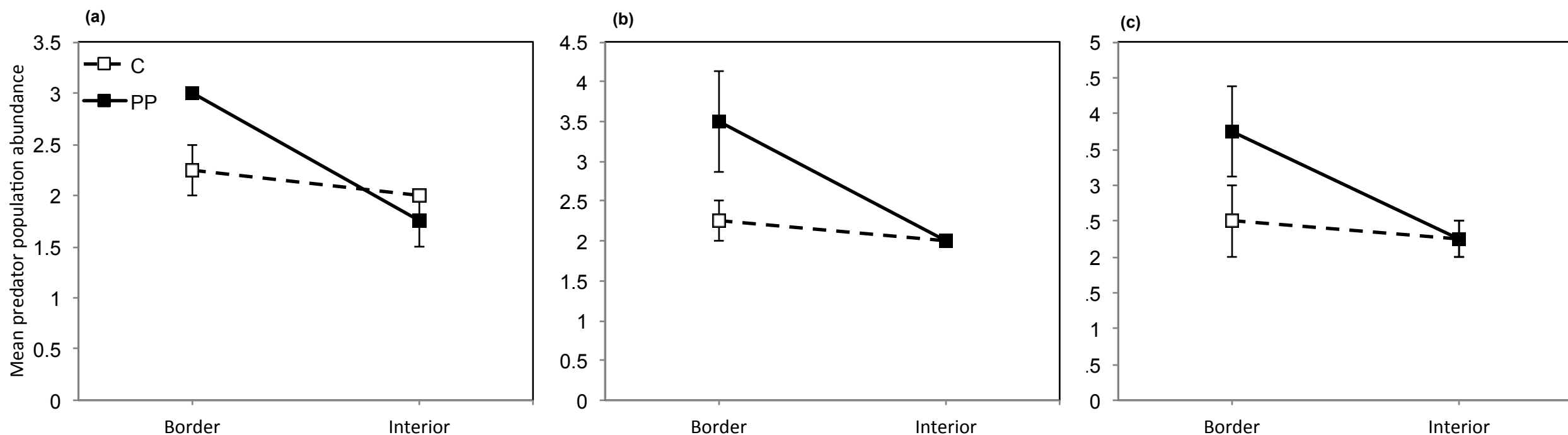


Fig. 21. Mean predator arthropod community collected on sticky cards (per plot) in field corn plots at (a) WM in 2014, (b) WM in 2015 and (c) CM in 2015. Abundances were pooled across weeks averaged by replicate, treatment and location. One sticky card was placed within the partridge pea stand (PP) or the natural vegetation area (C) adjacent to each border of each treatment plot. Plot interiors had 3 sticky card traps following an equidistant linear transect through the plot.

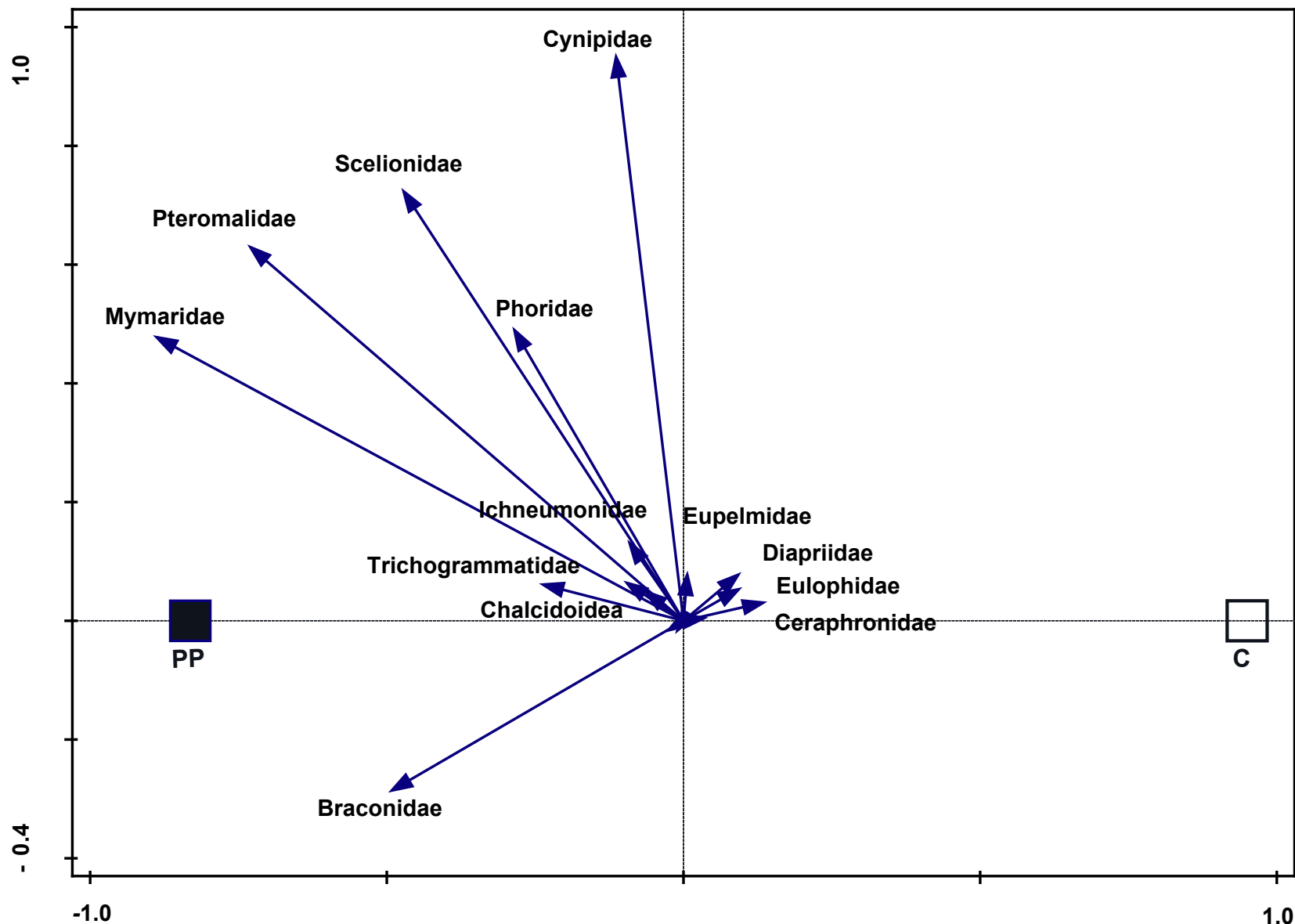


Figure 22. Redundancy analysis (RDA) biplot illustrating the relationship between partridge pea (PP) and monoculture/control (C) and composition of taxa in parasitic communities in WM in 2014. The first two axes explained 39.0% of the variation in the parasitic taxa data due to treatment. The parasitic community of PP was clearly and significantly separated from the C treatment (499 Monte Carlo permutations,  $P = 0.002$ ).

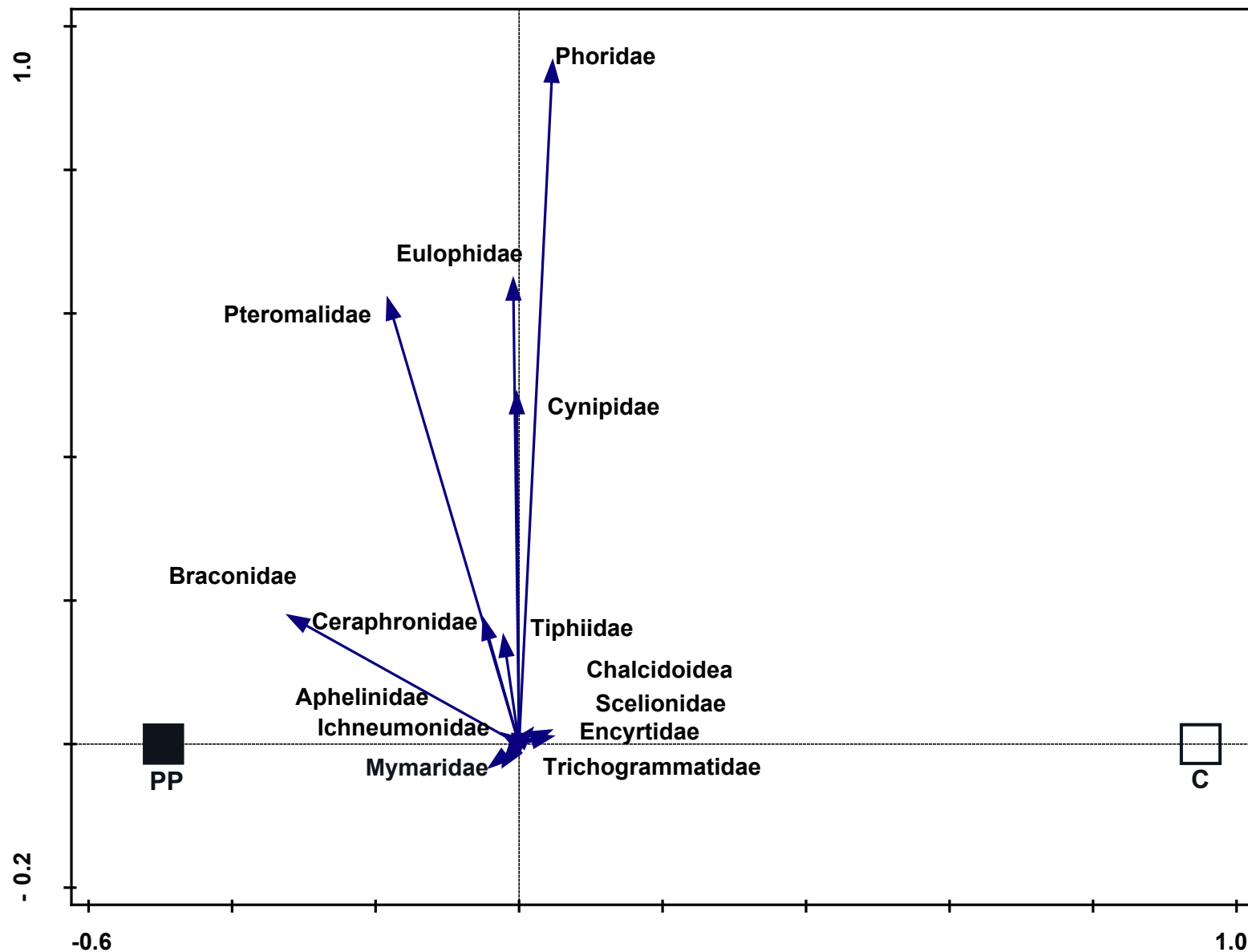


Figure 23. Redundancy analysis (RDA) biplot illustrating the relationship between partridge pea (PP) and monoculture/control (C) and composition of taxa in parasitic communities in WM in 2015. The first two axes explained 56.6% of the variation in the parasitic taxa data due to treatment. The parasitic community of PP was not distinct from that of the C treatment (499 Monte Carlo permutations,  $P = 0.306$ ).

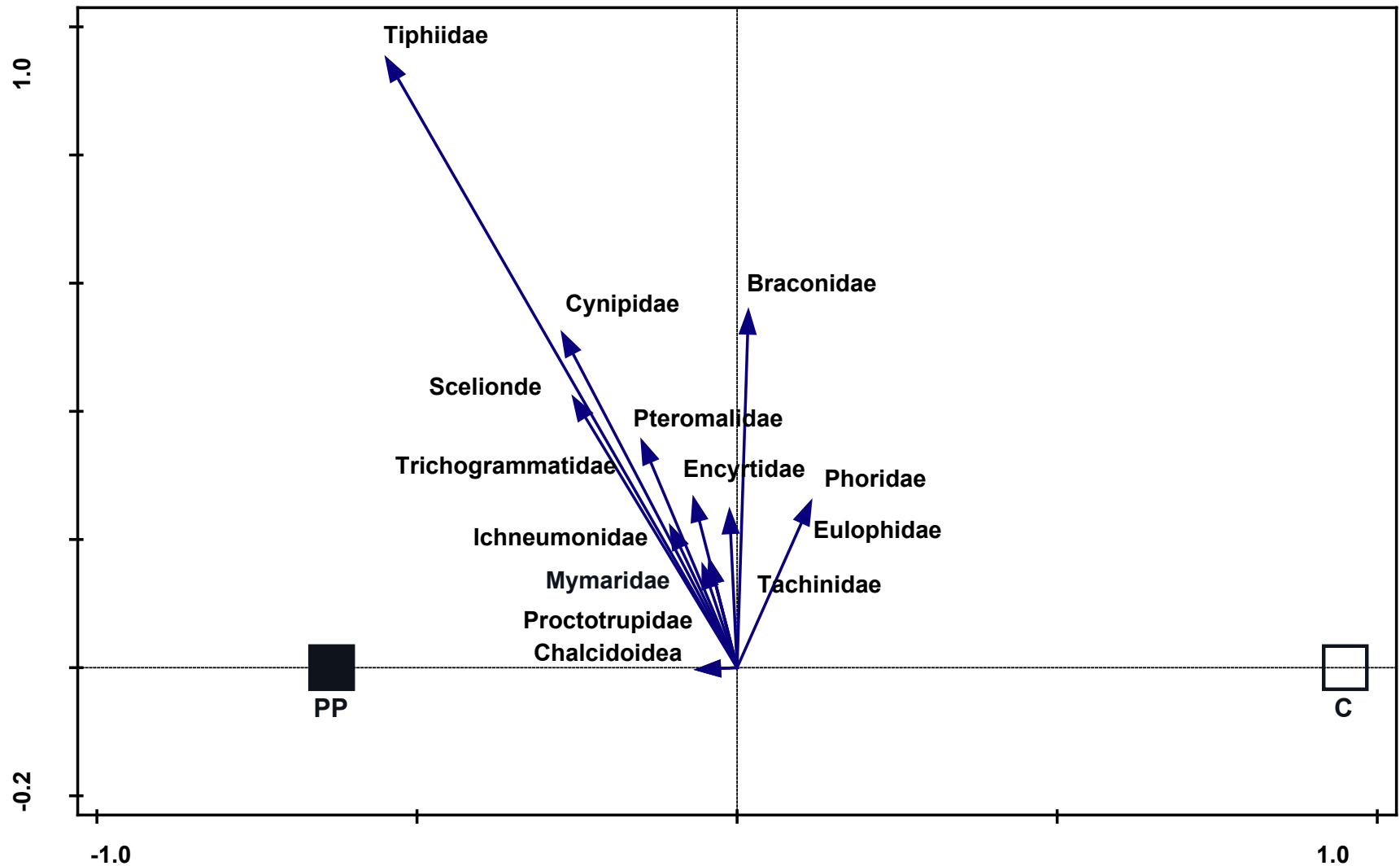


Figure 24. Redundancy analysis (RDA) biplot illustrating the relationship between partridge pea (PP) and monoculture/control (C) and composition of taxa in parasitic communities in CM in 2015. The first two axes explained 50.2% of the variation in the parasitic taxa data due to treatment. The parasitic community of PP was not distinct from that of the C treatment (499 Monte Carlo permutations,  $P = 0.068$ ).



**(a)** European corn borer damage



**(b)** Corn earworm damage



**(c)** Sap beetle damage



**(d)** Stink bug damage

Appendix A. Photos showing indicative visual symptoms of damage types due to field corn arthropods. European corn borer damage and corn earworm damage was measured in  $\text{cm}^2/\text{ear}$ . Sap beetle and stink bug damaged was measured in number of kernels.

(a)

<b>CORN GRAIN, CERTIFIED ORGANIC with PARTRIDGE PEA CRP</b> <b>0.85 Acre Corn: 0.15 Acre Partridge pea</b>				<b>2014</b>
ITEM	UNIT	QUANTITY	PRICE	TOTAL
<b>GROSS INCOME</b>				
CRP CONSERVATION PAYMENT	ACRE	0.15	\$154.89	\$23.23
COVER CROP PAYMENT	ACRE	1	\$45.00	\$45.00
CORN GRAIN	BUSHEL	BU/AC (0.85)	\$13.00	\$1,513.85
TOTAL				\$1,582.08
<b>VARIABLE COSTS</b>				
HAIRY VETCH SEED	POUND	10	\$3.46	\$34.60
RYE SEED	POUND	65	\$0.25	\$16.25
CRIMSON CLOVER SEED	POUND	16	\$1.80	\$28.80
PARTRIDGE PEA SEED	POUND	1.8	\$10.00	\$18.00
CORN SEED	1000 SEEDS	27	\$2.71	\$86.80
FERTILIZER, POULTRY MANURE	TON	1.377	\$400.00	\$550.80
LIME	TON	0.5	\$42.31	\$21.16
SOIL TEST	ACRE	1	\$0.30	\$0.30
CROP INSURANCE (RP 75%)	ACRE	0.85	\$29.07	\$24.71
INTEREST ON OPERATING CAPITAL	\$756.71	0.5	8.5%	\$32.16
TOTAL VARIABLE COSTS LISTED ABOVE				\$813.57
<b>FIXED/OVERHEAD COSTS</b>				
SEEDING OF COVER CROP	ACRE	0.85	\$14.49	\$12.32
MOWING	ACRE	0.85	\$43.53	\$43.53
VERTICAL TILLAGE	ACRE	0.85	\$18.41	\$15.65
DISKING WITH CULTIPACKER OR HARROW	ACRE	0.15	\$23.12	\$3.47
SEEDING OF PP	ACRE	0.15	\$20.91	\$3.14
CORN PLANTING - NOTILL W/O FERTILIZER	ACRE	0.85	\$21.56	\$18.33
FERTILIZER APPLICATION SIDEDRESS	ACRE	0.85	\$10.87	\$9.24

HARVESTING	ACRE	0.85	\$35.00	\$29.75
HAULING	BUSHEL	116.45	\$0.19	\$22.13
LAND CHARGE	ACRE	1	\$98.00	\$98.00
TOTAL FIXED COST LISTED ABOVE				\$255.54
TOTAL VARIABLE AND FIXED COST LISTED ABOVE				\$1,069.11
NET INCOME OVER VARIABLE & FIXED COSTS LISTED ABOVE				\$512.97
		PRICES		
NET INCOME ABOVE VARIABLE AND FIXED COSTS LISTED ABOVE FOR VARIOUS YIELDS AND PRICES	YIELDS	\$9.75	\$13.00	\$16.25
	87.3375	(\$217.57)	\$66.27	\$350.12
	116.45	\$66.27	\$444.74	\$823.20
	145.5625	\$350.12	\$823.20	\$1,296.28

(b)

CORN GRAIN, CERTIFIED ORGANIC, MONOCULTURE 1 Acre Corn				2014
ITEM	UNIT	QUANTITY	PRICE	TOTAL
<b>GROSS INCOME</b>				
COVER CROP PAYMENT	ACRE	1	\$45.00	\$45.00
CORN GRAIN	BUSHEL	BU/AC	\$13.00	\$1,933.40
TOTAL				\$1,978.40
<b>VARIABLE COSTS</b>				
HAIRY VETCH SEED	POUND	10	\$3.46	\$34.60
RYE SEED	POUND	65	\$0.25	\$16.25
CRIMSON CLOVER SEED	POUND	16	\$1.80	\$28.80
CORN SEED	1000 SEEDS	32	\$2.71	\$86.80
FERTILIZER, POULTRY MANURE	TON	1.62	\$400.00	\$648.00
LIME	TON	0.5	\$42.31	\$21.16
SOIL TEST	ACRE	1	\$0.30	\$0.30
CROP INSURANCE (RP 75%)	ACRE	1	\$29.07	\$29.07
INTEREST ON OPERATING CAPITAL	\$835.91	0.5	8.5%	\$35.53
TOTAL VARIABLE COSTS LISTED ABOVE				\$900.50



<b>FIXED/OVERHEAD COSTS</b>				
SEEDING OF COVER CROP	ACRE	1	\$14.49	\$14.49
MOWING	ACRE	1	\$43.53	\$43.53
VERTICAL TILLAGE	ACRE	1	\$18.41	\$18.41
CORN PLANTING - NOTILL W/O FERTILIZER	ACRE	1	\$21.56	\$21.56
FERTILIZER APPLICATION SIDEDRESS	ACRE	1	\$10.87	\$10.87
HARVESTING	ACRE	1	\$35.00	\$35.00
HAULING	BUSHEL	148.723	\$0.19	\$28.26
LAND CHARGE	ACRE	1	\$98.00	\$98.00
TOTAL FIXED COST LISTED ABOVE				\$270.12
TOTAL VARIABLE AND FIXED COST LISTED ABOVE				\$1,170.62
NET INCOME OVER VARIABLE & FIXED COSTS LISTED ABOVE				\$807.78
NET INCOME ABOVE VARIABLE AND FIXED COSTS LISTED ABOVE FOR VARIOUS YIELDS AND PRICES			PRICES	
	YIELDS		\$9.75	\$13.00
	111.54225		(\$83.08)	\$279.43
	148.723		\$279.43	\$762.78
	185.90375		\$641.94	\$1,246.13
				\$1,850.32

**Crop Budget Assumptions:**

Custom rates are used as a proxy for field operation costs

Local hauling within 30 miles of farm

Fertility rates based on MCE SFM-1 guidelines

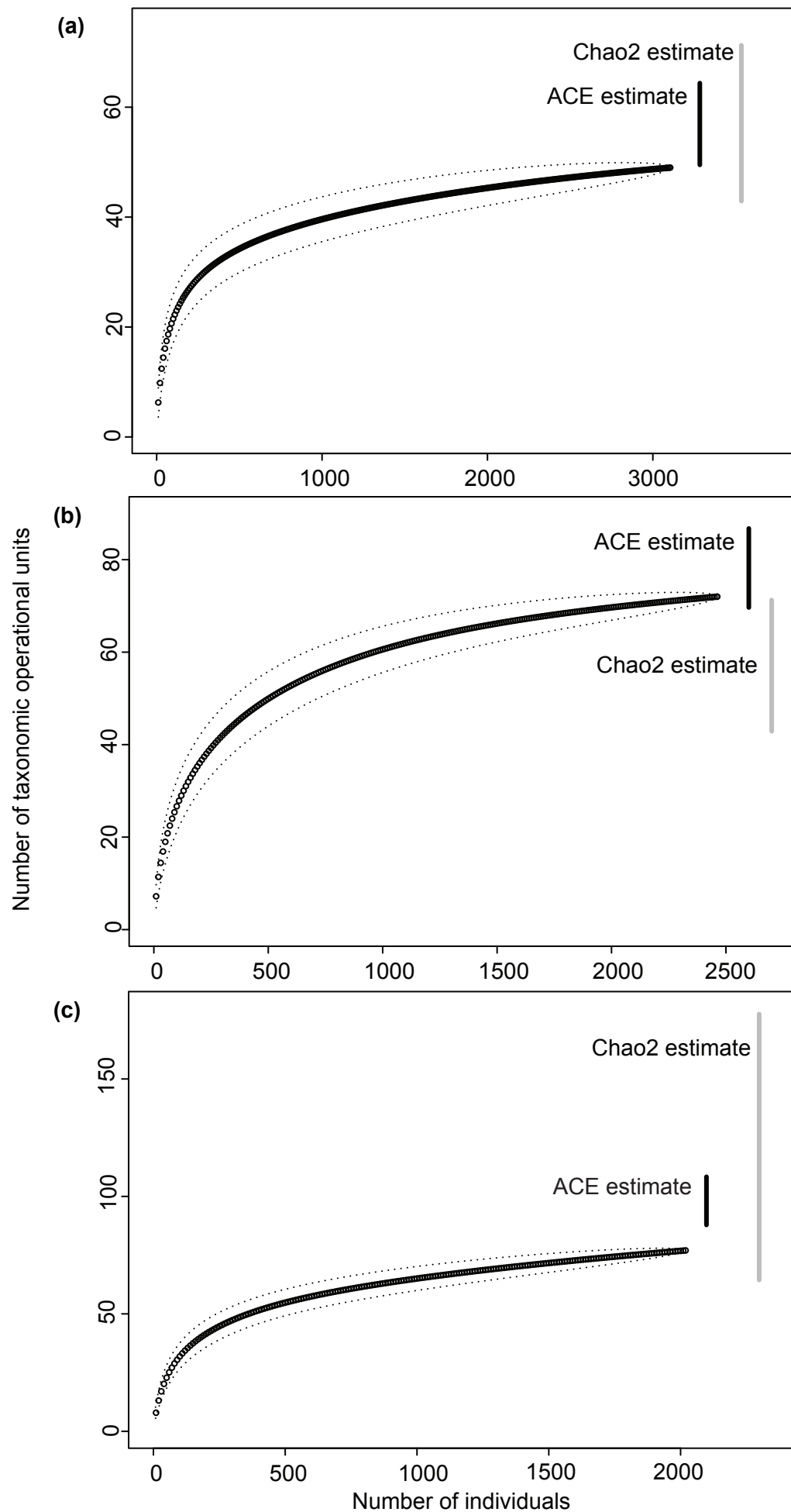
Assuming medium fertility levels

Sensitivity analysis based on 75%, 100% and 125% of typical yield and current forward contract price.

Appendix B. Sample budget tables used to determine profit/unit for PP (a) and C (b) treatments. Assumptions listed were the same for both treatments. Calculations were made for each yield estimate per replicate for 2014 and 2015 using actual yields and inputs listed in Appendix C.

INPUTS	UNIT	PRICE	PRICE	NOTES
YEAR		2014	2015	
<b>INCOME</b>				
CRP CONSERVATION PAYMENT	ACRE	\$154.89	\$154.89	2014, USDA FSA
COVER CROP PAYMENT	ACRE	\$45.00	\$45.00	MDA, Maryland Agricultural Water Quality Cost-Share
CORN	BUSHEL	\$13.00	\$13.00	2015, MD grower
<b>EXPENSES</b>				
<b>SEED</b>				
HAIRY VETCH	POUND	\$3.46	NA	
RYE SEED	POUND	\$0.25	\$0.25	
CRIMSON CLOVER SEED	POUND	\$1.80	\$1.80	
PARTRIDGE PEA	POUND	\$10.00	\$0.36	
CORN	1,000 SEEDS	\$2.71	\$2.84	
<b>FERTILIZER</b>				
FERTILIZER, POULTRY MANURE	TON	\$400.00	\$300.00	2014: Pellets 3-2-3; 2015: Crumbles 4-3-2
LIME (adjusted, applied every two years)	TON	\$42.31	\$44.86	UMD Extension Custom Rates, 2013 and 2015
<b>OTHER</b>				
SOIL TEST	ACRE	\$0.30	\$0.30	
CROP INSURANCE - Organic Non-Irr. Grain Corn	ACRE	\$29.07	\$29.07	RP 75%, 2016, Queen Anne's Co., MD
<b>FIXED COSTS - Custom Rates</b>				<b>UMD Extension Custom Rates, 2013 and 2015</b>
BROADCAST SEEDING	ACRE	\$14.49	\$9.83	Cover crop, small grain broadcast
MOWING	ACRE	\$43.53	\$31.96	Flail mowed cover crop
VERTICAL TILLAGE	ACRE	\$18.41	\$18.55	
DISKING	ACRE	\$23.12	\$18.70	Partridge pea region planting
NOTILL DRILLING				
SMALL GRAIN	ACRE	\$20.91	\$19.92	
PLANTING				Partridge pea
CORN	ACRE	\$21.56	\$19.30	
SIDEDRESSING	ACRE	\$10.87	\$10.63	
HARVESTING				
CORN	ACRE	\$35.00	\$35.00	UMD Extension 2011 Organic Crop Enterprise Budget
HAULING	BUSHEL	\$0.19	\$0.19	
LAND CHARGE	ACRE	\$98.00	\$98.00	

Appendix C. Table of inputs used in economic analysis. Actual variable costs were used. Fixed cost values were obtained from the custom work charge rates published by the University of Maryland Extension in 2013 and 2015. Average operation costs were used to determine total variable and fixed costs and net income for the corresponding field seasons.



Appendix D. Rarefaction curves modeled to determine robustness of visual assessment samplings. The Chao2 and abundance-based coverage estimator (ACE) estimate the total species richness. Curve asymptotes indicate sufficiency of samples to accurately characterize communities in WM in 2014 (a) and 2015 (b) and CM in 2015 (c).

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