# IMPACT OF INSECTICIDES ON CUCUMBER BEETLES (COLEOPTERA: CHRYSOMELIDAE) AND SPIDER PREDATORS IN WATERMELON AND CORN

by

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*This thesis is dedicated to my family and especially to my grandfather who passed away during my studies and who always encouraged me to become the person that I am.*

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## ABSTRACT

The primary goal of this research study was to provide updated pest management recommendations to growers, including the reduction of insecticide applications on a calendar basis by the use of pest economic thresholds, with the purpose of maximizing insecticide efficacy while minimizing the associated negative impacts on natural enemies and their ecosystem services.

Commercial watermelon (*Citrullus lanatus*) production in the Midwest typically relies on neonicotinoid and pyrethroid insecticides to manage insect pests, particularly striped and spotted cucumber beetles (*Acalymma vittatum* Fabricius and *Diabrotica undecimpunctata howardi* Barber, respectively). The role of arthropod predators in managing cucumber beetles is not well documented, and data on the effects of insecticides on predators in watermelon production are deficient. Common cucumber beetle predators include coccinellid beetles found on plants, ground-dwelling carabid beetles (Coleoptera: Carabidae) and spiders in several families that inhabit the soil surface in watermelon fields. I hypothesize that these generalist predators and the ecosystem services (e.g., pest predation) they provide are at risk from insecticides used for pest management without regard to economic thresholds. My study compared the effect of insecticide use on cucumber beetle pests, spider predators, collembola populations and field pest predation under two treatments: 1) watermelons treated with neonicotinoid soil drench and subsequent pyrethroid sprays, surrounded by corn with neonicotinoid-treated seeds (Conventional), and 2) watermelons treated only with pyrethroid spray when economic thresholds were reached, surrounded by corn with untreated seeds (IPM).

The frequent application of insecticides decreased cucumber beetles in the watermelon plots managed with Conventional pest management; however, they also reduced spider predators, collembola densities, and field pests predation measurements, possibly due to the subsequent

pyrethroids applications during the growing season. In addition, our study showed that neonicotinoid seed treatment in corn had no negative impact on any of the above-mentioned response variables measured.

Ultimately, following an IPM strategy and the use of pest monitoring helped to reduce unnecessary insecticides applications, conservation of pest regulatory services provided by natural enemies, and possibly less ecological impact to manage significant insect pests in watermelon plots.

# CHAPTER 1. INTRODUCTION

It is essential to determine how insect pests can be most efficiently managed with the smallest negative effects on the environment, ecosystem services, and non-target organisms because pest pressures can affect productivity and profitability, global food security, and public health (Waterfield et al., 2012). A valuable tool for addressing this threat is pest management. Although pest management includes different strategies for pest control, there are concerns that some strategies affect the environment, ecosystem services, and the nature of biological control (Waterfield et al., 2012). This research focused on evaluating the effects of insect pest management practices on biocontrol agents, primarily generalist spider predators.

Cucurbits, including cucumber, melon, watermelon, pumpkin, and squash, are important horticultural crops in the United States (Shelby, 2013). Watermelon (*Citrullus lanatus*) in the United States had a value of $657 million and covered a total area planted of 116,200 acres in 2018 (United States Department of Agriculture, 2018). Various U.S. states produce watermelon, but Indiana production is one of the highest in the country. Because of its economic benefit, watermelon contributed approximately $27 million to Indiana's economy in 2018 and ranked as one of the top 5 crops produced by the state (United States Department of Agriculture, 2018). Nevertheless, the production of watermelon faces significant pest management challenges.

Striped (*Acalymma vittatum* Fabricius) and spotted (*Diabrotica undecimpunctata howardi* Barber) cucumber beetles are the most important pests of watermelon. Watermelon growers in Indiana are concerned about the striped cucumber beetle due to its early feeding activity in spring and presence through harvest (Gould, 1943). Both adult and larval beetle life stages feed on watermelon (Sharma et al., 2016). Root-feeding larvae can reduce plant vigor, thus reducing the maturity of plants or even killing seedlings (Gould, 1943). Adults, on the other hand, feed on flowers, leaves, and stems at the base of the plant (Sharma et al., 2016), potentially impacting future production. Additionally, cucumber beetles can cause a reduction in fruit quality due to feeding on the rind of the fruit.

Different pest management strategies are used to control striped cucumber beetles. Many watermelon growers in Indiana rely on the use of insecticides without previous pest monitoring. However, an integrated pest management (IPM) approach should be an attractive strategy for watermelon cropping because of its potential economic and environmental value. IPM encourages growers to reduce insecticide applications by monitoring cucumber beetle populations and only applying insecticides when thresholds are reached with the goal to reduce production costs and achieve similar production yields while reducing undesirable side effects on pollinators and natural enemies (Lima et al., 2014).

Research is needed to determine the impact of insecticide use on spiders and their ecosystem services (e.g., pest predation) in watermelon systems. This study evaluated the effects of conventional pest management vs. IPM practices on striped cucumber beetles and spider predators in watermelon surrounded by a corn landscape. The ultimate goal of the research study was to evaluate the effects of implementing IPM as an economically viable alternative to a regular insecticide-treatment management strategy.

# CHAPTER 2. LITERATURE REVIEW

## Pest Management

Pest management is a strategy used to control any living organism that poses a risk to our food, fiber, and health security. Pest management has played an essential role in achieving the current food supply, and its importance will be critical in any agricultural production system (Waterfield et al., 2012). Since the beginning of agricultural development, growers have had to compete with harmful insects, collectively called 'pests' (Oerke, 2006). These organisms can reduce crop yields and fruit quality, damage plants, serve as disease vectors, and contaminate food crops.

Different strategies have been developed to control arthropod pests in agriculture, including chemical, cultural, plant resistance, mechanical and biological control methods (Flint et al., 2012). There is much concern about the use of chemicals for pest control due their cumulative non-sustainable adverse effects on the environment (Pimentel et al., 1986; Krupke et al., 2015; Sánchez-Bayo et al., 2016), particularly non-target effects on beneficial organisms, including natural enemies (e.g., predators, parasitoids, microorganisms) and pollinators (Fountain et al., 2007; Bonmatin et al., 2015; Krupke et al., 2017), and the potential for the development of pesticide resistance (Jensen, 2000; Kranthi et al., 2002). Additionally, the use of insecticides can create indirect costs, including impacts on human health in growers or consumers (e.g., poisoning), as well as long-term effects on the environment (e.g., bioaccumulation) (Margni et al., 2002; Van Lenteren, 2012). Given the various negative impacts associated with chemical control, there is a critical need for more environmentally sustainable alternative pest control methods in modern agriculture.

## Integrated Pest Management

Integrated pest management (IPM) was developed in the early 1970s as a strategy for pest control (Ehler, 2006) that promotes sustainable agriculture with a strong ecological basis (Kogan, 1998). IPM is an approach that incorporates various tactics for the control of all classes of pests (e.g., insects, pathogens, weeds, vertebrates) to create an ecologically and economically efficient production system (Ehler, 2006). These tactics include biological control, cultural practices, host-plant resistance, genetic manipulation, and the use of pesticides (Lewis et al., 1997; Thomas, 1999; Flint et al., 2012). The overall goal of IPM is to monitor pest populations and use insecticides only if economic threshold levels indicate a need. Also, IPM relies on the contribution of other control methods and tactics for controlling pests, while conserving beneficial insects and the environment (Thomas, 1999).

IPM tactics have been applied in cucurbit and corn production before the current concept of IPM was proposed (Flint et al., 2012). Bordeaux mixtures and crop covers made of tobacco muslin to protect cucumber and melon plants from mildew and striped cucumber beetles, respectively are early examples (Garman, 1901).

IPM has also been used in corn production. For example, a common management practice in use is crop rotation, where corn and soybeans are rotated in alternate seasons to reduce insect pests (Crookston et al., 1991). However, the introduction of Bt (*Bacillus thuringiensis*) corn in the agricultural market and insecticide seed treatments for pest management has resulted in many farmers ignoring the basic tenant of IPM – "treat only if necessary" – due to the assumption that pests are being controlled during the season using these two treatment methods (Onstad et al., 2011).

The application of IPM strategies continues to be researched and implemented in cucurbits and corn for the management of insect pests. However, there is an ongoing discrepancy when encouraging growers to implement an IPM approach. Resistance to IPM usually arises from constraints due to inadequate biology knowledge, difficulties in transferring the technical information to growers, and institutional conflicts (Stoner et al., 1986).

## Cucurbitaceae

Cucurbitaceae is a large family of plants that consists of about 130 genera and 900 species worldwide (Jeffrey, 2008). All plants in this family are easily damaged by frost; therefore, most are limited to warmer regions (e.g., tropical and neotropical) (Jeffrey, 2008). Cucurbit crops belong to this family and provide humans with consumable products and useful fibers (Bisognin, 2002). Cucurbit production in the U.S. consists of seven significant categories of crops: cucumber fresh and processing, cantaloupe, honeydew, pumpkin, squash, and watermelon (Cantliffe et al., 2007). The states in the U.S. with major watermelon production are in the southern and western regions (e.g., Florida, Georgia, California, and Texas) where the warm production season is the longest in the country (Wehner, 2008; United States Department of Agriculture, 2017 ). However, according to data from the 2018 United States Vegetable Summary (United States Department of Agriculture, 2018), the state of Indiana is also a major producer of watermelon, cantaloupe, and pumpkins, with a total area planted of 14,200 acres and an approximate economic value of $53 million in 2018. Indiana was ranked at numbers four and five in the list of top states for pumpkin and watermelon production, respectively, in 2017 (United States Department of Agriculture, 2017 ).

### *Watermelon*

Watermelon (*Citrullus lanatus*) is a plant member in the cucurbit family, Cucurbitaceae. Its flowering and fruit development are encouraged by high light intensity and temperature, which makes watermelon an ideal crop for summer production systems (Wehner, 2008). Watermelon grows in trailing vines on the ground; depending on the cultivar, the fruit can vary in size and shape (Wehner, 2008). Watermelon crops can be planted in the field as seed or by transplanting seedlings, usually on prepared plastic beds.

Commercially, seeded and seedless varieties are the typical commercial types of watermelon. The seeded and seedless types have red flesh, but are different in sizes. The seeded varieties are larger (8-11 kg), while the seedless varieties are oval shape and medium in size (5-8 kg) (Prohens-Tomás et al., 2007). However, seedless watermelon usually leads to a higher price compared to a seeded watermelon due to consumer demand and the appeal of its newness (Rangappa et al., 2002). Although the trends for watermelon types changed from seeded to seedless watermelon (Freeman et al., 2008), growers still have to include male pollinizer plants in their production to ensure a pollen source for fruit set in the seedless crop. Usually, a male pollinizer is planted between every third plant within the row (Freeman et al., 2007).

Economically, watermelon in the United States had a value of $657 million and covered a total area planted of 116,200 acres in 2018 (United States Department of Agriculture, 2018). Indiana was ranked fifth in the major states for watermelon production in 2017 (United States Department of Agriculture, 2017 ).

### *Current Cucurbit Production Practices*

Insect populations are affected by many practices in agricultural production. Conventional and organic production have major differences in terms of management strategies, but both are current systems used in cucurbit production (Lima et al., 2014; Schmidt et al., 2014; Cunha et al., 2015). Organic production relies more on cultural controls (e.g., row covers) and fewer chemical inputs for arthropod pest management than conventional systems (Skidmore, 2018). Conventional production uses a broad range of chemical inputs (e.g., insecticides, herbicides, fungicides) to manage pest organisms (Skidmore, 2018).

Synthetic insecticides such as imidacloprid, permethrin, and carbaryl are insecticides commonly used today to manage cucurbit arthropod pests in conventional production (Cline et al., 2008; Lima et al., 2014). Applications of natural plant-based insecticides (e.g., pyrethrin and spinosad) are the most common insecticides used in cucurbit organic production (Cline et al., 2008). Due to concerns about the overuse of synthetic chemical controls and their non-target impacts, IPM strategies have been developed to control pest problems and reduce the use of insecticides in cucurbit production, starting with the establishment of economic threshold levels (Brust et al., 1996).

### *IPM Practices in Cucurbit Production Systems*

IPM practices for pest control in cucurbits include the use of cultural control (Doughty et al., 2016), mechanical control (Summers et al., 2004), plant resistance (Walters, 2003), biological control (Dieterich Mabin, 2017) and chemical control (Allen et al., 2001). Cultural control is characterized by the use of management practices that manipulate the vegetation patterns to reduce the attractiveness of crop plants to pests (Damicone et al., 2007). For example, intercropping, which involves interplanting pumpkins among corn, is a practice in the U.S. to suppress/reduce pest populations during the growing season (Welbaum, 2015). Another cultural method is perimeter trap cropping (PTC), a technique in which the commercial crop is surrounded with a border trap crop that is attractive to insect pests. PTC is a cultural control practice that helps to decrease striped cucumber beetle populations, e.g., Blue Hubbard squash border crop (Cavanagh et al., 2009).

Mechanical controls are physical manipulations in the environment that alter the agroecosystem (Szendrei et al., 2016). The use of an intermediate mesh in high tunnels, a physical structure, could exclude cucumber beetles and prevent their herbivory on cucumbers and melons (Ingwell et al., 2019). The use of row covers to prevent pest colonization has been a widely recommended mechanical strategy to defend against cucumber beetles (Snyder, 2015).

Plant resistance includes cucurbit varieties that have been developed to tolerate or resist pathogens and feeding damage from insects (Wehner, 2008). Breeders at Cornell University produced a new cucumber variety, "Marketmore 97," which is resistant to the striped, *Acalymma vittatum* and the spotted cucumber beetle, *Diabrotica undecimpunctata howardi*. The fruit has green skin with white spines and an average length and diameter of 18.8 cm and 4.8 cm, respectively, and causes a non-feeding response in these beetles (Cavatorta et al., 2007).

Biological control has been defined by the use of natural enemies to prevent, delay, or reduce the pest populations in the system. Natural enemies in general, and spider predators (Araneae: Lycosidae) in particular, have been shown to control and alter the feeding rate of striped cucumber beetles on cucurbit plants (Williams et al., 2003). Also, field studies combined with soil bioassays revealed that *Steinernema riobravis* (Rhabditus: Steinernematidae) (entomopathogenic nematodes) reduced *Acalymma vittatum* larval development time in conventional and organic soil management systems. A 50% reduction in *Acalymma vittatum* densities in both systems, as determined by adult emergence, showed the potential use of *Steinernema riobravis* (entomopathogenic nematodes) for biological control of striped cucumber beetles in commercial cucumber production (Ellers-Kirk et al., 2000). An IPM approach commonly uses a combination of these management strategies to control pests in cucurbits.

### ***The Major Pests: Striped and Spotted Cucumber Beetles***

Cucurbit production faces many arthropod pest management challenges (Gould, 1943; Metcalf et al., 1962). However, our research focused on the major cucurbit pests in watermelon in the north-central region of the U.S. - the striped cucumber beetle, *Acalymma vittatum* F., which is the most economically important pest of cucurbits in Indiana (Gould, 1943), and the spotted cucumber beetle, *Diabrotica undecimpunctata howardi*.

Cucumber beetles overwinter as adults and appear in early spring when cucurbit fields are planted in Indiana (Foster et al., 1995). The first generation of striped cucumber beetles emerges as adults in June and early July to feed on foliage and flowers (Day, 2008), and they remain active until fall. The spotted cucumber beetle arrives later in the summer (June to mid-July) and has 1 to 2 generations per year (Foster, 2016).

Both species of adult beetles are vectors of the bacterium *Erwinia tracheiphila,* which causes bacterial wilt, a severe infectious disease of cucurbits (Foster et al., 1995). Since bacterial wilt harms cucurbit crop production in the midwestern and the northeastern United States, disease management usually relies on the use of insecticides to suppress vector populations, e.g., striped and spotted cucumber beetles (Rojas et al., 2015). Because watermelons are much less susceptible to bacterial wilt than other cucurbits (Foster et al., 1995), the level of management required is not as intense as in other cucurbits (e.g., muskmelons). The established threshold to treat for striped cucumber beetles on watermelons is an average of 5 beetles per plant (Foster, 2016).

### ***Current Watermelon Management Practices for Cucumber Beetles***

Growers have few realistic options for managing striped cucumber beetles in watermelons. For example, growers can physically protect young plants from striped cucumber beetle feeding with row covers, which are removed when flowering begins (Sharma et al., 2016). However, these

IPM strategies have been extensively researched and developed, and they are often not economically feasible for large scale watermelon production.

Many growers choose to use a neonicotinoid insecticide in the transplant water at the time of planting. The established threshold for cucumber beetles on watermelons is an average of 5 beetles per plant (Foster, 2016), and while some growers use that threshold, most use other criteria (i.e., the presence of beetles in the field) (Foster, unpublished data) to spray. The application of a systemic insecticide at planting provides approximately three weeks of control (Foster, 2016). Growers also have the option of spraying foliar insecticides to control beetles, and because fungicides are frequently applied to watermelons, growers commonly add an inexpensive pyrethroid insecticide as pest management “insurance” to the spray mixture. Additionally, growers rely on the use of neonicotinoids as corn seed treatments in the surrounding corn fields, which describes the typical agricultural landscape for watermelon fields in the state of Indiana.

### *Impact of Pest Management Practices on Biological Control Agents in Watermelon*

The importance of natural enemies in managing striped cucumber beetles is not well documented. This includes research on the effects of insecticides on beneficial arthropods in watermelon (Souza et al., 2012). However, there is some evidence that shows predators and the biological control ecosystem services they provide are at risk when pesticides are used (Desneux et al., 2007; Hoopwood et al., 2016). Neonicotinoids have been demonstrated to have a direct toxic effect on natural enemies under laboratory and field conditions (Cloyd et al., 2011), which may reduce predators and parasitoids efficacy and affect their ability to control pests. Sub-lethal effects of insecticides on natural enemies (e.g., reproduction) have also been studied (Desneux et al., 2007; Roubos et al., 2014; Pisa et al., 2015). Insects in the orders Lepidoptera, Diptera, Hymenoptera, Neuroptera, Hemiptera, and Coleoptera are affected by neonicotinoids (Pisa et al., 2015). However, other arthropods, spiders in particular, have been largely ignored in watermelon agroecosystems (Cunha et al., 2015). Ecotoxicological research on spiders has focused only on a few species (in particular, linyphiid and lycosid spiders) considered biocontrol agents against economic pests of various crops (Zaher et al., 2005).

Spiders, as general predators, are sensitive to agricultural management practices and are often used as bioindicators (Gerlach et al., 2013; Cunha et al., 2015). They are predators of cucurbit pests (Schmidt et al., 2014; Dieterich Mabin, 2017), and they can also change the feeding behavior of the striped cucumber beetle (Williams et al., 2003). The most common spider families observed in cucurbits are wolf spiders (Araneae: Lycosidae) (Snyder et al., 2001; Cunha et al., 2015) and sheet web spiders (Araneae: Linyphiidae) (Halaj et al., 2002); however, no research has been done on the spider community in watermelon in the state of Indiana (USA). Spiders can feed on different types of prey, including Collembola, Hemiptera, Diptera (Nyffeler, 1999), as well as other spiders. Their abundance and fitness can be disturbed by insecticides (Dinter et al., 1995; Souza et al., 2012; Chen et al., 2012). Evaluating the trade-off between insecticide management and benefit from general predators (e.g., spiders) could influence grower management decisions in watermelon production.

**Poaceae**

The family Poaceae is the most significant flowering plant families in the world. It contains approximately 800 genera and 11,000 species (Peterson, 2001). This is the most crucial plant family for food production and demand. Economically essential species include rice (*Oryza sativa* L.), wheat (*Triticum aestivum* L.), corn (*Zea mays* L.), barley (*Hordeum vulgare* L.), rye (*Secale cereale* L.), oats (*Avena sativa* L.), sorghum (*Sorghum bicolour* (L.) Moench), pearl millet (*Pennisetum glaucum* (L.) R. Br.), finger millet (*Eleusine coracana* (L.), Gaertn.), and teff

(*Eragrostis tef* (Zucc.) Trotter), which are all crops planted on a global scale (Peterson, 2001). The most important feature of this family is their grain, which is the food basis for all early and modern civilizations (Peterson, 2001).

***Corn***

*Zea mays* L., commonly called corn or maize, is in the genus *Zea* in the family Poaceae. Depending on the use, the grain is usually the most valuable part of the corn plant (Vincent, 2001; Sarwar et al., 2013). Corn is the most frequently produced crop in the United States, which accounts for more than 95% of total feed grain production. Most of the corn production is used for livestock feed, but it is also used for human consumption, alcohol, and ethanol (United States Department of Agriculture, 2018). This crop had an approximate area planted of 89 million acres and an economic worth of $51 billion in 2018 (United States Department of Agriculture, 2018). The state of Indiana is geographically located in the eastern corn belt; therefore, most of its agricultural land is designated for corn production.

***Current Corn Production Practices***

Generally, corn in the U.S. is planted by seed. With the increased adoption of no-tillage and reduced tillage farming, planting dates today are earlier on average (Duncan et al., 2007). Corn seed is put in the ground as soon as possible, weather and temperature permitting, to reach maturity at approximately 120 days after planting (Duncan et al., 2007). Cultural control (e.g., crop rotation), mechanical control (e.g., tillage), and the use of herbicides can contribute to weed control in corn production (Regehr et al., 2007). Most of the corn seed planted is transgenic with insecticide-resistant and herbicide-tolerant traits (Onstad et al., 2011). Insect management relies on seed protectants, usually neonicotinoids, for secondary pest control (Krupke et al., 2015). However, these insecticides may affect beneficial insects (e.g., natural enemies) and non-target areas in surrounding fields (Krupke et al., 2012).

### *IPM Practices in Corn Production Systems*

With the expansion of transgenic corn and the use of neonicotinoids as insecticide seed treatments (i.e., seed coating), these approaches are intended to control a large group of primary and secondary pests in corn (Onstad et al., 2011). Because these management practice decisions are made when the seeds are purchased, other field-based management practices commonly used in IPM (e.g., pest monitoring) are not as appealing to growers (Onstad et al., 2011). However, with the increased use of insecticide seed treatments and the examples of pest resistance (e.g., western corn rootworm resistance to Bt corn) (Gassmann et al., 2011), future research is focused on sustainability and understanding the effects of these technologies on beneficial insects and impacts in the environment (Bates et al., 2005; Hladik et al., 2018).

### *The Major Pest: Western Corn Rootworm*

Our research was conducted in field plots spread across the state of Indiana. Corn is usually the common landscape surrounding most specialty crops (e.g., cucurbits). The major pest of corn in Indiana is the western corn rootworm, (*Diabrotica virgifera virgifera*) (Coleoptera: Chrysomelidae (Alexander et al., 2005). The adult emerges in mid-summer, and females begin laying eggs about two weeks after emergence. They overwinter as eggs, and larvae are the most critical pest stage due to their root-feeding behavior. Also, adults can cause some damage to corn leaves or silks (Gibb et al., 2008).

### *Impact of IPM And Biological Control in Corn*

Natural enemies in corn are well documented. These include insect predators (e.g., Carabidae, Staphylinidae, Coccinellidae, Lycosidae, Phalangiidae, Hemiptera, and Formicidae; (Nordlund et al., 1984; Clark et al., 2001), parasitoids (e.g., Braconidae, Eulophidae, Ichneumonidae, Mermithidae, and Tachinidae; (Sparks et al., 1986; Smith, 1996; Agustí et al., 2005), microorganisms (e.g., entomopathogenic nematodes, including *Heterorhabditis* spp. and *Steinernema* spp.; (Millar et al., 2002; Rasmann et al., 2005), and entomopathogenic fungi (e.g., *Beauveria bassiana* and *Metarhizium anisopliae* sensu; (Rudeen et al., 2013). Generalist predators, such as spiders, have been demonstrated to prey on lepidopteran eggs and provide pest control services in corn systems (Pfannenstiel, 2008). Ground spiders, including members in the families Lycosidae, Thomisidae, and Gnaphosidae are found in corn production (Whitford et al., 1987). Most research in corn is being conducted to understand the target and non-target effects of seed treatments and GMO crops on arthropod communities (López et al., 2003; Dively, 2005; Harwood et al., 2007; Moser et al., 2009).

## Insect Ecosystem Services

Insects play an influential role in the activity and management of many ecosystem services (Noriega et al., 2017). Ecosystem services obtain from nature are benefits that humans use to support their quality of life (Harrington et al., 2010). The food supply, pollination, suppression of pests and diseases, and the decomposition of organic matter are examples of some of the ecological services on which humans depend. The largest and most diverse community that supports these services is insects. Insects are arthropods that contribute significantly to critical ecological functions such as pollination, pest control, decomposition, and maintenance of wildlife species, and have an approximate economic value of $57 billion per year in the United States (Losey et al., 2006).

Suppression of pests, one of the ecosystem services provided by natural enemies, has been estimated to have a value of $4.5 billion annually in the United States (Losey et al., 2006). However, natural enemies that provide this ecosystem service have been diminished by a wide variety of human activities (Daily, 2003). The adverse effects of human activities include i) habitat loss, intensive farming, and urbanization; ii) pollution, primarily by the use of synthetic pesticides and fertilizers; iii) pathogens and invasive species; and iv) climate change (Sánchez-Bayo et al., 2019).

Although ecosystem services continue to be impacted, the introduction of some new technologies (e.g., genetically modified organisms) have reduced the use of some pesticides (Benbrook, 2012). For example, in corn, millions of pounds of organophosphate, carbamate, pyrethroid, and other soil insecticides were used to protect corn from rootworms. The overall impact is dramatically less than it used to be (Benbrook, 2012). However, insecticide seed treatments, another modern technology that historical reduced agricultural pest populations (Elbert et al., 2008), are probably no longer justified for controlling pests because of little demonstrated need (Mourtzinis et al., 2019) coupled with their ecological risk (Van der Sluijs et al., 2015).

Intensive agriculture and the recurrent use of insecticides for controlling crop pests have caused a declining trend in natural enemies in agricultural systems (Losey et al., 2006). Additionally, pyrethroid, neonicotinoid, and fipronil insecticides have a negative impact on aquatic insects due to their chronic toxicity (Sánchez-Bayo et al., 2019). Neonicotinoids have been reported to have a direct toxic effect on natural enemies in laboratory and field conditions (Cloyd et al., 2011), and spiders are one of the most important natural enemies worldwide affected by neonicotinoid insecticides (Chen et al., 2012).

***Impact of Neonicotinoids on Spiders***

Annual predation by the global spider community is estimated to be in the range of 400–800 million metric tons (fresh weight) of prey with >90%, primarily insect and collembola communities (Nyffeler et al., 2017). In cucurbits, spider predation not only affect pest populations, but they can also influence pest feeding behavior (i.e., cucumber beetles feed less when spiders are present) (Snyder et al., 1999, 2000).

The importance of spiders as biological control agents begins early in the season when specialized predators are not present (Riechert, 1999). Their fitness can be disturbed by insecticides (Souza et al., 2012). Neonicotinoids are commonly used insecticides in pest management in watermelon production (Foster, 2016) that can affect the performance of spiders in terms of fecundity, the development time of unexposed offspring, and predation (Chen et al., 2012).

The ecotoxicology of spiders (about 3% of toxicology papers on natural enemies) has received limited attention (Theiling et al., 1988; Pekár, 2012). Early papers evaluated the effects of acaricides, insecticides, fungicides, and herbicides on spiders in the field and focused mainly on changes at the community level. The working group 'Pesticides and Beneficial Organisms' of the International Organization for Biological Control performed standardized testing of some pesticides on natural enemies, but rarely included spiders (Pekár, 2012). Laboratory studies found direct sublethal effects on movement, predation, and reproduction in some spiders, but not on all species. Such tests reveal details about intoxication, but often underestimate mortality in comparison with field studies (Wiles et al., 1992).

### *Impact of Neonicotinoids on Collembola as Food for Spiders*

Spiders, as generalist predators, eat a variety of prey, including insects, other spiders, and microarthropods such as collembola (Nyffeler, 1999). Collembola are ubiquitous alternative prey for lycosid and linyphiid spiders; they help to maintain spider populations when other prey are not present (Agustí et al., 2003; Kuusk et al., 2010). Collembola and spiders can be negatively affected by neonicotinoids (Chen et al., 2012; Pisa et al., 2015).

Collembola are common arthropods in terrestrial ecosystems and are considered bioindicators of soil health (Rusek, 1998). They disseminate the soil microbiome and are food sources for many predators including Coleoptera, Arachnida, and Diptera (Rusek, 1998). Intensive farming, including the use of insecticides, can affect the abundance of collembola (Rusek, 1998). Neonicotinoids and chlorpyrifos have been demonstrated to reduce collembola numbers (Fountain et al., 2007; Pisa et al., 2015), which in turn can affect the food chain that other organisms, such as spiders, rely on.

### *Impact of Pest Management Practices on Natural Enemies and their Ecosystem Services*

Pest suppression by predation is a valuable ecosystem service performed by arthropods (Losey et al., 2006). Arthropods including spiders and various insects, particularly beetles in the families Coccinellidae, Carabidae, and Staphylinidae are important generalist predators that consume a wide range of prey items in agricultural systems (Thorbek et al., 2004). Predation is the act of a predator feeding upon a prey item (Symondson et al., 2002). However, to be useful as a pest management action, predators need to keep pest populations from reaching economic thresholds. To measure this ecosystem service sentinel prey are sometimes used (Jones et al., 2014; Dieterich Mabin, 2017). Sentinel prey, such as eggs of various pest species (*Diabrotica undecimpunctata howardi* B.) and waxworm larvae (*Galleria mellonella*), are frequently grown in laboratory colonies and used in in a variety of lab and field experiments to measure predation (Dieterich Mabin, 2017; Rivers et al., 2018). To understand the effect of pest management practices on pest predation, sentinel prey predation studies have been conducted in cucurbit and corn agroecosystems (Brust et al., 1986; Phillips et al., 2016). However, no research has been done on predation in watermelon.

However, predation can be affected by crop management practices, including soil cultivation and pesticide application (Symondson et al., 2002). The most common insecticides used worldwide are neonicotinoids. These insecticides increased dramatically on field crops such as corn, wheat, soybean, and cotton in the U.S. after 2003 (Douglas et al., 2015). Treated corn seeds are used to prevent damage from a broad range of insect pests from different orders, such as Coleoptera, Lepidoptera, Diptera, Hemiptera, and Hymenoptera, especially when young corn plants are in the ground (Jeschke et al., 2011). In specialty crops, such as watermelon, the current primary pest control method adopted by Brazilian growers is a weekly application of thiamethoxam insecticide without regard to pest threshold recommendations (Lima et al., 2014).

Although these insecticides can be effective at pest control, they can also have negative impacts on other non-target arthropods (e.g., reduction in diversity and abundance) and the surrounding environment. Moreover, the use of insecticides without proper pest scouting to determine the correct time for application (i.e., the economic threshold level) may increase costs, negatively impact beneficial communities, and contribute to future pest outbreaks (Picanço, 2008).

## Concluding Remarks

Determining the impact of insecticides on predators in cucurbit and corn production could help growers understand the benefits that natural enemies bring to their production systems, and may influence their decisions regarding the best pest management strategy. The goal of this study was to provide updated management recommendations to growers so they can maximize insecticide efficacy while minimizing the impact on natural enemies. Our study was conducted in watermelon due to its economic importance and the production acreage in the state of Indiana.

We selected two pest management strategies as field treatments in watermelon production. These were conventional and integrated pest management strategies. Both strategies differed in the use of pest scouting (e.g., economic threshold level) to decide if and when insecticides were applied. We investigated how these pest management strategies influenced populations of striped cucumber beetle pests and their spider natural enemies, as well as the ecosystem services provided by natural enemies in a two-year study.

The results of the two-year study should help growers evaluate the trade-offs between systematic insecticide applications and natural enemy stewardship as a component of IPM. Finally, we want to help growers make the best pest management decisions by having the information that will help them be better informed about the pros and cons of an IPM program vs. today's common commercial practice of spraying insecticides on a calendar basis.

# CHAPTER 3. EVALUATING THE EFFECT OF INSECTICIDE USE ON SPIDER PREDATORS IN WATERMELON AND CORN


## Abstract

Commercial watermelon (*Citrullus lanatus*) production in the Midwest typically relies on neonicotinoid and pyrethroid insecticides to manage insect pests, particularly for striped and spotted cucumber beetles (*Acalymma vittatum* and *Diabrotica undecimpunctata howardi* Barber, respectively). Common cucumber beetle predators include spiders (Araneae) in the Lycosidae and Linyphiidae families that inhabit the soil surface in watermelon fields. However, these generalist predators and the ecosystem services (e.g., pest predation) they provide are usually at risk from pest management practices used without regard to economic thresholds. Our study compared the effects of insecticide use on cucumber beetle pests, spider predators and collembola (non-pest prey) populations under two treatments: 1) watermelons treated with neonicotinoid soil drench at planting and subsequent pyrethroid sprays, surrounded by corn with neonicotinoid treated seeds (Conventional pest management), and 2) watermelons treated with pyrethroid sprays only when economic thresholds were reached, surrounded by corn with untreated seeds (Integrated pest management - IPM). Insecticide treatments decreased striped cucumber beetle pests in the conventional fields; additionally, neonicotinoid soil drench at the time of planting and subsequent pyrethroid sprays in these fields reduced spider predators and collembola populations. In addition, our study showed that neonicotinoid seed treatment in corn had no impact on either spider or collembola densities. Implementing an IPM approach is an agroecological and viable alternative to an insecticide-dependent management strategy.

## Introduction

Cucurbits, including cucumber, melon, watermelon, pumpkin, and squash, are important horticultural crops in the United States (Shelby, 2013). Watermelon (*Citrullus lanatus*) in the United States had a value of $657 million and was planted on 116,200 acres in 2018 (United States Department of Agriculture, 2018). The production of cucurbit crops faces significant pest management challenges. Striped (*Acalymma vittatum*) and spotted (*Diabrotica undecimpunctata howardi* Barber) cucumber beetles are the most important pests of watermelon (Gould, 1943; Foster et al., 1995; Sharma et al., 2016). Striped cucumber beetle overwinter as an adult in nearby woodlands and leaf litter, and they reappear soon after cucurbits are planted (Foster, 2016). The first generation of striped cucumber beetles emerges as adults in June and early July to feed on foliage and flowers (Day, 2008), and they remain active until fall. The overwinter stages of the spotted cucumber beetle arrive later in the summer (June to mid-July), and they have 1 to 2 generations per year (Foster, 2016).

Both adult and immature (larval) beetles feed on watermelon. Larval stages can reduce the vigor of a plant, which results in a reduction in plant size (Sharma et al., 2016). Adults feed on flowers, leaves, and stems at the base of the plant (Sharma et al., 2016), likely decreasing yields. Both species serve as a vector of transmission of the bacterium *Erwinia tracheiphila* that causes bacterial wilt, a severe infectious disease of many varieties of cucurbits, but not watermelon (Foster et al., 1995).

A common management strategy for striped cucumber beetles in watermelon in Indiana is to apply a systemic neonicotinoid insecticide in the transplant water at planting. This preventative practice does not consider the likelihood of populations of cucumber beetles reaching the threshold of 5 beetles/plant, but will provide 3 weeks of effective control (Foster, 2016). Growers also have the option of spraying foliar insecticides, often pyrethroids, to control beetles; because fungicides are frequently applied to watermelons, growers commonly add an inexpensive insecticide to the spray mixture (Foster, 2019).

Most watermelon growers in Indiana and the Midwest grow corn as one of their primary rotation crops, creating a landscape in which watermelon fields are often surrounded by corn fields. Virtually all of the seeds used in planting these corn fields are now being treated with a neonicotinoid insecticide seed treatment (Krupke et al., 2017). Treated corn seeds are used to prevent damage from a broad range of soil and leaf-feeding pests from different orders including Coleoptera, Lepidoptera, Diptera, Hemiptera, and Hymenoptera, especially when young corn plants are in the ground (Jeschke et al., 2011). Studies have shown that the likelihood of developing damaging populations of any of these pests in Midwest corn fields is quite low (Krupke et al., 2017).

Although these insecticides are effective at pest control, there are concerns about negative impacts on other non-target arthropods. Feeding studies using seedling leaf tissue from a corn seed treated with thiamethoxam and clothianidin showed neurotoxic symptoms on non-target organisms such as coccinellids, a common natural enemy found in corn (Moser et al., 2009).

Spiders are generalist predators of cucurbit pests (Schmidt et al., 2014; Dieterich Mabin, 2017) that can also be negatively affected by neonicotinoids (Chen et al., 2012) and pyrethroids (Irungu, 2010). Spiders found in both watermelon and corn systems are sensitive to agricultural management practices, and are often used as bioindicators for ecosystem health (Gerlach et al., 2013; Cunha et al., 2015). The most abundant spider families observed in cucurbit growing systems are wolf spiders (Lycosidae) (Snyder et al., 2001; Cunha et al., 2015) and sheet web spiders (Linyphiidae) (Halaj et al., 2002). They can feed on different size prey including Collembola, Hemiptera, and Diptera depending on their feeding behaviors (Nyffeler, 1999).

Collembola are an important alternative prey for lycosid and linyphiid spiders and help maintain spider populations when other pests are not present (Agustí et al., 2003; Kuusk et al., 2010). Both collembola and spiders can be negatively affected by neonicotinoids (Chen et al., 2012; Pisa et al., 2015).

Monitoring effects of pest management practices on populations of collembola and spiders can shed light on the overall impact of those practices on the agroecosystem. Consequently, this study evaluated the effects of conventional pest management (CPM) vs. integrated pest management (IPM) practices on striped cucumber beetles, spiders and collembola as a potential spider food source in watermelon surrounded by a corn landscape. The ultimate goal of the study is to evaluate the effects of implementing an IPM approach as an economically viable alternative to an insecticide-dependent management strategy.

### *Research Question*

Do insecticides in watermelon production and the surrounding landscapes affect striped cucumber beetle pests, spider predators, and collembola densities?

### *Hypothesis*

Watermelon managed with IPM practices surrounded by corn planted with untreated seeds maintain cucumber beetle populations below the economic threshold without the reductions in spider population densities observed in watermelon fields using conventional pest management and surrounded by corn plant with neonicotinoid-treated seeds.

Conventional pest management (CPM) practices mentioned above reduce the spider natural enemy community, diversity, richness, and evenness.

***Objectives***

- Measure the abundance of striped cucumber beetles and spiders in watermelon fields subject to CPM and IPM practices.
- Measure the diversity, richness, and evenness of the spider natural enemy community.
- Quantify and compare the populations of spiders in corn fields planted with neonicotinoid-treated or untreated seed.

## Materials and Methods

***Site locations***

The research study took place at 5 Purdue Agricultural Centers (PACs) distributed across Indiana. The field plots were located at Throckmorton-PAC (Lafayette, IN) (TPAC), Pinney-PAC (Wanatah, IN) (PPAC), Northeast-PAC (Columbia City, IN) (NEPAC), Southeast-PAC (Butlerville, IN) (SEPAC), and Southwest-PAC (Vincennes, IN) (SWPAC) (Table 1, Figure 1). Each agricultural center had a pair of research fields planted with 0.20 ha of watermelon surrounded by 4.45 – 7.68 ha of corn as replicated blocks in the 2018 and 2019 growing seasons.

***Experimental design***

At each research center, the paired fields were randomly assigned either CPM or IPM field treatments. All the production practices for both corn and watermelon were the same except for insecticide use strategies.

Production practices in watermelon fields included raised beds covered with black plastic mulch (Grower Solution, 1211A Boyd Farris Road Cookeville, TN 38506, USA) with drip irrigation tape (Toro Ag 1588 N. Marshall Avenue El Cajon, CA 92020-1523, USA). Each bed had a width of 91.44 cm with a distance between rows of 182.88 cm and the distance between plants within a row of 121.92 cm. Seeds of the varieties Fascination seedless triploid and the pollinizer SP-6 (Syngenta, Greensboro, NC 27409) were planted in seed trays consisting of 72 square cell plugs in greenhouse conditions at SWPAC. Planted seed trays were moved from the greenhouse to the shade house before transplanting in the field.

Plant seedlings most excellent into beds for a total of 888 plants in 0.20 ha. The planting layout consisted of two Fascination plants followed by a transplant plug that contained both a Fascination plant and an SP-6 plant in a repeating pattern along each row. The corn plots were established by seeding using a seed planter with a 76.2 cm row width. The variety Spectrum hybrid 6334 (Spectrum Premium Non-GMO, 4105 East 200 South, Suite C, IN 47905, USA) was planted at a seed rate of 74.03 kg/ha on tilled fields. To simulate the environment often found surrounding watermelon fields in Indiana, each watermelon plot was planted surrounded by 4.45 – 7.68 ha of corn at > 3 m from the edge of the corn field, which was planted continuously beginning in 2017. Each watermelon plot had a dimension of approximately 45.72 m x 45.72 m with 24 separate rows.

All corn seeds were treated with the fungicides thiabendazole, fludioxonil, mefenoxam, azoxystrobin (Maxim Quattro) (Syngenta Canada Inc. 140 Research Lane, Research Park Guelph, ON N1G 4Z3), biological/micronutrient blend (Microking) (AGRA Solutions LLC, 23778 Delphos Jennings Road Delphos, OH 45833, USA), and pyraclostrobin (Stamina®) (BASF Ag products, 100 Park Avenue Florham Park, NJ 07932, USA). The CPM treated watermelon field was surrounded by corn planted from seeds treated with the insecticide thiamethoxam (1.25 mg ai/seed) (Cruiser Maxx 5FS) (Syngenta Canada Inc. 140 Research Lane, Research Park Guelph, ON N1G 4Z3), while the IPM watermelon field was surrounded by corn without the insecticide seed treatment.

IPM watermelon fields were not treated at planting with insecticide and were only treated by foliar application of lambda-cyhalothrin (Warrior II) (Syngenta Crop Protection, LLC Post Office Box 18300, Greensboro NC 27419, USA) if the pest threshold (i.e., 5 beetles per watermelon plant) was reached. CPM managed fields received an application of imidacloprid (Wrangler) (Loveland Products, INC, 3005 Rocky Mountain Ave Loveland, CO 80538, USA) at 59.49 L/ha as a soil drench by a spot application at the base of the plant added to the transplant water immediately following transplanting into the beds. Four prophylactic applications of lambda-cyhalothrin (every 2-3 weeks) were applied post-emergence to watermelon fields to replicate conventional pest management applications. The most common fungicides applied in both watermelon fields were chlorothalonil (Initiate) (Loveland Products, Inc., PO Box 1286, Greeley, CO 80632), pyraclostrobin (Cabrio) (BASF Corporation 100 Park Avenue Florham Park, NJ 07932, USA), and fluopyram-tebuconazole (Luna Experience) (Bayer CropScience 2 T.W. Alexander Drive Research Triangle PK, NC 27709, USA) . In CPM watermelon field, insecticide was applied post-emergence in a tank mix with the fungicide. The spray records on each field are included in the Appendix.

In 2019, the watermelon plot occupied a different footprint within the corn plots while remaining > 3 m from the edge of the corn field. The planting time of both corn and watermelon was based on local practices as weather permitted (Table 2).

***Field sampling methods***

*Visual observations of striped cucumber beetles and spider predators*

One week after watermelon seedling transplant, visual counts were made of all striped cucumber beetle pests and spider predators found on 15 randomly selected plants distributed across five transects in the plot. Each transect included three plants at 15, 25, and 35 m from the field edge. When watermelon plants overlapped within the row (i.e., when vines were longer than 1 m) a 1 $m^2$ section of a single plant row was sampled. The sampling frequency was weekly beginning one week after transplanting until harvest, approximately 12 weeks later.

*Spider populations*

To estimate spider abundance, pitfall traps were placed in both the watermelon and corn fields. Watermelon field plots were divided into 4 equal quadrants where one centrally located pitfall trap was placed on the base of a watermelon plant 15 m from the field edge one week after transplanting. The traps were collected biweekly for six sampling periods that coincided after corn planting. Traps included a plastic planting pot (16 cm diameter; 22 cm depth) with holes punched in the bottom. A plastic funnel, also 16 cm in diameter, with the stem cut off was placed inside the pot to direct trapped spiders and other arthropods into a 350 ml plastic deli cup at the bottom of each planting pot in 2018, but in 2019 the plastic deli cup up was enlarged to 470 ml to help prevent the traps from flooding. Each cup was filled with 100% propylene glycol to a depth of 2.5 cm. Above the trap, a 20 cm x 20 cm sheet of corrugated PVC was held in place with turf pins as a rain roof. Pitfall traps in corn were placed 15.24 m from the edge of each side of the watermelon fields in 4 approximately equal sections of the field.

Collected pitfall traps were processed and spiders were removed to record numbers and diversity. Specimens were preserved in 70% ethanol for further identification**.** Spiders were identified to family level, and where possible, to genus and species using species-level taxonomic keys (Ubick et al., 2017). Voucher specimens of the identified spiders are stored in the Purdue Entomological Research Collection (PERC) in the Department of Entomology at Purdue University.

*Collembola sampling*

Watermelon fields were divided into the same 4 quadrants used in the pitfall trap sampling. Using a bulb planter 10.16-cm depth by 7.62-cm width, one soil core sample was taken within 5.08 cm of the base of a watermelon plant in each quadrant. Soil cores were taken using the same bulb planter in the corn field 15.24 m from the edge of the watermelon plot in each of the 4 quadrants of the field. Samples were collected during the early (June), mid (July), and late (August) parts of the season. Collembola specimens were extracted by placing the soil core sample in a Berlese funnel (Sabu et al., 2011) for three days. Specimens were captured in 70% ethanol and stored in the lab for counting.

***Statistical analysis***

Data collected were analyzed based on this research question: Do insecticides in watermelon production and the surrounding landscapes affect striped cucumber beetle pests, spider predators, and collembola densities? Counts from the response variables of visual plant observations, pitfall trap samples, soil core sampling, and spider community metrics, which were calculated based on spider densities at family level and included Richness, Shannon's Diversity Index (H), and Evenness metric (J'), were analyzed using a general linear model (GLIMMIX procedure in SAS) based on a Poisson distribution with repeated measurements. The results were collapsed across sampling dates to early, mid and late season periods to limit the number of zeros. The structure of the model for the response variables was based on the main effects between replicates for location, treatment, and season. The model, as a fully factorial design, was modified to run without interactions when the initial runs would not converge. The means were separated using a Tukey-Kramer test at $p = 0.05$. Spearman correlations were made with the response variables of mean total spider and collembola densities.

## Results

### *Spider community*

The major spider community complex consisted of species in the families Lycosidae and Linyphiidae, corresponding to the guilds of wandering and web-builders, respectively. Spiders in the family Lycosidae collected in watermelon and corn fields represented 64% of the 3703 spider species collected during 2018 and 2019. Linyphiidae were 32% of the spider species with the remaining 4% of the spider species in the families Agelenidae, Anyphaenidae, Araneidae, Clubionidae, Corinnidae, Dictynidae Gnaphosidae, Phrurolithidae, Pisauridae, Theridiidae, Thomisidae, Salticidae, Tetragnathidae and Uloboridae (Table 3, Figure 2).

### *Watermelon visual pest and spider plant counts*

The response of striped cucumber beetles from the visual pest plant counts was statistically significant for location, treatment and season during 2018; likewise for 2019 except for season (Table 4).

Striped cucumber beetle populations in the IPM plots never reached the economic threshold of 5 beetles per plant in either year in four of the study sites. Densities exceeded the threshold at PPAC in both years, but a single application of lambda cyhalothrin brought the population density below the threshold for the remainder of the season. As expected, the densities of striped cucumber beetles and spiders found on watermelon plants subjected to IPM practices were significantly higher than those compared to the CPM treated fields in both seasons (Table 5). The total number of spiders visually observed on watermelon plants in the IPM treatment were higher than those observed in the conventional plots during both years of the study (Table 5).

***Spider pitfall trap densities***

The response of lycosid densities in watermelon was statistically significant for location, treatment and season during both years of the study; however, lycosid densities in corn were only affected by treatment during 2018 and by location and season during the 2019 season. In 2018, location and season had a statistically significant effect on Linyphiid densities in watermelon and corn; however, only for location in corn during 2019 (Table 4).

The mean total spiders and mean lycosids collected in watermelon IPM plots were both statistically higher than the number found in conventional plots in 2018 and 2019 (Table 6). However, more total spiders and lycosid spiders were collected in the surrounding corn plots planted with neonicotinoid treated seed compared to the untreated corn plots in 2018, but differences not significant in 2019. Linyphiid spider means were not statistically different between treatments in either crop in 2018 or 2019 (Table 6, 7).

Spider family community diversity metrics, Shannon diversity index (H), Richness, and Evenness, were only significantly affected by season in watermelon and corn in 2018; there was an effect of treatment on Evenness in corn during 2018 season (Table 8). The means of the Shannon diversity index (H), Richness, and Evenness were not significantly different in either treatment or crop during both years of the study (Table 9); however, only untreated corn plots were more Even in spider populations compared with the treated corn plots during the 2018 season (Table 10).

***Collembola soil core densities***

Collembola densities in watermelon were significantly affected by treatment during both years of the study, and also by location and season during the 2019 season. In corn, the only statistically significant effect on collembola densities was for location in 2018 (Table 4).

Collembola densities in watermelon were significantly higher in IPM treatments in 2018 and 2019; however, their densities were not significantly different in corn plots, regardless of treatment in either year (Table 11). Mean collembola densities were only significantly higher in mid-season in watermelon during 2019 (Table 12).

Mean total spider densities in the untreated corn correlated significantly with collembola densities in both years (2018: r = 0.44151, n = 120, P = 0.0397; 2019: r = 0.4315, n = 120, P = 0.0277). There were no significant correlations in watermelon managed with either IPM or CPM treatments, or in treated corn during both years of the study.

## Discussion

This study found an effect of pest management practices in watermelon fields on the densities of pests (e.g., striped cucumber beetles), their natural enemies (e.g., spiders), non-pest prey (e.g., collembola), but not on spider diversity at the family level. IPM appears to be a suitable pest management strategy for watermelon production because it would decrease the use of insecticides by using economic pest thresholds and conserve valuable pest natural enemies (Kogan, 1998). Although, conventional pest management and integrated pest management (IPM) options are practices currently available, most growers choose conventional pest management practices, presumable because of improved crop cultivation and economic profitability.

Striped cucumber beetle (SCB) pests in watermelon can be managed without regular applications of insecticide sprays. This was demonstrated during the 2018 and 2019 growing seasons, where only one site (PPAC) reached the action threshold level of 5 beetles per plant and was treated with a pyrethroid insecticide. This indicates that most conventionally managed watermelon plots were sprayed unnecessarily, and consequently, increased production costs and disrupted natural enemy communities (e.g., reduced spider densities and other non-pest prey).

Striped cucumber beetle densities varied during the season and between locations. However, SCB pest populations remained below the economic threshold level in nearly all of the watermelon fields. This may be because background beetle densities were low prior to the growing season, and when coupled with local cucumber beetle natural enemies, they rarely reached the economic threshold during the growing season. While local natural enemies were likely contributing factors, tis were not specifically measured in this study.

Another benefit of using IPM strategies is the maintenance of local natural predators to help suppress pest populations. During this study, the most common spiders species collected in watermelon and corn were in the families Lycosidae and Linyphiidae, as observed in previous studies conducted in Midwest cucurbits and corn (Brust et al., 1986; Cunha et al., 2015; Dieterich Mabin, 2017). Significantly higher numbers of spiders were collected in watermelon in the IPM managed plots in both years of the study; the pyrethroids applied in the conventionally treated watermelon fields negatively affected SCB densities, but also reduced both spiders and other prey.

Conventionally managed watermelon and corn fields were only treated at planting with neonicotinoids as a soil drench (imidacloprid) and seed coating (thiamethoxan), respectively. The difference between conventional treated watermelon and corn fields was the subsequent pyrethroid insecticides that were applied every 2 or 3 weeks only in the watermelon fields. However, higher numbers of total spiders and lycosid spiders were collected in corn plots planted with neonicotinoid-treated seeds surrounding watermelon managed with conventional practices in 2018, but not in 2019. This suggested that lycosid spiders are resilient to neonicotinoid seed treatments compared with non-treated corn seeds in some circumstances. Although, neonicotinoids were the only insecticide applied as a seed treatment in the conventionally managed corn fields, there was no evidence that these treatments affected ecological services (e.g., pest predation) or collembola densities. A 5-year field study comparing the effects of corn that was either treated or not with a neonicotinoid seed coating found no effect on densities of spiders (López et al., 2003) as shown in this study.

Spiders are usually the first predators to reach agricultural fields (Öberg et al., 2008). Lycosids, corresponding to the guild of wandering spiders, disperse by cursorial movement, and their hunting behavior is primarily on the soil surface (Bishop et al., 1990). On the contrary, linyphiids, belonging to a different guild of spiders (e.g., web-builders ), use ballooning behavior as the primary means of movement for migration and construct webs to catch prey (Weyman, 1993). Their hunting behaviors are different, but as generalist predators, they feed on a variety of prey (Nyffeler, 1999). Lycosid spiders hunt by a "sit-and-move" strategy (Samu et al., 2003), making them potentially more susceptible to insecticide exposure (as suggested by our results) compared with the linyphiids, which employ a "sit-and-wait" strategy to catch their prey using a web built near the ground (Enders, 1975).

Previous studies showed that both spider families can feed on collembola as a food source (Harwood et al., 2001; Kuusk et al., 2010). In our study, collembola densities were statistically different between treatments in watermelon fields. The decline in collembola prey in the treated fields can disrupt the food chain that spiders rely on when other prey are not present. Collembola are sensitive to insecticides (Fountain et al., 2007; Pisa et al., 2015) and are considered bioindicators of soil health (Gerlach et al., 2013). In a 3-year field study, neonicotinoids applied as a soil drench decreased collembola densities (Peck, 2009). The combination of neonicotinoids applied as a soil drench at planting, and regular pyrethroid sprays in the conventionally managed watermelon fields probably contributed to their decline. However, there did not appear to be a lingering negative effect of neonicotinoids in corn with treated seed.

Conventional pest management treatments in watermelon decreased striped cucumber beetle densities as desired, but also diminished spider and collembola densities compared with IPM practices. The intensive use of insecticides (calendar sprays) reduce natural enemies (e.g., spiders) and their food sources (e.g., striped cucumber beetles and collembola). Scouting and the use of pest management action thresholds would reduce the use of unnecessary insecticides and conserve non-target species (e.g., spider predators and collembola populations).

This study demonstrated how pest management practices in watermelon can jeopardize natural communities of predators and non-pest prey (e.g., spiders and collembola) when insecticides are used without regard to economic pest thresholds. In addition, our study found that neonicotinoid seed treatment in corn had no negative impact on either spider or collembola densities. Overall, the use of IPM to manage watermelon fields compared with conventional pest management showed two crucial benefits: first and foremost, a decrease in the number of insecticide applications needed to manage striped cucumber beetle densities; and secondly, the conservation of predator populations (e.g., spiders) and a non-pest prey (e.g., collembola) necessary for sustaining the ecosystem regulatory services provided by natural enemies.

# CHAPTER 4. EVALUATING THE EFFECT OF INSECTICIDE USE ON PREDATION IN WATERMELON AND CORN


## Abstract

Commercial watermelon (*Citrullus lanatus*) production in the Midwest typically relies on neonicotinoid and pyrethroid insecticides to manage insect pests, particularly for striped and spotted cucumber beetles (*Acalymma vittatum* and *Diabrotica undecimpunctata howardi* Barber, respectively). Common cucumber beetle predators include coccinellid beetles found on plants, ground-dwelling carabid beetles (Coleoptera: Carabidae) and lycosid spiders on the soil surface. However, these predators and the ecosystem services they provide (e.g., pest predation) are at risk from pest management practices used without regard to economic pest threshold levels. Our study compared pest predation under two treatments 1) watermelons treated with neonicotinoid soil drench at planting followed by regular pyrethroid sprays (Conventional Pest Management - CPM), and 2) watermelons treated with pyrethroid sprays only when economic pest thresholds were reached (IPM). We measured field predation in three locations across the state of Indiana during the 2019 growing season. Waxworm larvae (*Galleria mellonella*) and adult striped cucumber beetles (*Acalymma vittatum* F.) were used as surrogate prey to measure field predation in replicated 24-hour assays in both corn and watermelon plots. In watermelon, field predation was higher in the fields managed with IPM treatments where spider predators and non-pest prey populations were also higher. No difference was found in field predation between treatments in the corn fields.

## Introduction

Insects play an influential role in the regulation and dynamics of many ecosystem services (Noriega et al., 2017). Ecosystem services are benefits that humans use and obtain from nature to support their quality of life (Harrington et al., 2010). The food supply, pollination, suppression of pests and diseases, and the decomposition of organic matter are some of the essential ecological services on which humans depend. The largest and most diverse group that supports these services are insects. Insects and other arthropods contribute to important ecological functions such as pest control, pollination, and decomposition of organic matter (Losey et al., 2006). These beneficial outcomes have an estimated economic value of $57 billion per year in the United States (Losey et al., 2006).

Different crops depend on the services provided by insects. For example, watermelon, (*Citrullus lanatus*) a plant member of the cucurbit family, Cucurbitaceae, depends on pollination for fruit establishment (Foster et al., 1995), as well as suppression of pests – an ecosystem regulatory service provided by natural enemies. However, there is limited data on the effect of insecticides on the predators (Souza et al., 2012) and predation services they provide in Midwest watermelon production. No research has been done on pest predation in watermelon.

Suppression of pests is estimated to have a value of $4.5 billion annually in the United States (Losey et al., 2006). However, natural enemies that provide this ecosystem service are often disrupted by a wide variety of human activities (Daily, 2003). These activities include: i) habitat loss, intensive farming, and urbanization, and ii) pollution, primarily by synthetic pesticides and fertilizers (Sánchez-Bayo et al., 2019). Individually or in combinations, these activities can negatively impact these ecosystem services over time.

Intensification of agriculture and the recurrent use of insecticides for controlling crop pests have caused a widespread decline in natural enemies and the ecosystem services they provide

(Losey et al., 2006). Pyrethroid, neonicotinoid, and fipronil insecticides have an impact on aquatic insects due to their chronic toxicity (Sánchez-Bayo et al., 2019). Also, neonicotinoids have been reported to have a direct toxic effect a wide range of natural enemies in laboratory and field conditions (Cloyd et al., 2011; Douglas et al., 2015)

Predatory arthropods and their ecosystem services are at risk when pesticides are used (Desneux et al., 2007; Hoopwood et al., 2016). Predation has been measured in different crops in the Midwest including corn and cucurbit production using sentinel prey (Jones et al., 2014; Dieterich Mabin, 2017). Sentinel prey (i.e., prey growing in laboratory conditions) used to measure field predation in these studies included insect eggs (*Diabrotica undecimpunctata howardi* B.) and waxworm larvae (*Galleria mellonella*). These prey are strategically placed in the field for a specific period of time and then are collected and scored for signs of predation (Dieterich Mabin, 2017; Rivers et al., 2018). However, no field predation research has been done in watermelon.

The present study evaluated the effects of conventional vs. IPM practices on pest predation in watermelon and in the adjacent corn. We assessed predation by quantifying the differences between caged and uncaged surrogate prey under conventional pest management or IPM practices as field treatments. The differences in predation will confirm whether there is a difference of conventional management practices, which will ultimately help us better understand how to manage watermelon pests while preserving natural enemy ecosystem services. The ultimate goal of the study is to show growers the benefits of implementing an IPM approach that can maintain an economically viable trade-off between insecticide use and conservation of natural enemies.

***Research question***

Do insecticide treatments in watermelon and the adjacent corn affect field predation?

### *Hypothesis*

Watermelon production managed using conventional pest management surrounded by corn planted with neonicotinoid-treated seeds has less predation than watermelon managed with IPM practices surrounded by corn planted with untreated seeds.

### *Objectives*

- Measure predation in watermelon fields subject to conventional pest management and IPM management practices.
- Quantify and compare predation in adjacent corn fields planted with neonicotinoid-treated or untreated seeds.

## Materials and Methods

### *Site locations*

This study was conducted in TPAC, PPAC, and SWPAC research centers. Coordinates and sizes of the field plots by these locations are described in Chapter 3.

### *Experimental design*

This study was conducted in field plots based on the same experimental design described in Chapter 3.

### *Field experiments*

*Preliminary field trials in corn and watermelon using sentinel eggs and waxworm larvae during the 2018 season*

This work was conducted at Throckmorton-Purdue Agricultural Center (Lafayette, IN) in an area dedicated for specialty crop research. The agricultural center had a pair of research fields

(GPS coordinates 40.3010, -86.9091; 40.2708; -86.8766) planted with 0.20 ha of watermelon surrounded by 6.07 acres of corn in the 2018 growing season.

To determine the amount of predation occurring in watermelon and corn fields under different pest management treatments, we conducted a field predation study using surrogate prey in sentinel predation assays during mid-late season.

Each watermelon field was divided into 4 equal quadrants. Each quadrant received two sentinel prey replicates consisting of spotted cucumber beetle eggs (*Diabrotica undecimpunctata howardi* Barber), and waxworm larvae (*Galleria mellonella*) mounted on plastic cards. Separate cards were created for each prey species by gluing 30 viable spotted cucumber beetle eggs and securing one live waxworm larva. The eggs were glued using nontoxic silicone aquarium sealant (Phillips et al., 2016), and the live larvae were attached with transparent rubber bands to the top third of separate white plastic plant markers (2.54-cm length x 1.58-cm width) in a circular area of 1.5 cm in diameter. Two egg and two larval cards per replicate were placed on the soil with two cards unprotected and the other two protected with a clip cage as an environmental control. All cards were placed on the soil in a horizontal position enclosed by a secured small metal cage (8-cm length x 8-cm width) with 1-cm$^2$ openings for free access of arthropods. There were eight replicates per field treatment for a total of 32 cards (= 8 reps x 2 treatments x 2 crops = 32 cards).

Egg cards were placed 10 cm from a plant base with the cards facing north to limit direct sunlight. In the watermelon fields, sets of cards were placed at the base of two randomly selected plants within each quadrant of the field for a total of 8 locations within each field. Cards were placed in the corn fields 15.24 m from the edge of each side of the watermelon fields. Cards were set up in the field at 9:00 am and left for 24 hr. The following morning, the cards were collected and returned to the lab to determine the proportion of eggs and larvae subjected to predation. In the laboratory, all egg and larval cards collected were scored for predation. The protocol for scoring predation consisted of a binary system on a scale of 1 and 0 with predation determined by any sign of damage or no damage in comparison with the environmental controls.

*Field trials in watermelon and corn using waxworm larvae and striped cucumber beetle during the 2019 season*

Based on our preliminary field trials in 2018, we decided to conduct field predation trials in additional locations repeated over the entire field season. The study was conducted with two single prey items, waxworm larvae (*Galleria mellonella*) and striped cucumber beetle adults (*Acalymma vittatum* F.), during early, mid and late season to determine field predation between conventional pest management (CPM) and IPM field treatments. Cucumber beetle eggs were not included in these trials because there were no signs of predation in preliminary field trials conducted with this single prey item.

This work was conducted at Throckmorton-Purdue Agricultural Center (Lafayette, IN) (GPS coordinates 40.3010, -86.9091; 40.2708), Pinney-PAC (Wanatah, IN) (GPS coordinates 41.4551; -86.9364; 41.4037; -86.8959) and Southwest-PAC (Vincennes, IN) (GPS coordinates 38.7811; -87.4505; 38.7393; -87.4903) in an area dedicated for specialty crop research. Each agricultural center had a pair of research fields planted with 0.20 ha of watermelon surrounded by 6.07 ha of corn in the 2019 growing season.

To determine the amount of predation occurring in the differently managed watermelon and corn fields, we conducted field predation assay during the early (June), mid (July), and late (August) periods of the 2019 growing season. Each watermelon field was divided into 4 equal quadrants. Each quadrant received two sentinel prey replicates consisting of waxworm larvae (*Galleria mellonella*) and one replicate of a striped cucumber beetle adult (*Acalymma vittatum* F.) mounted on plastic plant markers (2.54-cm length x 1.58-cm width) in a small circular area of 1.5

cm in diameter. Separate cards were created by mounting one live waxworm larvae tied with transparent rubber bands and one live striped cucumber beetle adult glued on its elytra in prone position. Two larval and two cucumber beetle cards per replicate were placed on the soil with one card unprotected and the other protected with a clip cage as an environmental control. All cards were placed on the soil in a horizontal position enclosed by a secured small metal cage (8-cm length x 8-cm width) with 1-cm$^2$ openings for free access of arthropods. There were 12 replicates per watermelon and corn field for a total of 48 cards.

Waxworm larvae and cucumber beetle cards were placed 10 cm from the plant base with the cards facing north to limit direct sunlight. In the watermelon fields, sets of cards were placed at the base of three randomly selected plants within each quadrant for a total of 12 locations in each field. Cards were placed in the corn fields 15.24 m from the edge of each of the four sides of the watermelon fields. Cards were set up in the field at 9:00 am and left for 24 hr. The following morning, the cards were collected and returned to the lab to determine the proportion of larvae and cucumber beetles subjected to predation. The protocol for scoring predation consisted of a binary system on a scale of 1 and 0 with predation determined by any sign of damage or no damage in comparison with the environmental controls.

***Statistical analysis***

Predation studies were analyzed based on this research question: Do insecticide treatments in watermelon production and the surrounding corn landscapes affect field predation rates? Predation was analyzed using a general linear model (GLIMMIX procedure in SAS). The response variable, which was the proportion of prey subject to predation, was transformed using the arcsin function to stabilize variances and normalize proportional data. The structure of the model for the response variable was based on the main effects between replicates for location, treatment and season. The means were separated using a Tukey-Kramer test at p = 0.05.

## Results

### *Preliminary field trials in watermelon and corn conducted in TPAC during 2018*

In the 2018 season, the mean proportion predation of waxworm larvae and spotted cucumber beetle eggs in watermelon and corn plots was significantly higher in plots managed with IPM vs CPM treatments (Table 13). The interaction of Treatment*Prey was statistically different in watermelon ($F_{1,54} = 8.97$, P = 0.001) and corn plots ($F_{1,22} = 9.86$, P = 0.0048); there was no difference between prey in watermelon ($F_{1,54} = 0.10$, P = 0.7543), but a difference between prey in corn ($F_{1,22} = 6.57$, P = 0.0178). On the other hand, the treated neonicotinoid corn field had less predation compared with the untreated field. Overall, field predation was higher in corn compared to watermelon, regardless of prey.

### *Field trials in watermelon during 2019*

In the 2019 season, the mean proportion predation of waxworm larvae ($F_{1,126} = 11.41$, P = 0.001) and striped cucumber beetles ($F_{1,64} = 20.74$, P < 0.0001) in watermelon plots was significantly higher in plots managed with IPM vs conventional pest management treatments (Table 15). Mid and late season predation was significantly higher than the early season (Table 16). The mean proportion predation was significantly affected by treatment and season in both type of preys (e.g., striped cucumber beetle and waxworm larvae), but there was an effect by location only for waxworm larvae, based on the structure of the statistical model (Table 14).

***Field trials in corn during 2019***

In the 2019 season, there was no difference in the proportion predation of waxworm larvae ($F_{1,129}$= 0.05, P = 0.8175) and striped cucumber beetles ($F_{1,62}$= 0.62, P = 0.4353) in corn plots, regardless of treatment (Table 15). The mean proportion predation was significantly higher mid season (Table 16). Overall, corn plots had a higher mean proportion predation compared with watermelon plots as observed in 2018. The mean proportion predation was significantly affected by season in both type of preys (e.g., striped cucumber beetle and waxworm larvae), but there was an effect of location only for striped cucumber beetles (Table 14).

**Discussion**

Suppression of pests and diseases, pollination, and the decomposition of organic matter are the major beneficial ecosystem services provided by insects and other vertebrates. These free services, on which agricultural production depends, can be affected by different human activities.

Intensive farming, in particular the use of pesticides, contributed to the worldwide declination of insects (Sánchez-Bayo et al., 2019). Some species of this group are considered natural predators of insect pests in agricultural fields. The overuse of insecticides and the intensification of agriculture may have affected the regulatory pest services (e.g., predation) contributed by these organisms.

Predation is one of the valuable ecosystem services provided by natural enemies that have been affected by pest management practices (Brust et al., 1986; Monteiro et al., 2013). The overuse of insecticides can reduce the number of pests, but they can also decrease the number of natural predators and other non-pest species in agricultural fields (Croft et al., 1975). Neonicotinoids and pyrethroids reveal to have adverse effects on the abundance of natural predators (Douglas et al., 2016). These insecticides, commonly used to manage cucumber beetle pests, may have decreased the abundance of arthropod natural enemies and their major ecological service (e.g., pest predation) in watermelon plots.

Reducing the frequency of unnecessary insecticide sprays in the IPM fields help maintain predators that are needed for their pest regulation services. This is what we found in our watermelon plots (Chapter 3). Fields managed with IPM practices maintained higher densities of spider predators and non-pest prey (collembola) compared with the conventionally managed fields. However, field predation in the corn fields did not differ between treatments. This is probably because corn fields were basically unmanaged in terms of insect pest management treatments once they were planted.

Field predation was greater in the IPM managed plots and varied during the season in both crops. Predation of striped cucumber beetles and waxworm larvae increased as the season progressed. The reduced number of insecticide applications in these fields contributed to the maintenance of natural predators and their ecosystem services, resulting in a pest and natural enemy equilibrium, in which pests are managed by natural predators without the use of insecticides to control them.

Spider predators were not the only predators found in the pitfall traps, but they may have contributed to the general predation in the IPM treatment (Chapter 3). Other predators observed in the field preying upon the sentinel prey during the assays included spiders, carabids, coccinellids, and ants. The observed abundance of natural enemies in the IPM treatment certainly contributed to this free ecosystem service.

Overall, watermelon growers need to reevaluate their pest management practices and make changes that will improve their production and reduce the negative impacts on non-target species and the surrounding environments. Predation is an ecosystem service that must be valued just as pollination is in watermelon production, and growers need to take it into consideration when deciding on the best pest management strategy. Growers can effectively manage their pests without the frequent use of insecticides if they follow IPM practices that also help maintain natural enemies and preserve the predation regulation they provide as a necessary and valuable ecological service.

# CHAPTER 5. CONCLUSIONS

In this study, we found that growers in Indiana can successfully manage watermelon pests, reduce the frequent use of insecticides, and enhance the ecosystem services provided by natural enemies by monitoring pest populations for economic pest thresholds before they spray. Integrated pest management (IPM) has proven to be a tool that reduces the exposure of watermelon predators and other non-target species to the negative impacts of insecticides. Although growers do not typically follow an IPM approach to manage pests in commercial watermelon production, we demonstrated that this practice can successfully manage the pests without disrupting natural enemies and the ecosystem services (e.g., pest predation) they provide.

Achieving economic pest management and also conserving natural enemies are reasons why integrated pest management is needed in commercial watermelon production. Integrated pest management is a way to reduce insecticide usage, lower production costs, and conserve natural communities. Additionally, other benefits include reduced non-target environmental impacts and lowered risks of effects on human health. This study suggests shifting the current intensive agricultural pest management practices, which raised concerns about the indiscriminate use of insecticides, to a more agroecologically sustainable approach. Growers who embrace integrated pest management in their production can begin replacing some of their intensive agriculture practices with more sustainable approaches.

This study adds valuable information towards understanding the effects of insecticides on predators in watermelon production, which is information that was previously lacking, and consequently, poorly understood.

Table 1: Coordinates and size of the field plots by location, treatment and crop in 2018 and 2019.

| Location | Field treatment | Latitude - Longitude | Plot Size (ha) | |
|---|---|---|---|---|
| | | | Watermelon | Corn |
| TPAC | Conventional | 40.2708; -86.8766 | 0.2 | 4.58 |
| TPAC | IPM | 40.3010; -86.9091 | 0.2 | 5 |
| SWPAC | Conventional | 38.7811; -87.4505 | 0.2 | 5.18 |
| SWPAC | IPM | 38.7393; -87.4903 | 0.2 | 4.98 |
| SEPAC | Conventional | 39.0288; -85.5358 | 0.2 | 4.82 |
| SEPAC | IPM | 39.0795; -85.5058 | 0.2 | 7.32 |
| PPAC | Conventional | 41.4037; -86.8959 | 0.2 | 7.85 |
| PPAC | IPM | 41.4551; -86.9364 | 0.2 | 5.7 |
| NEPAC | Conventional | 41.1171; -85.4504 | 0.2 | 6.17 |
| NEPAC | IPM | 41.1957; -85.3962 | 0.2 | 5.71 |

Table 2: Dates of planting, harvest and pitfall trap sampling by location and treatment in 2018 and 2019.

| | | 2018 | | | | | |
|---|---|---|---|---|---|---|---|
| Location | Treatment | Planting | | Harvesting | | Pitfall trap sampling | |
| | | Watermelon | Corn | Watermelon | Corn | Initial | End |
| TPAC | Conventional | 22-May | May-8 | 3-Aug-18 | 17-Oct | 1-Jun | 16-Aug |
| TPAC | IPM | 22-May | May-2 | 3-Aug-18 | 29-Oct | 1-Jun | 16-Aug |
| PPAC | Conventional | 4-Jun | 1-Jun | 20-Aug-18 | 15-Oct | 13-Jun | 28-Aug |
| PPAC | IPM | 4-Jun | 1-Jun | 20-Aug-18 | 1-Nov | 13-Jun | 28-Aug |
| NEPAC | Conventional | 8-Jun | 30-Apr | 31-Aug-18 | 9-Oct | 12-Jun | 30-Aug |
| NEPAC | IPM | 8-Jun | 30-Apr | 31-Aug-18 | 3-Oct | 12-Jun | 30-Aug |
| SEPAC | Conventional | 24-May | 9-May | 2-Aug-18 | 4-Oct | 31-May | 24-Aug |
| SEPAC | IPM | 24-May | 8-May | 2-Aug-18 | 5-Oct | 31-May | 24-Aug |
| SWPAC | Conventional | 18-May | 30-Apr | 24-Jul-18 | 5-Oct | 23-May | 8-Aug |
| SWPAC | IPM | 18-May | 30-Apr | 24-Jul-18 | 23-Sept; 29-Sept | 23-May | 8-Aug |

| | | 2019 | | | | | |
|---|---|---|---|---|---|---|---|
| Location | Treatment | Planting | | Harvesting | | Pitfall trap sampling | |
| | | Watermelon | Corn | Watermelon | Corn | Initial | End |
| TPAC | Conventional | 28-May | 2-Jun | 6-Aug | 4-Nov | 3-Jun | 22-Aug |
| TPAC | IPM | 28-May | 2-Jun | 6-Aug | 4-Nov | 3-Jun | 22-Aug |
| PPAC | Conventional | 11-Jun | 27-May | 28-Aug | 1-Nov | 17-Jun | 26-Aug |
| PPAC | IPM | 11-Jun | 27-May | 20-Sept | 28-Oct | 17-Jun | 26-Aug |
| NEPAC | Conventional | 17-Jun | 7-Jun | 30-Aug | - | 20-Jun | 2-Sep |
| NEPAC | IPM | 17-Jun | 7-Jun | 30-Aug | - | 20-Jun | 2-Sep |
| SEPAC | Conventional | 3-Jun | 5-Jun | 16-Aug | 6-Nov | 7-Jun | 20-Aug |
| SEPAC | IPM | 3-Jun | 1-Jun | 16-Aug | 15-Oct | 7-Jun | 20-Aug |
| SWPAC | Conventional | 22-May | 19-May | 1-Aug | 1-Oct | 28-May | 13-Aug |
| SWPAC | IPM | 17-May | 28-May; 4-Jun | 1-Aug | 23-Oct | 28-May | 13-Aug |

Table 3: Spiders collected, identified, and counted by family from watermelon and corn by treatment in 2018 and 2019.

| Crop | Watermelon | Watermelon | Corn | Corn | Total |
|---|---|---|---|---|---|
| Treatment | Conventional | IPM | Conventional | IPM | |
| Lycosidae | 320 | 1087 | 625 | 442 | 2474 |
| Linyphiidae | 324 | 270 | 210 | 273 | 1077 |
| Gnaphosidae | 4 | 3 | 6 | 10 | 23 |
| Thomisidae | 6 | 6 | 12 | 6 | 30 |
| Theridiidae | 9 | 3 | 2 | 5 | 19 |
| Agelenidae | 2 | 0 | 3 | 3 | 8 |
| Phrurolithidae | 7 | 2 | 6 | 3 | 18 |
| Clubionidae | 0 | 1 | 2 | 2 | 5 |
| Salticidae | 3 | 3 | 2 | 2 | 10 |
| Tetragnathidae | 2 | 2 | 11 | 2 | 17 |
| Unknown | 3 | 5 | 5 | 2 | 15 |
| Anyphaenidae | 0 | 0 | 1 | 1 | 2 |
| Uloboridae | 0 | 0 | 0 | 1 | 1 |
| Dictynidae | 0 | 0 | 0 | 1 | 1 |
| Araneidae | 0 | 0 | 1 | 0 | 1 |
| Corinnidae | 0 | 1 | 0 | 0 | 1 |
| Pisauridae | 0 | 1 | 0 | 0 | 1 |
| Total | 680 | 1384 | 886 | 753 | 3703 |

Table 4: Main effects of location, treatment and season on response variable densities by crop in 2018 and 2019 using a general linear model (GLIMMIX procedure in SAS).

| | | 2018 | | | | | |
|---|---|---|---|---|---|---|---|
| | | Watermelon | | | Corn | | |
| | | Location | Treatment | Season | Location | Treatment | Season |
| Response variable densities | Sampling unit | Pr > F | | | Pr > F | | |
| Striped cucumber beetles | Visual plant count | <.0001* | <.0001* | <.0001* | ~ | ~ | ~ |
| Total spiders | Visual plant count | <.0001* | 0.0004* | <.0001* | ~ | ~ | ~ |
| Lycosids | Pitfall trap | 0.0492* | 0.0007* | 0.0005* | 0.6086 | 0.0089* | 0.1712 |
| Linyphiids | Pitfall trap | 0.0071* | 0.7553 | <.0001* | 0.0008* | 0.2974 | <.0001* |
| Total spiders | Pitfall trap | 0.0935 | 0.0037* | 0.0007* | 0.8523 | 0.0341* | 0.0232* |
| Collembola | Soil cores | 0.142 | 0.003* | 0.0723 | 0.0011* | 0.7184 | 0.1482 |

| | | 2019 | | | | | |
|---|---|---|---|---|---|---|---|
| | | Watermelon | | | Corn | | |
| | | Location | Treatment | Season | Location | Treatment | Season |
| Response variable densities | Sampling unit | Pr > F | | | Pr > F | | |
| Striped cucumber beetles | Visual plant count | <.0001* | <.0001* | <.0001* | ~ | ~ | ~ |
| Total spiders | Visual plant count | <.0001* | <.0001* | 0.1169 | ~ | ~ | ~ |
| Lycosids | Pitfall trap | 0.0087* | <.0001* | <.0001* | 0.0022* | 0.1263 | <.0001* |
| Linyphiids | Pitfall trap | 0.172 | 0.1245 | 0.1058 | 0.0014* | 0.7936 | 0.1036 |
| Total spiders | Pitfall trap | 0.0085* | <.0001* | <.0001* | 0.0045* | 0.166 | <.0001* |
| Collembola | Soil cores | 0.0002* | 0.0001* | <.0001* | 0.5402 | 0.4775 | 0.5494 |

* Statistically significant fixed effect at F<0.05

Table 5: Mean striped cucumber beetle (SCB) and total spider densities per watermelon plant across season and locations by treatment in 2018 and 2019.

| | 2018 | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Striped cucumber beetles | | | | Total spiders | | | |
| Treatment | N | Mean | Std | StdErr | N | Mean | Std | StdErr |
| Conventional | 690 | 0.06 | 0.27 | 0.01 | 690 | 0.38 | 0.70 | 0.03 |
| IPM | 690 | 0.61* | 1.32 | 0.05 | 690 | 0.52* | 0.79 | 0.03 |

| | 2019 | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Striped cucumber beetles | | | | Total spiders | | | |
| Treatment | N | Mean | Std | StdErr | N | Mean | Std | StdErr |
| Conventional | 750 | 0.13 | 0.43 | 0.02 | 750 | 0.21 | 0.48 | 0.02 |
| IPM | 750 | 1.63* | 2.07 | 0.08 | 750 | 0.56* | 0.79 | 0.03 |

* Means statistically significant at p<0.05 level (Tukey-Kramer)

Table 6: Mean Lycosidae, Linyphiidae and total spider densities per pitfall trap across season and locations by treatment and crop in 2018.

| | Watermelon | | | | Corn | | | |
|---|---|---|---|---|---|---|---|---|
| | Lycosidae | | | | Lycosidae | | | |
| Treatment | N | Mean | Std | StdErr | N | Mean | Std | StdErr |
| Conventional | 95 | 1.51 | 1.87 | 0.19 | 80 | 3.94* | 10.32 | 1.15 |
| IPM | 101 | 4.38* | 7.80 | 0.78 | 100 | 1.35 | 1.70 | 0.17 |

| | Linyphiidae | | | | Linyphiidae | | | |
|---|---|---|---|---|---|---|---|---|
| Treatment | N | Mean | Std | StdErr | N | Mean | Std | StdErr |
| Conventional | 95 | 1.59 | 2.39 | 0.25 | 80 | 1.15 | 2.24 | 0.25 |
| IPM | 101 | 1.40 | 2.42 | 0.24 | 100 | 1.35 | 2.03 | 0.20 |

| | Total spiders | | | | Total spiders | | | |
|---|---|---|---|---|---|---|---|---|
| Treatment | N | Mean | Std | StdErr | N | Mean | Std | StdErr |
| Conventional | 95 | 3.28 | 3.09 | 0.32 | 80 | 5.35* | 10.90 | 1.22 |
| IPM | 101 | 5.87* | 8.14 | 0.81 | 100 | 2.86 | 2.73 | 0.27 |

* Means statistically significant at p<0.05 level (Tukey-Kramer)

Table 7: Mean Lycosidae, Linyphiidae and total spider densities per pitfall trap across season and locations by treatment and crop in 2019.

| | Watermelon | | | | Corn | | | |
|---|---|---|---|---|---|---|---|---|
| | Lycosidae | | | | Lycosidae | | | |
| Treatment | N | Mean | Std | StdErr | N | Mean | Std | StdErr |
| Conventional | 113 | 1.57 | 1.86 | 0.17 | 98 | 3.16 | 8.67 | 0.88 |
| IPM | 112 | 5.76* | 9.45 | 0.89 | 112 | 2.74 | 4.31 | 0.41 |

| | Linyphiidae | | | | Linyphiidae | | | |
|---|---|---|---|---|---|---|---|---|
| Treatment | N | Mean | Std | StdErr | N | Mean | Std | StdErr |
| Conventional | 113 | 1.53 | 2.04 | 0.19 | 98 | 1.20 | 1.69 | 0.17 |
| IPM | 112 | 1.15 | 1.68 | 0.16 | 112 | 1.23 | 1.63 | 0.15 |

| | Total spiders | | | | Total spiders | | | |
|---|---|---|---|---|---|---|---|---|
| Treatment | N | Mean | Std | StdErr | N | Mean | Std | StdErr |
| Conventional | 113 | 3.26 | 2.79 | 0.26 | 98 | 4.67 | 9.06 | 0.92 |
| IPM | 112 | 7.06* | 9.74 | 0.92 | 112 | 4.17 | 4.39 | 0.42 |

* Means statistically significant at p<0.05 level (Tukey-Kramer)

Table 8: Main effects of location, treatment and season on spider family Richness, Shannon's Diversity Index (H) and Evenness metric (J') by crop in 2018 and 2019 using a general linear model (GLIMMIX procedure in SAS).

| | 2018 | | | | | |
|---|---|---|---|---|---|---|
| | Watermelon | | | Corn | | |
| | Location | Treatment | Season | Location | Treatment | Season |
| Response variables | Pr > F | | | | | |
| Richness | 0.1314 | 0.3586 | <.0001* | 0.1885 | 0.4978 | <.0001* |
| Shannon Diversity Index | 0.1018 | 0.8712 | <.0001* | 0.2437 | 0.1069 | 0.0008* |
| Evenness | 0.1163 | 0.5388 | <.0001* | 0.4861 | 0.0214* | 0.0007* |

| | 2019 | | | | | |
|---|---|---|---|---|---|---|
| | Watermelon | | | Corn | | |
| | Location | Treatment | Season | Location | Treatment | Season |
| Response variables | Pr > F | | | Pr > F | | |
| Richness | 0.0731 | 0.6192 | 0.2831 | 0.1483 | 0.9087 | 0.3645 |
| Shannon Diversity Index | 0.4008 | 0.7521 | 0.6902 | 0.1212 | 0.5446 | 0.9067 |
| Evenness | 0.5889 | 0.9539 | 0.7618 | 0.1113 | 0.5154 | 0.7352 |

* Statistically significant fixed effect at F<0.05

Table 9: Mean spider community diversity metrics (e.g., Richness, Shannon's Diversity Index (H) and Evenness metric (J')) by treatment and crop in 2018 and 2019.

| | 2018 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Watermelon | | | | | | | | | | | |
| | Richness | | | | Shannon | | | | Evenness | | | |
| Treatment | N | Mean | Std | StdErr | N | Mean | Std | StdErr | N | Mean | Std | StdErr |
| Conventional | 95 | 1.29 | 0.86 | 0.09 | 95 | 0.26 | 0.35 | 0.04 | 95 | 0.33 | 0.43 | 0.04 |
| IPM | 101 | 1.40 | 0.72 | 0.07 | 101 | 0.26 | 0.31 | 0.03 | 101 | 0.36 | 0.43 | 0.04 |

| | Corn | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Richness | | | | Shannon | | | | Evenness | | | |
| Treatment | N | Mean | Std | StdErr | N | Mean | Std | StdErr | N | Mean | Std | StdErr |
| Conventional | 80 | 1.18 | 0.96 | 0.11 | 80 | 0.17 | 0.32 | 0.04 | 80 | 0.19 | 0.33 | 0.04 |
| IPM | 100 | 1.30 | 0.85 | 0.08 | 100 | 0.27 | 0.36 | 0.04 | 100 | 0.36* | 0.45 | 0.05 |

| | 2019 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Watermelon | | | | | | | | | | | |
| | Richness | | | | Shannon | | | | Evenness | | | |
| Treatment | N | Mean | Std | StdErr | N | Mean | Std | StdErr | N | Mean | Std | StdErr |
| Conventional | 113 | 1.31 | 0.79 | 0.07 | 113 | 0.26 | 0.34 | 0.03 | 113 | 0.34 | 0.44 | 0.04 |
| IPM | 112 | 1.36 | 0.75 | 0.07 | 112 | 0.24 | 0.29 | 0.03 | 112 | 0.33 | 0.40 | 0.04 |

| | Corn | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Richness | | | | Shannon | | | | Evenness | | | |
| Treatment | N | Mean | Std | StdErr | N | Mean | Std | StdErr | N | Mean | Std | StdErr |
| Conventional | 98 | 1.38 | 0.94 | 0.09 | 98 | 0.29 | 0.36 | 0.04 | 98 | 0.37 | 0.45 | 0.05 |
| IPM | 112 | 1.38 | 0.80 | 0.08 | 112 | 0.26 | 0.37 | 0.03 | 112 | 0.32 | 0.44 | 0.04 |

* Means statistically significant at p<0.05 level (Tukey-Kramer)

Table 10: Mean collembola densities per soil core across season and locations by treatment and crop in 2018 and 2019.

| | 2018 | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Watermelon | | | | Corn | | | |
| Treatment | N | Mean | Std | StdErr | N | Mean | Std | StdErr |
| Conventional | 56 | 3.91 | 9.75 | 1.30 | 56 | 4.59 | 7.62 | 1.02 |
| IPM | 54 | 15.37* | 25.90 | 3.52 | 56 | 4.98 | 6.75 | 0.90 |

| | 2019 | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Watermelon | | | | Corn | | | |
| Treatment | N | Mean | Std | StdErr | N | Mean | Std | StdErr |
| Conventional | 59 | 2.53 | 4.15 | 0.54 | 56 | 7.00 | 11.20 | 1.50 |
| IPM | 60 | 7.90* | 16.87 | 2.18 | 60 | 5.70 | 6.36 | 0.82 |

* Means statistically significant at p<0.05 level (Tukey-Kramer)

Table 11: Mean collembola densities per soil core across locations and treatment by season and crop in 2018 and 2019.

| | 2018 | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Watermelon | | | | Corn | | | |
| Season | N | Mean | Std | StdErr | N | Mean | Std | StdErr |
| Early | 32 | 7.53 | 19.60 | 3.46 | 32 | 7.28 | 8.11 | 1.43 |
| Mid | 38 | 5.74 | 8.84 | 1.43 | 40 | 3.80 | 6.55 | 1.04 |
| Late | 40 | 14.75 | 26.71 | 4.22 | 40 | 3.78 | 6.64 | 1.05 |

| | 2019 | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Watermelon | | | | Corn | | | |
| Season | N | Mean | Std | StdErr | N | Mean | Std | StdErr |
| Early | 40 | 1.65 | 2.91 | 0.46 | 40 | 5.58 | 12.15 | 1.92 |
| Mid | 39 | 11.23* | 20.34 | 3.26 | 38 | 7.74 | 6.54 | 1.06 |
| Late | 40 | 2.98 | 3.51 | 0.56 | 38 | 5.71 | 7.12 | 1.16 |

* Means statistically significant at $p<0.05$ level (Tukey-Kramer)

Table 12: Mean proportion predation by treatment, crop and prey type at TPAC in 2018.

| | Watermelon | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Eggs | | | | Waxworm larvae | | | |
| Treatment | N | Mean | Std | StdErr | N | Mean | Std | StdErr |
| Conventional | 8 | 0.14 | 0.18 | 0.06 | 8 | 0.13 | 0.35 | 0.13 |
| IPM | 8 | 0.32* | 0.39 | 0.14 | 8 | 0.88* | 0.35 | 0.13 |

| | Corn | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Eggs | | | | Waxworm larvae | | | |
| Treatment | N | Mean | Std | StdErr | N | Mean | Std | StdErr |
| Conventional | 5 | 0.74 | 0.23 | 0.10 | 5 | 0.20 | 0.45 | 0.20 |
| IPM | 8 | 0.98* | 0.03 | 0.01 | 8 | 1.00* | 0.00 | 0.00 |

* Means statistically significant at $p<0.05$ level (Tukey-Kramer)

Table 13: Main effects of location, treatment and season on proportion predation by crop and prey type in 2019 using a general linear model (GLIMMIX procedure in SAS).

| | Striped cucumber beetles | | Waxworm larvae | |
|---|---|---|---|---|
| | Watermelon | Corn | Watermelon | Corn |
| Fixed effect | Pr > F | | | |
| Location | 0.6075 | 0.0079* | 0.0116* | 0.1178 |
| Treatment | <.0001* | 0.4353 | 0.001* | 0.8175 |
| Season | 0.0356* | 0.0069* | 0.0003* | <.0001* |

* Statistically significant fixed effect at $F<0.05$

Table 14: Mean proportion predation across season and locations by treatment, crop and prey type in 2019.

| | Watermelon | | | | Corn | | | |
|---|---|---|---|---|---|---|---|---|
| | Striped cucumber beetles | | | | Striped cucumber beetles | | | |
| Treatment | N | Mean | Std | StdErr | N | Mean | Std | StdErr |
| Conventional | 36 | 0.25 | 0.44 | 0.07 | 36 | 0.75 | 0.44 | 0.07 |
| IPM | 36 | 0.72* | 0.45 | 0.08 | 34 | 0.68 | 0.48 | 0.08 |

| | Waxworm larvae | | | | Waxworm larvae | | | |
|---|---|---|---|---|---|---|---|---|
| Treatment | N | Mean | Std | StdErr | N | Mean | Std | StdErr |
| Conventional | 66 | 0.46 | 0.50 | 0.06 | 65 | 0.79 | 0.41 | 0.05 |
| IPM | 68 | 0.71* | 0.46 | 0.06 | 72 | 0.79 | 0.41 | 0.05 |

* Means statistically significant at p<0.05 level (Tukey-Kramer)

Table 15: Mean proportion predation by season, crop and prey type across location in 2019.

| | Watermelon | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Striped cucumber beetles | | | | Waxworm larvae | | | |
| Season | N | Mean | Std | StdErr | N | Mean | Std | StdErr |
| Early | 24 | 0.29 | 0.46 | 0.10 | 44 | 0.36 | 0.49 | 0.07 |
| Mid | 24 | 0.58* | 0.50 | 0.10 | 43 | 0.72* | 0.45 | 0.07 |
| Late | 24 | 0.58* | 0.50 | 0.10 | 47 | 0.66 | 0.48 | 0.07 |

| | Corn | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Striped cucumber beetles | | | | Waxworm larvae | | | |
| Season | N | Mean | Std | StdErr | N | Mean | Std | StdErr |
| Early | 23 | 0.48 | 0.51 | 0.11 | 44 | 0.57 | 0.50 | 0.08 |
| Mid | 23 | 0.87* | 0.34 | 0.07 | 45 | 0.91* | 0.29 | 0.04 |
| Late | 24 | 0.79 | 0.42 | 0.09 | 48 | 0.88 | 0.33 | 0.05 |

* Means statistically significant at p<0.05 level (Tukey-Kramer)


Figure 1: Field plot locations across Indiana during 2018 and 2019. Red and blue pins represent IPM and conventional field sites, respectively.

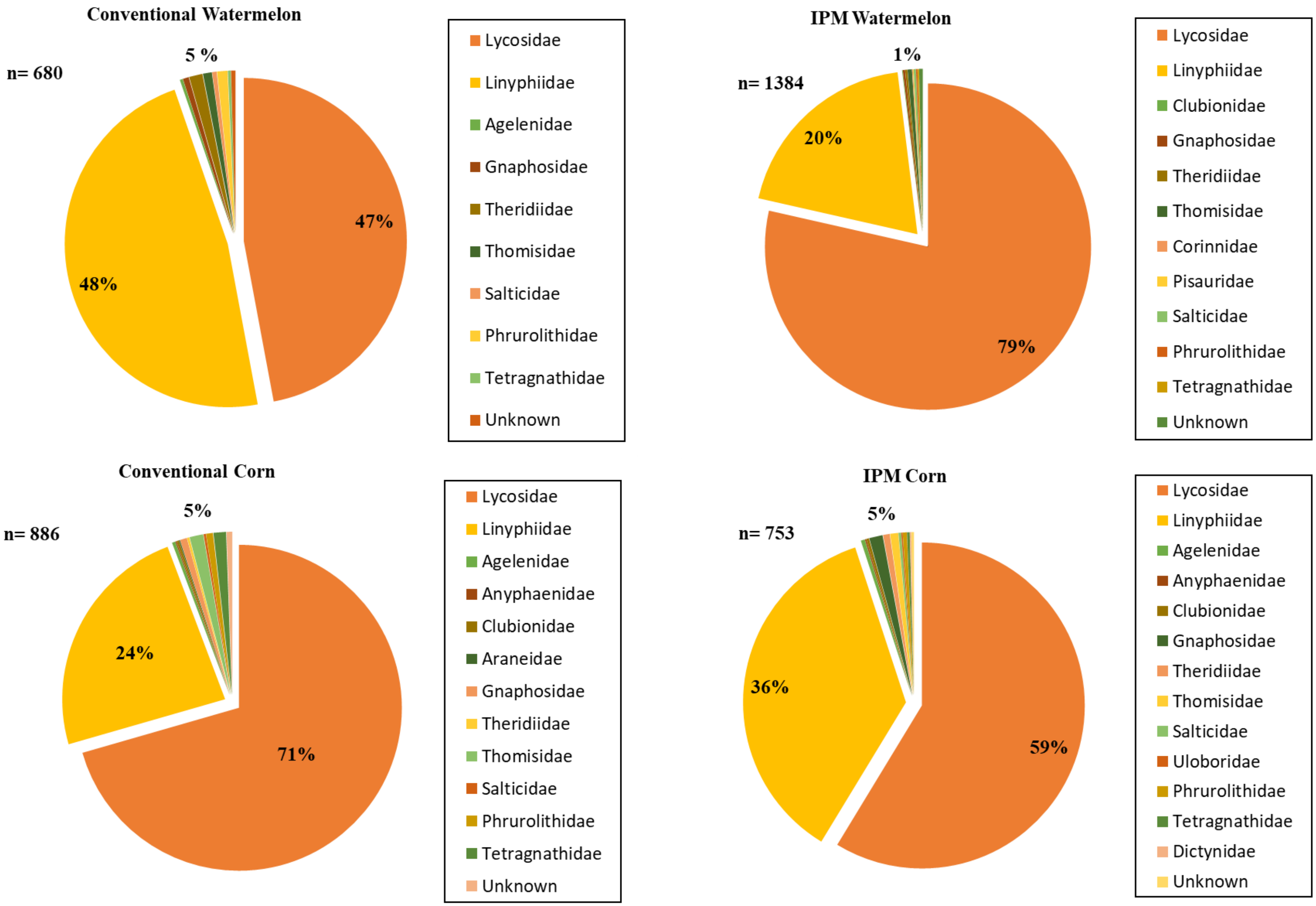


Figure 2: Pie chart of spider families collected by pitfall trap from watermelon and corns plots in 2018 and 2019.

# APPENDIX

Table 16: Pesticide spray records including the product type and trade name, active ingredients, company, application type, application number, rate, and volume for watermelon fields by location and treatment during 2018 and 2019.

| Location | Treatment | Product type | Trade name | Active ingredient | Company | Application type | Spray date | Application number | Rate (lb ai/ha) | Volume (L/ha) |
|---|---|---|---|---|---|---|---|---|---|---|
| NEPAC | Conventional | Fungicide | Luna Experience | Fluopyram, Tebuconazole | Bayer CropScience | Foliar | 13-Jul-18 | 2 | 4.94 | 170.89 |
| NEPAC | Conventional | Insecticide | Wrangler | Imidacloprid | Loveland Products, INC | Soil drench at planting | 17-Jun-19 | 0 | 1.72 | 59.49 |
| NEPAC | Conventional | Insecticide | Wrangler | Imidacloprid | Loveland Products, INC | Soil drench at planting | 08-Jun-18 | 0 | 1.72 | 59.49 |
| NEPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 27-Jun-18 | 1 | 4.94 | 170.89 |
| NEPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 12-Jul-19 | 1 | 4.94 | 170.89 |
| NEPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 13-Jul-18 | 2 | 7.41 | 256.34 |
| NEPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 24-Jul-19 | 2 | 4.94 | 170.89 |
| NEPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 27-Jul-18 | 3 | 4.94 | 170.89 |
| NEPAC | Conventional | Fungicide | Cabrio | Pyraclostrobin | BASF | Foliar | 27-Jul-18 | 3 | 7.41 | 256.34 |
| NEPAC | Conventional | Fungicide | Cabrio | Pyraclostrobin | Loveland Products, INC | Foliar | 08-Aug-19 | 3 | 4.94 | 170.89 |
| NEPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 08-Aug-19 | 3 | 4.94 | 170.89 |
| NEPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 07-Aug-18 | 4 | 7.41 | 256.34 |
| NEPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 21-Aug-19 | 4 | 4.94 | 170.89 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| NEPAC | Conventional | Fungicide | Inspire super | Difenoconazole, Cyprodinil | Syngenta | Foliar | 21-Aug-19 | 4 | 4.94 | 170.89 |
| NEPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 17-Aug-18 | 5 | 7.41 | 256.34 |
| NEPAC | Conventional | Fungicide | Cabrio | Pyraclostrobin | Loveland Products, INC | Foliar | 06-Sep-19 | 5 | 4.94 | 170.89 |
| NEPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 06-Sep-19 | 5 | 4.94 | 170.89 |
| NEPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 31-Aug-18 | 6 | 7.41 | 256.34 |
| NEPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 12-Sep-18 | 7 | 7.41 | 256.34 |
| NEPAC | Conventional | Insecticide | Warrior | Lambda-cyhalothrin | Syngenta | Foliar | 27-Jun-18 | 1 | 0.31 | 10.68 |
| NEPAC | Conventional | Insecticide | Warrior II | Lambda-cyhalothrin | Syngenta | Foliar | 12-Jul-19 | 1 | 0.30 | 10.25 |
| NEPAC | Conventional | Insecticide | Warrior | Lambda-cyhalothrin | Syngenta | Foliar | 23-Jul-18 | 2 | 0.23 | 8.01 |
| NEPAC | Conventional | Insecticide | Warrior II | Lambda-cyhalothrin | Syngenta | Foliar | 24-Jul-19 | 2 | 0.00 | 10.25 |
| NEPAC | Conventional | Insecticide | Warrior | Lambda-cyhalothrin | Syngenta | Foliar | 07-Aug-18 | 3 | 0.15 | 5.34 |
| NEPAC | Conventional | Insecticide | Warrior II | Lambda-cyhalothrin | Syngenta | Foliar | 21-Aug-19 | 3 | 0.30 | 10.25 |
| NEPAC | Conventional | Insecticide | Warrior | Lambda-cyhalothrin | Syngenta | Foliar | 31-Aug-18 | 4 | 0.15 | 5.34 |
| NEPAC | Conventional | Insecticide | Warrior II | Lambda-cyhalothrin | Syngenta | Foliar | 08-Aug-19 | 4 | 0.30 | 10.25 |
| NEPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 27-Jun-18 | 1 | 4.94 | 170.89 |
| NEPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 12-Jul-19 | 1 | 4.94 | 170.89 |
| NEPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 13-Jul-18 | 2 | 7.41 | 256.34 |
| NEPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 24-Jul-19 | 2 | 4.94 | 170.89 |
| NEPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 27-Jul-18 | 3 | 4.94 | 170.89 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| NEPAC | IPM | Fungicide | Cabrio | Pyraclostrobin | BASF | Foliar | 27-Jul-18 | 3 | 7.41 | 256.34 |
| NEPAC | IPM | Fungicide | Cabrio | Pyraclostrobin | Loveland Products, INC | Foliar | 08-Aug-19 | 3 | 4.94 | 170.89 |
| NEPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 08-Aug-19 | 3 | 4.94 | 170.89 |
| NEPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 07-Aug-18 | 4 | 7.41 | 256.34 |
| NEPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 21-Aug-19 | 4 | 4.94 | 170.89 |
| NEPAC | IPM | Fungicide | Inspire super | Difenoconazole, Cyprodinil | Syngenta | Foliar | 21-Aug-19 | 4 | 4.94 | 170.89 |
| NEPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 17-Aug-18 | 5 | 7.41 | 256.34 |
| NEPAC | IPM | Fungicide | Cabrio | Pyraclostrobin | Loveland Products, INC | Foliar | 06-Sep-19 | 5 | 4.94 | 170.89 |
| NEPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 06-Sep-19 | 5 | 4.94 | 170.89 |
| NEPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 31-Aug-18 | 6 | 7.41 | 256.34 |
| NEPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 12-Sep-18 | 7 | 7.41 | 256.34 |
| PPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 18-Jun-18 | 2 | 4.94 | 170.89 |
| PPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 13-Sep-18 | 2 | 7.41 | 256.34 |
| PPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 06-Sep-19 | 3 | 4.94 | 170.89 |
| PPAC | Conventional | Insecticide | Wrangler | Imidacloprid | Loveland Products, INC | Soil drench at planting | 11-Jun-19 | 0 | 1.72 | 59.49 |
| PPAC | Conventional | Insecticide | Warrior | Lambda-cyhalothrin | Syngenta | Foliar | 28-Jun-18 | 1 | 0.30 | 10.25 |
| PPAC | Conventional | Insecticide | Warrior | Lambda-cyhalothrin | Syngenta | Foliar | 20-Jul-18 | 2 | 0.30 | 10.25 |
| PPAC | Conventional | Insecticide | Warrior | Lambda-cyhalothrin | Syngenta | Foliar | 03-Aug-18 | 3 | 0.30 | 10.25 |
| PPAC | Conventional | Insecticide | Warrior | Lambda-cyhalothrin | Syngenta | Foliar | 31-Aug-18 | 4 | 0.30 | 10.25 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| PPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 28-Jun-18 | 2 | 4.94 | 170.89 |
| PPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 06-Jul-18 | 2 | 7.41 | 256.34 |
| PPAC | Conventional | Fungicide | Luna Experience | Fluopyram, Tebuconazole | Bayer CropScience | Foliar | 06-Jul-18 | 2 | 2.47 | 85.45 |
| PPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 12-Jul-19 | 2 | 4.94 | 170.89 |
| PPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 24-Jul-19 | 2 | 4.94 | 170.89 |
| PPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 21-Aug-19 | 2 | 4.94 | 170.89 |
| PPAC | Conventional | Fungicide | Inspire Super | Difenoconazole, Cyprodinil | Syngenta | Foliar | 21-Aug-19 | 2 | 4.94 | 170.89 |
| PPAC | Conventional | Fungicide | Cabrio | Pyraclostrobin | BASF | Foliar | 20-Jul-18 | 3 | 2.47 | 85.45 |
| PPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 20-Jul-18 | 3 | 7.41 | 256.34 |
| PPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 03-Aug-18 | 3 | 7.41 | 256.34 |
| PPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 16-Aug-18 | 3 | 7.41 | 256.34 |
| PPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 31-Aug-18 | 3 | 7.41 | 256.34 |
| PPAC | Conventional | Fungicide | Cabrio | Pyraclostrobin | BASF | Foliar | 08-Aug-19 | 3 | 2.47 | 85.45 |
| PPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 08-Aug-19 | 3 | 4.94 | 170.89 |
| PPAC | Conventional | Fungicide | Cabrio | Pyraclostrobin | BASF | Foliar | 06-Sep-19 | 3 | 3.09 | 106.81 |
| PPAC | Conventional | Insecticide | Wrangler | Imidacloprid | Loveland Products, INC | Soil drench at planting | 04-Jun-18 | 0 | 1.72 | 59.49 |
| PPAC | Conventional | Insecticide | Warrior II | Lambda-cyhalothrin | Syngenta | Foliar | 11-Jul-19 | 1 | 0.30 | 10.25 |
| PPAC | Conventional | Insecticide | Warrior II | Lambda-cyhalothrin | Syngenta | Foliar | 25-Jul-19 | 2 | 0.30 | 10.25 |
| PPAC | Conventional | Insecticide | Warrior II | Lambda-cyhalothrin | Syngenta | Foliar | 08-Aug-19 | 3 | 0.30 | 10.25 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| PPAC | Conventional | Insecticide | Warrior II | Lambda-cyhalothrin | Syngenta | Foliar | 16-Aug-19 | 4 | 0.30 | 10.25 |
| PPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 18-Jun-18 | 2 | 4.94 | 170.89 |
| PPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 28-Jun-18 | 2 | 4.94 | 170.89 |
| PPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 06-Jul-18 | 2 | 7.41 | 256.34 |
| PPAC | IPM | Fungicide | Luna Experience | Fluopyram, Tebuconazole | Bayer CropScience | Foliar | 06-Jul-18 | 2 | 2.47 | 85.45 |
| PPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 13-Sep-18 | 2 | 7.41 | 256.34 |
| PPAC | IPM | Fungicide | Cabrio | Pyraclostrobin | BASF | Foliar | 20-Jul-18 | 3 | 2.47 | 85.45 |
| PPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 20-Jul-18 | 3 | 7.41 | 256.34 |
| PPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 03-Aug-18 | 3 | 7.41 | 256.34 |
| PPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 16-Aug-18 | 3 | 7.41 | 256.34 |
| PPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 31-Aug-18 | 3 | 7.41 | 256.34 |
| PPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 06-Sep-19 | 3 | 4.94 | 170.89 |
| PPAC | IPM | Insecticide | Warrior | Lambda-cyhalothrin | Syngenta | Foliar | 25-Jul-18 | 1 | 0.30 | 10.25 |
| PPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 12-Jul-19 | 2 | 4.94 | 170.89 |
| PPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 24-Jul-19 | 2 | 4.94 | 170.89 |
| PPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 21-Aug-19 | 2 | 4.94 | 170.89 |
| PPAC | IPM | Fungicide | Inspire Super | Difenoconazole, Cyprodinil | Syngenta | Foliar | 21-Aug-19 | 2 | 3.09 | 106.81 |
| PPAC | IPM | Fungicide | Cabrio | Pyraclostrobin | BASF | Foliar | 08-Aug-19 | 3 | 2.47 | 85.45 |
| PPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 08-Aug-19 | 3 | 4.94 | 170.89 |
| PPAC | IPM | Fungicide | Cabrio | Pyraclostrobin | BASF | Foliar | 06-Sep-19 | 3 | 2.47 | 85.45 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| PPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 06-Sep-19 | 3 | 4.94 | 170.89 |
| SEPAC | Conventional | Fungicide | Cabrio | Pyraclostrobin | BASF | Foliar | 19-Jul-19 | 3 | 3.09 | 106.81 |
| SEPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 19-Jul-19 | 3 | 4.94 | 170.89 |
| SEPAC | Conventional | Insecticide | Wrangler | Imidacloprid | Loveland Products, INC | Soil drench at planting | 24-May-18 | 0 | 1.72 | 59.49 |
| SEPAC | Conventional | Insecticide | Wrangler | Imidacloprid | Loveland Products, INC | Soil drench at planting | 03-Jun-19 | 0 | 1.72 | 59.49 |
| SEPAC | Conventional | Insecticide | Warrior | Lambda-cyhalothrin | Syngenta | Foliar | 11-Jul-18 | 2 | 0.30 | 10.25 |
| SEPAC | Conventional | Insecticide | Warrior II | Lambda-cyhalothrin | Syngenta | Foliar | 19-Jul-19 | 2 | 4.94 | 10.25 |
| SEPAC | Conventional | Insecticide | Warrior II | Lambda-cyhalothrin | Syngenta | Foliar | 05-Jul-19 | 3 | 4.94 | 10.25 |
| SEPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 08-Jun-18 | 1 | 4.94 | 170.89 |
| SEPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 21-Jun-19 | 1 | 4.94 | 170.89 |
| SEPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 18-Jun-18 | 2 | 4.94 | 170.89 |
| SEPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 05-Jul-19 | 2 | 4.94 | 170.89 |
| SEPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 28-Jun-18 | 3 | 4.94 | 170.89 |
| SEPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 11-Jul-18 | 4 | 7.41 | 256.34 |
| SEPAC | Conventional | Fungicide | Luna Experience | Fluopyram, Tebuconazole | Bayer CropScience | Foliar | 11-Jul-18 | 4 | 7.41 | 256.34 |
| SEPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 02-Aug-19 | 4 | 4.94 | 170.89 |
| SEPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 23-Jul-18 | 5 | 7.41 | 256.34 |
| SEPAC | Conventional | Fungicide | Cabrio | Pyraclostrobin | BASF | Foliar | 23-Jul-18 | 5 | 4.94 | 170.89 |
| SEPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 16-Aug-19 | 5 | 4.94 | 170.89 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| SEPAC | Conventional | Fungicide | Cabrio | Pyraclostrobin | BASF | Foliar | 16-Aug-19 | 5 | 2.47 | 85.45 |
| SEPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 02-Aug-18 | 6 | 7.41 | 256.34 |
| SEPAC | Conventional | Fungicide | Cabrio | Pyraclostrobin | BASF | Foliar | 30-Aug-19 | 6 | 2.47 | 85.45 |
| SEPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 30-Aug-19 | 6 | 4.94 | 170.89 |
| SEPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 13-Aug-18 | 7 | 7.41 | 256.34 |
| SEPAC | Conventional | Insecticide | Warrior | Lambda-cyhalothrin | Syngenta | Foliar | 18-Jun-18 | 1 | 0.30 | 10.25 |
| SEPAC | Conventional | Insecticide | Warrior II | Lambda-cyhalothrin | Syngenta | Foliar | 21-Jun-19 | 1 | 4.94 | 10.25 |
| SEPAC | Conventional | Insecticide | Warrior | Lambda-cyhalothrin | Syngenta | Foliar | 23-Jul-18 | 3 | 0.30 | 10.25 |
| SEPAC | Conventional | Insecticide | Warrior II | Lambda-cyhalothrin | Syngenta | Foliar | 02-Aug-19 | 4 | 4.94 | 10.25 |
| SEPAC | Conventional | Insecticide | Warrior | Lambda-cyhalothrin | Syngenta | Foliar | 03-Aug-18 | 4 | 0.30 | 10.25 |
| SEPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 08-Jun-18 | 1 | 4.94 | 170.89 |
| SEPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 21-Jun-19 | 1 | 4.94 | 170.89 |
| SEPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 18-Jun-18 | 2 | 4.94 | 170.89 |
| SEPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 05-Jul-19 | 2 | 4.94 | 170.89 |
| SEPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 28-Jun-18 | 3 | 4.94 | 170.89 |
| SEPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 11-Jul-18 | 4 | 7.41 | 256.34 |
| SEPAC | IPM | Fungicide | Luna Experience | Fluopyram, Tebuconazole | Bayer CropScience | Foliar | 11-Jul-18 | 4 | 7.41 | 256.34 |
| SEPAC | IPM | Fungicide | Inspire Super | Difenoconazole, Cyprodinil | Syngenta | Foliar | 02-Aug-19 | 4 | 4.94 | 170.89 |
| SEPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 23-Jul-18 | 5 | 7.41 | 256.34 |
| SEPAC | IPM | Fungicide | Cabrio | Pyraclostrobin | BASF | Foliar | 23-Jul-18 | 5 | 2.47 | 85.45 |

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|---|---|---|---|---|---|---|---|---|---|---|
| SEPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 16-Aug-19 | 5 | 4.94 | 170.89 |
| SEPAC | IPM | Fungicide | Cabrio | Pyraclostrobin | BASF | Foliar | 16-Aug-19 | 5 | 2.47 | 85.45 |
| SEPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 02-Aug-18 | 6 | 7.41 | 256.34 |
| SEPAC | IPM | Fungicide | Cabrio | Pyraclostrobin | BASF | Foliar | 30-Aug-19 | 6 | 2.47 | 85.45 |
| SEPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 30-Aug-19 | 6 | 4.94 | 170.89 |
| SEPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 13-Aug-18 | 7 | 7.41 | 256.34 |
| SEPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 19-Jul-19 | 3 | 4.94 | 170.89 |
| SEPAC | IPM | Fungicide | Cabrio | Pyraclostrobin | BASF | Foliar | 19-Jul-19 | 3 | 2.47 | 85.45 |
| SEPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 02-Aug-19 | 4 | 4.94 | 170.89 |
| SEPAC | IPM | Fungicide | Inspire Super | Difenoconazole, Cyprodinil | Syngenta | Foliar | 02-Aug-19 | 4 | 4.94 | 170.89 |
| SWPAC | Conventional | Insecticide | Wrangler | Imidacloprid | Loveland Products, INC | Soil drench at planting | 18-May-18 | 0 | 1.72 | 59.49 |
| SWPAC | Conventional | Insecticide | Wrangler | Imidacloprid | Loveland Products, INC | Soil drench at planting | 22-May-19 | 0 | 1.72 | 59.49 |
| SWPAC | Conventional | Insecticide | Warrior | Lambda-cyhalothrin | Syngenta | Foliar | 14-Jun-18 | 1 | 0.30 | 10.25 |
| SWPAC | Conventional | Insecticide | Warrior II | Lambda-cyhalothrin | Syngenta | Foliar | 11-Jun-19 | 1 | 0.30 | 10.25 |
| SWPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 01-Jun-18 | 1 | 4.94 | 170.89 |
| SWPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 01-Jun-18 | 1 | 4.94 | 170.89 |
| SWPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 14-Jun-18 | 2 | 4.94 | 170.89 |
| SWPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 14-Jun-18 | 2 | 4.94 | 170.89 |
| SWPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 26-Jun-18 | 3 | 4.94 | 170.89 |
| SWPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 26-Jun-18 | 3 | 4.94 | 170.89 |

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|---|---|---|---|---|---|---|---|---|---|---|
| SWPAC | Conventional | Fungicide | Luna Experience | Fluopyram, Tebuconazole | Bayer CropScience | Foliar | 26-Jun-18 | 3 | 7.41 | 256.34 |
| SWPAC | Conventional | Fungicide | Luna Experience | Fluopyram, Tebuconazole | Bayer CropScience | Foliar | 26-Jun-18 | 3 | 7.41 | 256.34 |
| SWPAC | Conventional | Fungicide | Cabrio | Pyraclostrobin | BASF | Foliar | 03-Jul-19 | 3 | 2.47 | 85.45 |
| SWPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 03-Jul-19 | 3 | 4.94 | 170.89 |
| SWPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 09-Jul-19 | 4 | 4.94 | 170.89 |
| SWPAC | Conventional | Fungicide | Inspire Super | Difenoconazole, Cyprodinil | Syngenta | Foliar | 09-Jul-19 | 4 | 3.09 | 106.81 |
| SWPAC | Conventional | Fungicide | Cabrio | Pyraclostrobin | BASF | Foliar | 18-Jul-19 | 5 | 2.47 | 85.45 |
| SWPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 18-Jul-19 | 5 | 4.94 | 170.89 |
| SWPAC | Conventional | Fungicide | Cabrio | Pyraclostrobin | BASF | Foliar | 01-Aug-19 | 6 | 2.47 | 85.45 |
| SWPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 01-Aug-19 | 6 | 4.94 | 170.89 |
| SWPAC | Conventional | Insecticide | Warrior | Lambda-cyhalothrin | Syngenta | Foliar | 26-Jun-18 | 2 | 0.30 | 10.25 |
| SWPAC | Conventional | Insecticide | Warrior II | Lambda-cyhalothrin | Syngenta | Foliar | 20-Jun-19 | 2 | 0.30 | 10.25 |
| SWPAC | Conventional | Insecticide | Warrior II | Lambda-cyhalothrin | Syngenta | Foliar | 18-Jul-19 | 3 | 0.30 | 10.25 |
| SWPAC | Conventional | Insecticide | Warrior | Lambda-cyhalothrin | Syngenta | Foliar | 23-Jul-18 | 4 | 0.30 | 10.25 |
| SWPAC | Conventional | Insecticide | Warrior II | Lambda-cyhalothrin | Syngenta | Foliar | 03-Jul-19 | 4 | 0.30 | 10.25 |
| SWPAC | Conventional | Insecticide-miticide | Portal | Fenpyroximate | Nichino America, Inc | Foliar | 26-Jul-19 | 5 | 4.94 | 170.89 |
| SWPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 29-Jun-18 | 4 | 7.41 | 256.34 |
| SWPAC | Conventional | Fungicide | Cabrio | Pyraclostrobin | BASF | Foliar | 29-Jun-18 | 4 | 2.47 | 85.45 |
| SWPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 12-Jul-18 | 5 | 7.41 | 256.34 |

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|---|---|---|---|---|---|---|---|---|---|---|
| SWPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 23-Jul-18 | 6 | 2.47 | 85.45 |
| SWPAC | Conventional | Fungicide | Cabrio | Pyraclostrobin | BASF | Foliar | 23-Jul-18 | 6 | 2.47 | 85.45 |
| SWPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 01-Aug-18 | 7 | 7.41 | 256.34 |
| SWPAC | Conventional | Fungicide | Aprovia Top | Difenoconazole, Solatenol® (Benzovindiflupyr) | Syngenta | Foliar | 13-Aug-19 | 7 | 2.01 | 69.42 |
| SWPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 13-Aug-19 | 7 | 4.94 | 170.89 |
| SWPAC | Conventional | Fungicide | Zampro | Amectoctradin, Dimethomorph | Syngenta | Foliar | 13-Aug-19 | 7 | 2.16 | 74.77 |
| SWPAC | Conventional | Insecticide | Warrior | Lambda-cyhalothrin | Syngenta | Foliar | 12-Jul-18 | 3 | 0.30 | 10.25 |
| SWPAC | Conventional | Insecticide | Assail | Acetamiprid | United Phosphorus Inc | Foliar | 16-Aug-19 | 5 | 0.62 | 21.36 |
| SWPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 01-Jun-18 | 1 | 4.94 | 170.89 |
| SWPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 01-Jun-18 | 1 | 4.94 | 170.89 |
| SWPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 11-Jun-19 | 1 | 4.94 | 170.89 |
| SWPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 14-Jun-18 | 2 | 4.94 | 170.89 |
| SWPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 14-Jun-18 | 2 | 4.94 | 170.89 |
| SWPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 20-Jun-19 | 2 | 4.94 | 170.89 |
| SWPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 26-Jun-18 | 3 | 4.94 | 170.89 |
| SWPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 26-Jun-18 | 3 | 4.94 | 170.89 |
| SWPAC | IPM | Fungicide | Luna Experience | Fluopyram, Tebuconazole | Bayer CropScience | Foliar | 26-Jun-18 | 3 | 7.41 | 256.34 |
| SWPAC | IPM | Fungicide | Luna Experience | Fluopyram, Tebuconazole | Bayer CropScience | Foliar | 26-Jun-18 | 3 | 7.41 | 256.34 |

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|---|---|---|---|---|---|---|---|---|---|---|
| SWPAC | IPM | Fungicide | Cabrio | Pyraclostrobin | BASF | Foliar | 03-Jul-19 | 3 | 2.47 | 85.45 |
| SWPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 03-Jul-19 | 3 | 4.94 | 170.89 |
| SWPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 29-Jun-18 | 4 | 7.41 | 256.34 |
| SWPAC | IPM | Fungicide | Cabrio | Pyraclostrobin | BASF | Foliar | 29-Jun-18 | 4 | 2.47 | 85.45 |
| SWPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 09-Jul-19 | 4 | 4.94 | 170.89 |
| SWPAC | IPM | Fungicide | Inspire Super | Difenoconazole, Cyprodinil | Syngenta | Foliar | 09-Jul-19 | 4 | 3.09 | 106.81 |
| SWPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 12-Jul-18 | 5 | 7.41 | 256.34 |
| SWPAC | IPM | Fungicide | Cabrio | Pyraclostrobin | BASF | Foliar | 18-Jul-19 | 5 | 2.47 | 85.45 |
| SWPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 18-Jul-19 | 5 | 4.94 | 170.89 |
| SWPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 23-Jul-18 | 6 | 2.47 | 85.45 |
| SWPAC | IPM | Fungicide | Cabrio | Pyraclostrobin | BASF | Foliar | 23-Jul-18 | 6 | 2.47 | 85.45 |
| SWPAC | IPM | Fungicide | Cabrio | Pyraclostrobin | BASF | Foliar | 01-Aug-19 | 6 | 2.47 | 85.45 |
| SWPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 01-Aug-19 | 6 | 4.94 | 170.89 |
| SWPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 01-Aug-18 | 7 | 7.41 | 256.34 |
| SWPAC | IPM | Fungicide | Aprovia Top | Difenoconazole, Solatenol® (Benzovindiflupyr) | Syngenta | Foliar | 13-Aug-19 | 7 | 2.01 | 69.42 |
| SWPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 13-Aug-19 | 7 | 4.94 | 170.89 |
| SWPAC | IPM | Fungicide | Zampro | Amectoctradin, Dimethomorph | Syngenta | Foliar | 13-Aug-19 | 7 | 2.16 | 74.77 |
| TPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 14-Jun-18 | 1 | 4.94 | 170.89 |

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|---|---|---|---|---|---|---|---|---|---|---|
| TPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 28-Jun-18 | 2 | 4.94 | 170.89 |
| TPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 09-Jul-18 | 3 | 7.41 | 256.34 |
| TPAC | Conventional | Fungicide | Luna Experience | Chlorothalonil | Loveland Products, INC | Foliar | 09-Jul-18 | 3 | 7.41 | 256.34 |
| TPAC | Conventional | Fungicide | Luna Experience | Chlorothalonil | Loveland Products, INC | Foliar | 09-Jul-18 | 3 | 7.41 | 256.34 |
| TPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 19-Jul-18 | 4 | 4.94 | 170.89 |
| TPAC | Conventional | Fungicide | Cabrio | Pyraclostrobin | BASF | Foliar | 19-Jul-18 | 4 | 2.47 | 85.45 |
| TPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 19-Jul-18 | 4 | 4.94 | 170.89 |
| TPAC | Conventional | Fungicide | Cabrio | Pyraclostrobin | BASF | Foliar | 19-Jul-18 | 4 | 2.47 | 85.45 |
| TPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 25-Jul-18 | 5 | 7.41 | 256.34 |
| TPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 25-Jul-18 | 5 | 7.41 | 256.34 |
| TPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 21-Jun-19 | 5 | 4.94 | 170.89 |
| TPAC | Conventional | Fungicide | Cabrio | Pyraclostrobin | BASF | Foliar | 19-Jul-19 | 5 | 2.47 | 85.45 |
| TPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 19-Jul-19 | 5 | 4.94 | 170.89 |
| TPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 02-Aug-19 | 5 | 4.94 | 170.89 |
| TPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 03-Aug-18 | 6 | 7.41 | 256.34 |
| TPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 03-Aug-18 | 6 | 7.41 | 256.34 |
| TPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 05-Jul-19 | 6 | 4.94 | 170.89 |
| TPAC | Conventional | Fungicide | Inspire Super | Difenoconazole, Cyprodinil | Syngenta | Foliar | 02-Aug-19 | 6 | 3.09 | 106.81 |
| TPAC | Conventional | Fungicide | Cabrio | Pyraclostrobin | BASF | Foliar | 16-Aug-19 | 6 | 2.47 | 85.45 |

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|---|---|---|---|---|---|---|---|---|---|---|
| TPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 16-Aug-19 | 6 | 4.94 | 170.89 |
| TPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 30-Aug-19 | 6 | 4.94 | 170.89 |
| TPAC | Conventional | Fungicide | Cabrio | Pyraclostrobin | BASF | Foliar | 30-Aug-19 | 6 | 2.47 | 85.45 |
| TPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 10-Aug-18 | 7 | 7.41 | 256.34 |
| TPAC | Conventional | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 10-Aug-18 | 7 | 7.41 | 256.34 |
| TPAC | Conventional | Insecticide | Warrior | Lambda-cyhalothrin | Syngenta | Foliar | 14-Jun-18 | 1 | 0.30 | 10.25 |
| TPAC | Conventional | Insecticide | Warrior | Lambda-cyhalothrin | Syngenta | Foliar | 21-Jun-19 | 1 | 0.30 | 10.25 |
| TPAC | Conventional | Insecticide | Warrior | Lambda-cyhalothrin | Syngenta | Foliar | 09-Jul-18 | 2 | 0.30 | 10.25 |
| TPAC | Conventional | Insecticide | Warrior | Lambda-cyhalothrin | Syngenta | Foliar | 19-Jul-19 | 2 | 0.30 | 10.25 |
| TPAC | Conventional | Insecticide | Warrior | Lambda-cyhalothrin | Syngenta | Foliar | 19-Jul-18 | 3 | 0.30 | 10.25 |
| TPAC | Conventional | Insecticide | Warrior | Lambda-cyhalothrin | Syngenta | Foliar | 05-Jul-19 | 3 | 0.30 | 10.25 |
| TPAC | Conventional | Insecticide | Warrior | Lambda-cyhalothrin | Syngenta | Foliar | 03-Aug-18 | 4 | 0.30 | 10.25 |
| TPAC | Conventional | Insecticide | Warrior | Lambda-cyhalothrin | Syngenta | Foliar | 02-Aug-19 | 4 | 0.30 | 10.25 |
| TPAC | Conventional | Insecticide | Warrior | Lambda-cyhalothrin | Syngenta | Foliar | 10-Aug-18 | 5 | 0.30 | 10.25 |
| TPAC | Conventional | Insecticide | Wrangler | Imidacloprid | Loveland Products, INC | Soil drench at planting | 22-May-18 | 0 | 1.72 | 59.49 |
| TPAC | Conventional | Insecticide | Wrangler | Imidacloprid | Loveland Products, INC | Soil drench at planting | 28-May-19 | 0 | 1.72 | 59.49 |
| TPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 14-Jun-18 | 1 | 4.94 | 170.89 |
| TPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 28-Jun-18 | 2 | 4.94 | 170.89 |
| TPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 09-Jul-18 | 3 | 7.41 | 256.34 |

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|---|---|---|---|---|---|---|---|---|---|---|
| TPAC | IPM | Fungicide | Luna Experience | Chlorothalonil | Loveland Products, INC | Foliar | 09-Jul-18 | 3 | 7.41 | 256.34 |
| TPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 19-Jul-18 | 4 | 4.94 | 170.89 |
| TPAC | IPM | Fungicide | Cabrio | Pyraclostrobin | BASF | Foliar | 19-Jul-18 | 4 | 2.47 | 85.45 |
| TPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 25-Jul-18 | 5 | 7.41 | 256.34 |
| TPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 21-Jun-19 | 5 | 4.94 | 170.89 |
| TPAC | IPM | Fungicide | Cabrio | Pyraclostrobin | BASF | Foliar | 19-Jul-19 | 5 | 2.47 | 85.45 |
| TPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 19-Jul-19 | 5 | 4.94 | 170.89 |
| TPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 02-Aug-19 | 5 | 4.94 | 170.89 |
| TPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 03-Aug-18 | 6 | 7.41 | 256.34 |
| TPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 05-Jul-19 | 6 | 4.94 | 170.89 |
| TPAC | IPM | Fungicide | Inspire Super | Difenoconazole, Cyprodinil | Syngenta | Foliar | 02-Aug-19 | 6 | 3.09 | 106.81 |
| TPAC | IPM | Fungicide | Cabrio | Pyraclostrobin | BASF | Foliar | 16-Aug-19 | 6 | 2.47 | 85.45 |
| TPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 16-Aug-19 | 6 | 4.94 | 170.89 |
| TPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 30-Aug-19 | 6 | 4.94 | 170.89 |
| TPAC | IPM | Fungicide | Cabrio | Pyraclostrobin | BASF | Foliar | 30-Aug-19 | 6 | 2.47 | 85.45 |
| TPAC | IPM | Fungicide | Initiate | Chlorothalonil | Loveland Products, INC | Foliar | 10-Aug-18 | 7 | 7.41 | 256.34 |

# REFERENCES

Agustí, N., Bourguet, D., Spataro, T., Delos, M., Eychenne, N., Folcher, L., & Arditi, R. (2005). Detection, identification and geographical distribution of European corn borer larval parasitoids using molecular markers. Molecular Ecology, 14(10), 3267-3274. doi:10.1111/j.1365-294X.2005.02650.x

Agustí, N., Shayler, S. P., Harwood, J. D., Vaughan, I. P., Sunderland, K. D., & Symondson, W. O. C. (2003). Collembola as alternative prey sustaining spiders in arable ecosystems: prey detection within predators using molecular markers. Molecular Ecology, 12(12), 3467-3475. doi:10.1046/j.1365-294X.2003.02014.x

Alexander, C., & Van Mellor, T. (2005). Determinants of corn rootworm resistant corn adoption in Indiana. AgBioForum, 8(4), 197-201.

Allen, J. K. M. I. , Scott-dupree, C. D., Tolman, J. H., & Harris, C. R. (2001). Evaluation of application methods for the chemical control of striped cucumber beetle (Coleoptera: Chrysomelidae) attacking seedling cucurbits. Journal of Vegetable Crop Production, 7(2), 83-95. doi:10.1300/J068v07n02_09

Bates, S. L., Zhao, J, Roush, T, & Shelton, M. (2005). Insect resistance management in GM crops: past, present and future. Nature Biotechnology, 23(1), 57-62. doi:10.1038/nbt1056

Benbrook, C. M. (2012). Impacts of genetically engineered crops on pesticide use in the U.S. - the first sixteen years. Environmental Sciences Europe, 24(1), 24. doi:10.1186/2190-4715-24-24

Bishop, L., & Riechert, S. E. (1990). Spider colonization of agroecosystems: mode and source. Environmental Entomology, 19(6), 1738-1745. doi:10.1093/ee/19.6.1738

Bisognin, D. (2002). Origin and evolution of cultivated cucurbits. Ciência Rural, 32(4), 715-723.

Bonmatin, J. M., Giorio, C., Girolami, V., Goulson, D., Kreutzweiser, D. P., Krupke, C., Liess, M., Long, E., Marzaro, M., Mitchell, E. A. D., Noome, D. A., Simon-Delso, N., & Tapparo, A. (2015). Environmental fate and exposure; neonicotinoids and fipronil. Environmental Science and Pollution Research, 22(1), 35-67. doi:10.1007/s11356-014-3332-7

Brust, G. E., Foster, R. E., & Buhler, W. G. (1996). Comparison of insecticide use programs for managing the striped cucumber beetle (Coleoptera: Chrysomelidae) in muskmelon. Journal of economic entomology, 89(4), 981-986. doi:10.1093/jee/89.4.981

Brust, G. E., Stinner, B. R., & McCartney, D. A. (1986). Predator activity and predation in corn agroecosystems. Environmental Entomology, 15(5), 1017-1021. doi:10.1093/ee/15.5.1017

Cantliffe, J. D., Shaw, L. N., & Stoffella, J. P. (2007). Current trends in cucurbit production in the U.S.

Cavanagh, A., Hazzard, R., Adler, L. S., & Boucher, J. (2009). Using trap crops for control of *Acalymma vittatum* (Coleoptera: Chrysomelidae) reduces insecticide use in butternut squash. Journal of economic entomology, 102(3), 1101-1107. doi:10.1603/029.102.0331

Cavatorta, J., Moriarty, G., Henning, M., Glos, M., Kreitinger, M., Munger, H. M., & Jahn, M. (2007). 'Marketmore 97': A monoecious slicing cucumber inbred with multiple disease and insect resistances. Hortscience, 42(3), 707-709.

Chen, X., Xiao, Y., Wu, L., Chen, Y., & Peng, Y. (2012). Imidacloprid affects *Pardosa pseudoannulata* adults and their unexposed offspring. Bulletin of Environmental Contamination and Toxicology, 88(5), 654-658. doi:10.1007/s00128-012-0584-0

Clark, T. L., Meinke, L. J., Skoda, S. R., & Foster, J. E. (2001). Occurrence of wolbachia in selected Diabroticite (Coleoptera: Chrysomelidae) beetles. Annals of the Entomological Society of America, 94(6), 877-885. doi:10.1603/0013-8746(2001)094[0877:Oowisd]2.0.Co;2

Cline, G. R., Sedlacek, J. D., Hillman, S. L., Parker, S. K., & Silvernail, A. F. (2008). Organic management of cucumber beetles in watermelon and muskmelon production. HortTechnology, 18(3), 436-444.

Cloyd, R. A., & Bethke, J. A. (2011). Impact of neonicotinoid insecticides on natural enemies in greenhouse and interiorscape environments. Pest Manag Sci, 67(1), 3-9. doi:10.1002/ps.2015

Croft, B , & Brown, A. (1975). Responses of arthropod natural enemies to insecticides. Annual Review of Entomology, 20(1), 285-335. doi:10.1146/annurev.en.20.010175.001441

Crookston, R. K., Kurle, J. E., Copeland, P. J., Ford, J. H., & Lueschen, W. E. (1991). Rotational cropping sequence affects yield of corn and soybean. Agronomy Journal, 83(1), 108-113.

Cunha, J. A. S., Andrade, E. B., Silva, P. R. R., & Barros, R. F. M. (2015). Araneofauna (Arachnida, Araneae) in conventional and organic crops of watermelon (*Citrullus lanatus*) in northeastern Brazil. Revista Colombiana De Entomologia, 41(1), 68-75.

Daily, G. (2003). What are ecosystem services. Global environmental challenges for the twenty-first century: Resources, consumption and sustainable solutions, 227-231.

Damicone, J. P., Edelson, J. V., Sherwood, J. L., Myers, L. D., & Motes, J. E. (2007). Effects of border crops and intercrops on control of cucurbit virus diseases. Plant Disease, 91(5), 509-516. doi:10.1094/PDIS-91-5-0509

Day, E. (2008). Cucumber beetles. In (pp. 2). Blacksburg, VA: Virginia Polytechnic Institute and State University Extension Bulletin No. 2808-1009.

Desneux, N., Decourtye, A., & Delpuech, J. M. (2007). The sublethal effects of pesticides on beneficial arthropods. Annual Review of Entomology, 52(1), 81-106. doi:10.1146/annurev.ento.52.110405.091440

Dieterich Mabin, M. E. (2017). Effects of conservation biological control practices on predatory arthropod assemblages and molecular identification of cucumber beetle biological control agents. The Ohio State University, Retrieved from http://rave.ohiolink.edu/etdc/view?acc_num=osu1492531428052099

Dinter, A., & Poehling, H. M. (1995). Side-effects of insecticides on two erigonid spider species. Entomologia Experimentalis Et Applicata, 74(2), 151-163. doi:10.1111/j.1570-7458.1995.tb01887.x

Dively, G. P. (2005). Impact of transgenic Vip3A × Cry1Ab lepidopteran-resistant field corn on the nontarget arthropod community. Environmental Entomology, 34(5), 1267-1291. doi:10.1093/ee/34.5.1267

Doughty, H. B., Wilson, J. M., Schultz, P. B., & Kuhar, T. P. (2016). Squash bug (Hemiptera: Coreidae): biology and management in cucurbitaceous crops. Journal of Integrated Pest Management, 7(1). doi:10.1093/jipm/pmv024

Douglas, M. R., Rohr, J. R., & Tooker, J. F. (2015). Neonicotinoid insecticide travels through a soil food chain, disrupting biological control of non-target pests and decreasing soya bean yield. Journal of Applied Ecology, 52(1), 250-260. doi:10.1111/1365-2664.12372

Douglas, M. R., & Tooker, J. F. (2015). Large-scale deployment of seed treatments has driven rapid increase in use of neonicotinoid insecticides and preemptive pest management in U.S. field crops. Environ Sci Technol, 49(8), 5088-5097. doi:10.1021/es506141g

Douglas, M. R., & Tooker, J. F. (2016). Meta-analysis reveals that seed-applied neonicotinoids and pyrethroids have similar negative effects on abundance of arthropod natural enemies. PeerJ, 4, e2776. doi:10.7717/peerj.2776

Duncan, S. R. , Fjell, D. L. , & Vanderlip, R. L. (2007). Corn production handbook (Vol. C-560): Kansas State University

Ehler, L. E. (2006). Integrated pest management (IPM): definition, historical development and implementation, and the other IPM. Pest Manag Sci, 62(9), 787-789.

Elbert, A., Haas, M., Springer, B., Thielert, W., & Nauen, R. (2008). Applied aspects of neonicotinoid uses in crop protection. Pest Manag Sci, 64(11), 1099-1105. doi:10.1002/ps.1616

Ellers-Kirk, Fleischer, S. J., Synder, R. H., & Lynch, J. P. (2000). Potential of entomopathogenic nematodes for biological control of *Acalymma vittatum* (Coleoptera: Chrysomelidae) in cucumbers grown in conventional and organic soil management systems. Journal of economic entomology, 93(3), 605-612.

Enders, F. (1975). The influence of hunting manner on prey size, particularly in spiders with long attack distances (Araneidae, Linyphiidae, and Salticidae). The American Naturalist, 109(970), 737-763. doi:10.1086/283040

Flint, M. L., & Van den Bosch, R. (2012). Introduction to integrated pest management: Springer Science & Business Media.

Foster, R. E. (2016). Managing striped cucumber beetle populations on cantaloupe and watermelon. In (pp. 4). West Lafayette, IN: Purdue Extension Bulletin.

Foster, R. E. (2019, 10/03/2019). [Watermelon production].

Foster, R. E., & Brust, G. E. (1995). Effects of insecticides applied to control cucumber beetles (Coleoptera: Chrysomelidae) on watermelon yields. Crop Protection, 14(8), 619-624. doi:https://doi.org/10.1016/0261-2194(95)00071-2

Fountain, M. T., Brown, V. K., Gange, A. C., Symondson, W. O. C., & Murray, P. J. (2007). The effects of the insecticide chlorpyrifos on spider and collembola communities. Pedobiologia, 51(2), 147-158.

Freeman, J., & Olson, S. (2008). Characteristics of watermelon pollenizer cultivars for use in triploid production. International Journal of Vegetable Science, 13(2), 73-80. doi:10.1300/J512v13n02_07

Freeman, J., & Olson, S. (2007). Using in-row pollenizers for seedless watermelon production. In (Vol. 71, pp. 30). University of Florida

Garman, H. (1901). Enemies of cucumbers and related plants; experiments with potato scab; the food of the toad. In Experiments with potato scab: Kentucky Agricultural Experiment Station of the State College of Kentucky.

Gassmann, A. J., Petzold-Maxwell, J. L., Keweshan, R. S., & Dunbar, M. W. (2011). Field-evolved resistance to Bt maize by western corn rootworm. PLoS ONE, 6(7), e22629. doi:10.1371/journal.pone.0022629

Gerlach, J., Samways, M., & Pryke, J. (2013). Terrestrial invertebrates as bioindicators: an overview of available taxonomic groups. Journal of Insect Conservation, 17(4), 831-850. doi:10.1007/s10841-013-9565-9

Gibb, T. , & Carroll, N. (2008). Indiana 4-H Entomology Insect flash cards In Purdue extension (Ed.).

Gould, G. E. (1943). Insect pests of cucurbit crops in Indiana. Paper presented at the Proceedings of the Indiana Academy of Science.

Halaj, J., & Wise, D. H. (2002). Impact of a detrital subsidy on trophic cascades in a terrestrial grazing food web. Ecology, 83(11), 3141-3151. doi:10.1890/0012-9658(2002)083[3141:Ioadso]2.0.Co;2

Harrington, R., Anton, C., Dawson, T. P., de Bello, F., Feld, C. K., Haslett, J. R., Kluvánkova-Oravská, T., Kontogianni, A., Lavorel, S., Luck, G. W., Rounsevell, M. D. A., Samways, M. J., Settele, J., Skourtos, M., Spangenberg, J. H., Vandewalle, M., Zobel, M., & Harrison, P. A. (2010).

Ecosystem services and biodiversity conservation: concepts and a glossary. Biodiversity and Conservation, 19(10), 2773-2790. doi:10.1007/s10531-010-9834-9

Harwood, J. D., Samson, R. A., & Obrycki, J. J. (2007). Temporal detection of Cry1Ab-endotoxins in coccinellid predators from fields of *Bacillus thuringiensis* corn. Bulletin of Entomological Research, 97(6), 643-648. doi:10.1017/S000748530700524X

Harwood, J.D., Sunderland, K.D., & Symondson, W.O.C. (2001). Living where the food is: web location by linyphiid spiders in relation to prey availability in winter wheat. Journal of Applied Ecology, 38(1), 88-99. doi:doi:10.1046/j.1365-2664.2001.00572.x

Hladik, M. L., Main, R., & Goulson, D. (2018). Environmental risks and challenges associated with neonicotinoid insecticides. Environ Sci Technol, 52(6), 3329-3335. doi:10.1021/acs.est.7b06388

Hoopwood, J., Black, S. H., Vaughan, M., & Lee-Mäder, E. (2016). Beyond the birds and the bees: effects of neonicotinoid insecticides on agriculturally important beneficial invertebrates: Xerxes Society for Invertebrate Conservation.

Ingwell, L. L. , & Kaplan, I. (2019). Insect exclusion screens reduce cucumber beetle infestations in high tunnels, increasing cucurbit yield. Journal of economic entomology. doi:10.1093/jee/toz060

Irungu, R. W. (2010). Effects of spinosad and Lambda-cyhalothrin on their targets, cabbage looper, *Trichoplusia ni* and diamondback moth, Plutella Xylostella, and on their non-targets, spiders, on cabbage in south texas. (Doctor of Philosophy Master of Science ), Texas A & M University,

Jeffrey, C. (2008). A review of the Cucurbitaceae. Botanical Journal of the Linnean Society, 81(3), 233-247. doi:10.1111/j.1095-8339.1980.tb01676.x

Jensen, S. E. (2000). Insecticide resistance in the western flower thrips, *Frankliniella occidentalis*. Integrated Pest Management Reviews, 5(2), 131-146. doi:10.1023/A:1009600426262

Jeschke, Peter, Nauen, Ralf, Schindler, Michael, & Elbert, Alfred. (2011). Overview of the status and global strategy for neonicotinoids. J Agric Food Chem, 59(7), 2897-2908. doi:10.1021/jf101303g

Jones, A. L., Jennings, D. E., Hooks, C. R. R., & Shrewsbury, P. M. (2014). Sentinel eggs underestimate rates of parasitism of the exotic brown marmorated stink bug, *Halyomorpha halys*. Biological Control, 78, 61-66. doi:https://doi.org/10.1016/j.biocontrol.2014.07.011

Kogan, M. (1998). Integrated pest management: historical perspectives and contemporary developments. Annual Review of Entomology, 43(1), 243-270.

Kranthi, K. R., Jadhav, D. R., Kranthi, S., Wanjari, R. R., Ali, S. S., & Russell, D. A. (2002). Insecticide resistance in five major insect pests of cotton in India. Crop Protection, 21(6), 449-460. doi:https://doi.org/10.1016/S0261-2194(01)00131-4

Krupke, C. H , & Long, E. Y. (2015). Intersections between neonicotinoid seed treatments and honey bees. Current Opinion in Insect Science, 10, 8-13. doi:https://doi.org/10.1016/j.cois.2015.04.005

Krupke, C. H., Holland, J. D., Long, E. Y., & Eitzer, B. D. (2017). Planting of neonicotinoid-treated maize poses risks for honey bees and other non-target organisms over a wide area without consistent crop yield benefit. Journal of Applied Ecology, 54(5), 1449-1458. doi:10.1111/1365-2664.12924

Krupke, C. H., Hunt, G. J., Eitzer, B. D., Andino, G., & Given, K. (2012). Multiple routes of pesticide exposure for honey bees living near agricultural fields. PLoS ONE, 7(1), e29268.

Kuusk, A., & Ekbom, B. (2010). Lycosid spiders and alternative food: feeding behavior and implications for biological control. Biological Control, 55(1), 20-26. doi:https://doi.org/10.1016/j.biocontrol.2010.06.009

Lewis, W. J., van Lenteren, J. C., Phatak, Sharad C., & Tumlinson, J. H. (1997). A total system approach to sustainable pest management. Proceedings of the National Academy of Sciences, 94(23), 12243-12248. doi:10.1073/pnas.94.23.12243

Lima, C. H. O., Sarmento, R. A., Rosado, J. F., Silveira, M. C. A. C., Santos, G. R., Pedro Neto, M., Erasmo, E. A. L., Nascimento, I. R., & Picanço, M. C. (2014). Efficiency and economic feasibility of pest control systems in watermelon cropping. Journal of economic entomology, 107(3), 1118-1126. doi:10.1603/EC13512

López, C., Pons, X., & Albajes, R. (2003). Predatory fauna in cornfields and response to imidacloprid seed treatment. Journal of economic entomology, 96(6), 1805-1813. doi:10.1093/jee/96.6.1805

Losey, J. E., & Vaughan, M. (2006). The economic value of ecological services provided by insects. BioScience, 56(4), 311-323. doi:10.1641/0006-3568(2006)56[311:tevoes]2.0.co;2

Margni, M., Rossier, D., Crettaz, P., & Jolliet, O. (2002). Life cycle impact assessment of pesticides on human health and ecosystems. Agriculture, Ecosystems & Environment, 93(1), 379-392. doi:https://doi.org/10.1016/S0167-8809(01)00336-X

Metcalf, C. L., & Flint, W. P. (1962). Destructive and useful insects. Their habits and control: New York & London, McGraw-Hill Book Co., Inc.

Millar, L. C., & Barbercheck, M. E. (2002). Effects of tillage practices on entomopathogenic nematodes in a corn agroecosystem. Biological Control, 25(1), 1-11. doi:https://doi.org/10.1016/S1049-9644(02)00042-7

Monteiro, L. B., Lavigne, C., Ricci, B., Franck, P., Toubon, J., & Sauphanor, B. (2013). Predation of codling moth eggs is affected by pest management practices at orchard and landscape levels. Agriculture, Ecosystems & Environment, 166, 86-93. doi:https://doi.org/10.1016/j.agee.2011.10.012

Moser, S. E., & Obrycki, J. J. (2009). Non-target effects of neonicotinoid seed treatments; mortality of coccinellid larvae related to zoophytophagy. Biological Control, 51(3), 487-492. doi:https://doi.org/10.1016/j.biocontrol.2009.09.001

Mourtzinis, S , Krupke, C. H., Esker, P. D., Varenhorst, A., Arneson, N. J., Bradley, C. A., Byrne, A. M., Chilvers, M. I., Giesler, L. J., Herbert, A., Kandel, Y. R., Kazula, M. J., Hunt, C., Lindsey, L. E., Malone, S., Mueller, D. S., Naeve, S., Nafziger, E., Reisig, D. D., Ross, W. J., Rossman, D. R., Taylor, S., & Conley, S. P. (2019). Neonicotinoid seed treatments of soybean provide negligible benefits to US farmers. Scientific Reports, 9(1), 11207. doi:10.1038/s41598-019-47442-8

Nordlund, D. A., Chalfant, R. B., & Lewis, W. J. (1984). Arthropod populations, yield and damage in monocultures and polycultures of corn, beans and tomatoes. Agriculture, Ecosystems & Environment, 11(4), 353-367. doi:https://doi.org/10.1016/0167-8809(84)90007-0

Noriega, J. A., Hortal, J., Azcárate, F. M., Berg, M. P., Bonada, N., Briones, M. J. I., Del Toro, I., Goulson, D., Ibanez, S., Landis, D. A., Moretti, M., Potts, S. G., Slade, E. M., Stout, J. C., Ulyshen, M.l D., Wackers, F. L., Woodcock, B. A., & Santos, A. M. C. (2017). Research trends in ecosystem services provided by insects. Basic and Applied Ecology. doi:https://doi.org/10.1016/j.baae.2017.09.006

Nyffeler, M., & Birkhofer, K. (2017). An estimated 400–800 million tons of prey are annually killed by the global spider community. The Science of Nature, 104(3), 30. doi:10.1007/s00114-017-1440-1

Nyffeler, Martin. (1999). Prey selection of spiders in the field. The Journal of Arachnology, 27(1), 317-324.

Öberg, S., Mayr, S., & Dauber, J. (2008). Landscape effects on recolonisation patterns of spiders in arable fields. Agriculture, Ecosystems & Environment, 123(1), 211-218. doi:https://doi.org/10.1016/j.agee.2007.06.005

Oerke, E. C. (2006). Crop losses to pests. The Journal of Agricultural Science, 144(1), 31-43. doi:10.1017/S0021859605005708

Onstad, D. W., Mitchell, P. D., Hurley, T. M., Lundgren, J. G., Patrick Porter, R., Krupke, C. H., Spencer, J. L., Difonzo, C. D., Baute, T. S., & Hellmich, R. L. (2011). Seeds of change: corn seed mixtures for resistance management and integrated pest management. Journal of economic entomology, 104(2), 343-352.

Peck, D. C. (2009). Comparative impacts of white grub (Coleoptera: Scarabaeidae) control products on the abundance of non-target soil-active arthropods in turfgrass. Pedobiologia, 52(5), 287-299. doi:https://doi.org/10.1016/j.pedobi.2008.10.003

Pekár, S. (2012). Spiders (Araneae) in the pesticide world: an ecotoxicological review. Pest Manag Sci, 68(11), 1438-1446. doi:doi:10.1002/ps.3397

Peterson, P. M. (2001). Poaceae (Gramineae). Encyclopedia of Life Sciences.

Pfannenstiel, R. S. (2008). Spider predators of lepidopteran eggs in south Texas field crops. Biological Control, 46(2), 202-208. doi:https://doi.org/10.1016/j.biocontrol.2008.03.011

Phillips, B. W., & Gardiner, M. M. (2016). Does local habitat management or large-scale landscape composition alter the biocontrol services provided to pumpkin agroecosystems? Biological Control, 92, 181-194. doi:10.1016/j.biocontrol.2015.10.001

Picanço, M. C., E.G.F. Morais, G. A. Silva, V. M. Xavier, R. B. Queiro, and N. R. Silva. (2008). Inseticidas, acaricidas e moluscicidas no manejo integrado de pragas. In M. C. Picanço L. Zambolin, A. A. Silva, L. R. Ferreira and F. A. Ferreira (Ed.), Produtos fitossanitários: fungicidas, inseticidas, acaricidas e herbicidas. (pp. 541-576). Universidade Federal de Viçosa, Viçosa, MG. Pinto, Z. V., J.A.M. Rezende, V. A. Yuk.

Pimentel, D., & Levitan, L. (1986). Pesticides: amounts applied and amounts reaching pests. BioScience, 36(2), 86-91.

Pisa, L. W., Amaral-Rogers, V., Belzunces, L. P., Bonmatin, J. M., Downs, C. A., Goulson, D., Kreutzweiser, D. P., Krupke, C., Liess, M., McField, M., Morrissey, C. A., Noome, D. A., Settele, J., Simon-Delso, N., Stark, J. D., Van der Sluijs, J. P., Van Dyck, H., & Wiemers, M. (2015). Effects of neonicotinoids and fipronil on non-target invertebrates. Environmental Science and Pollution Research, 22(1), 68-102. doi:10.1007/s11356-014-3471-x

Prohens-Tomás, J., Nuez, F., & Carena, M. J. (2007). Vegetables I : Asteraceae, Brassicaceae, Chenopodicaceae, and Cucurbitaceae. New York, United States Springer.

Rangappa, M., Hamama, A. A., & Bhardwaj, H. L. (2002). Legume and grass cover crops for seedless watermelon production. 12(2), 245. doi:10.21273/horttech.12.2.245

Rasmann, S., Köllner, T. G., Degenhardt, J., Hiltpold, I., Toepfer, S., Kuhlmann, U., Gershenzon, J., & Turlings, T. C. J. (2005). Recruitment of entomopathogenic nematodes by insect-damaged maize roots. Nature, 434(7034), 732-737. doi:10.1038/nature03451

Regehr, D. L. , Olson, B. , & Thompson, C. (2007). Corn production handbook (Vol. C-560). Kansas Kansas State University

Riechert, S. E. (1999). The hows and whys of successful pest suppression by spiders: insights from case studies. Journal of Arachnology, 387-396.

Rivers, A. N., Mullen, C. A., & Barbercheck, M. E. (2018). Cover crop species and management influence predatory arthropods and predation in an organically managed, reduced-tillage cropping system. Environmental Entomology, 47(2), 340-355. doi:10.1093/ee/nvx149

Rojas, E. S., Batzer, J. C., Beattie, G. A., Fleischer, S. J., Shapiro, L. R., Williams, M. A., Bessin, R., Bruton, B. D., Boucher, T. J., Jesse, L. C. H., & Gleason, M. L. (2015). Bacterial wilt of cucurbits: resurrecting a classic pathosystem. Plant Disease, 99(5), 564-574. doi:10.1094/PDIS-10-14-1068-FE

Roubos, C. R., Rodriguez-Saona, C., & Isaacs, R. (2014). Mitigating the effects of insecticides on arthropod biological control at field and landscape scales. Biological Control, 75, 28-38. doi:10.1016/j.biocontrol.2014.01.006

Rudeen, M. L., Jaronski, S. T., Petzold-Maxwell, J. L., & Gassmann, A. J. (2013). Entomopathogenic fungi in cornfields and their potential to manage larval western corn rootworm *Diabrotica virgifera virgifera*. Journal of Invertebrate Pathology, 114(3), 329-332. doi:https://doi.org/10.1016/j.jip.2013.09.009

Rusek, J. (1998). Biodiversity of collembola and their functional role in the ecosystem. Biodiversity & Conservation, 7(9), 1207-1219. doi:10.1023/A:1008887817883

Sabu, T. K., Shiju, R.T., Vinod, K. V., & Nithya, S. (2011). A comparison of the pitfall trap, Winkler extractor and Berlese funnel for sampling ground-dwelling arthropods in tropical montane cloud forests. Journal of Insect Science, 11(1). doi:10.1673/031.011.0128

Samu, F., Szirányi, A., & Kiss, B. (2003). Foraging in agricultural fields: local ‘sit-and-move’ strategy scales up to risk-averse habitat use in a wolf spider. Animal Behaviour, 66(5), 939-947. doi:https://doi.org/10.1006/anbe.2003.2265

Sánchez-Bayo, F., Goka, K., & Hayasaka, D. (2016). Contamination of the aquatic environment with neonicotinoids and its implication for ecosystems. Frontiers in Environmental Science, 4(71). doi:10.3389/fenvs.2016.00071

Sánchez-Bayo, F., & Wyckhuys, K. A. G. (2019). Worldwide decline of the entomofauna: A review of its drivers. Biological Conservation, 232, 8-27. doi:https://doi.org/10.1016/j.biocon.2019.01.020

Sarwar, M. H., Sarwar, M. F., Sarwar, M., Qadri, N.A., & Moghal, S. (2013). The importance of cereals (Poaceae: Gramineae) nutrition in human health: A review. Journal of cereals and oilseeds, 4(3), 32-35.

Schmidt, J. M., Barney, S.K., Williams, M.A., Bessin, R. T., Coolong, T. W., & Harwood, J. D. (2014). Predator–prey trophic relationships in response to organic management practices. Molecular Ecology, 23(15), 3777-3789. doi:10.1111/mec.12734

Sharma, A., Rana, C., & Shiwani, K. (2016). 19 important insect pests of cucurbits and their management. In.

Shelby, K. (2013). Functional immunomics of the squash bug, *Anasa tristis* (De Geer) (Heteroptera: Coreidae). Insects, 4(4), 712.

Skidmore, A (2018). Impact of integrated pest management on arthropods in cucurbit production systems (Doctorate of Philosophy Doctoral dissertation ), University of Kentucky Lexington

Smith, S. M. (1996). Biological control with trichogramma: advances, successes, and potential of their use. Annual Review of Entomology, 41(1), 375-406. doi:10.1146/annurev.en.41.010196.002111

Snyder, W. E (2015). Managing cucumber beetles in organic farming systems. Department of Entomology, Washington State University Pullman, WA.

Snyder, W. E., & Wise, D. H. (1999). Predator interference and the establishment of generalist predator populations for biocontrol. Biological Control, 15(3), 283-292. doi:https://doi.org/10.1006/bcon.1999.0723

Snyder, W. E., & Wise, D. H. (2000). Antipredator behavior of spotted cucumber beetles (Coleoptera: Chrysomelidae) in response to predators that pose varying risks. Environmental Entomology, 29(1), 35-42. doi:10.1603/0046-225X-29.1.35

Snyder, W. E., & Wise, D. H. (2001). Contrasting trophic cascades generated by a community of generalist predators. Ecology, 82(6), 1571-1583.

Souza, C. R., Sarmento, R. A., Venzon, M., Barros, E. C., dos Santos, G. R., & Chaves, C. C. (2012). Impact of insecticides on non-target arthropods in watermelon crop. Semina: Ciências Agrárias, 33(5), 1789-1801.

Sparks, A. N., Raulston, J. R., Martin, P. B., & Pair, S. D. (1986). Fall armyworm (Lepidoptera: Noctuidae) parasitoids: differential spring distribution and incidence on corn and sorghum in the southern United States and northeastern Mexico. Environmental Entomology, 15(2), 342-348. doi:10.1093/ee/15.2.342

Stoner, K. A., Sawyer, A. J., & Shelton, A. M. (1986). Constraints to the implementation of IPM programs in the U.S.A.: A course outline. Agriculture, Ecosystems & Environment, 17(3), 253-268. doi:https://doi.org/10.1016/0167-8809(86)90046-0

Summers, C. G., Mitchell, J. P., & Stapleton, J. J. (2004). Non-chemical insect and disease management in cucurbit production systems. Acta Horticulturae, 119-126.

Symondson, W. O. C. , Sunderland, K. D. , & Greenstone, M. H. . (2002). Can generalist predators be effective biocontrol agents? Annual Review of Entomology, 47(1), 561-594. doi:10.1146/annurev.ento.47.091201.145240

Szendrei, Z., Quinn, N. F., & Brainard, D. C. (2016). The effect of conservation tillage and cover crop residue on beneficial arthropods and weed seed predation in acorn squash. Environmental Entomology, 45(6), 1543-1551. doi:10.1093/ee/nvw139

Theiling, K. M., & Croft, B. A. (1988). Pesticide side-effects on arthropod natural enemies: A database summary. Agriculture, Ecosystems & Environment, 21(3), 191-218. doi:https://doi.org/10.1016/0167-8809(88)90088-6

Thomas, Matthew B. (1999). Ecological approaches and the development of “truly integrated” pest management. Proceedings of the National Academy of Sciences, 96(11), 5944-5951. doi:10.1073/pnas.96.11.5944

Thorbek, P., & Bilde, T. (2004). Reduced numbers of generalist arthropod predators after crop management. Journal of Applied Ecology, 41(3), 526-538. doi:10.1111/j.0021-8901.2004.00913.x

Ubick, D., Paquin, P., & Cushing, P. E. (2017). Spiders of north America: an identification manual: American Arachnological Society.

United States Department of Agriculture, National Agricultural Statistics Service. (2018). National statistics for corn. Retrieved from https://www.nass.usda.gov/Statistics_by_Subject/result.php?08638011-B478-3942-B44F-FA130ADDE283&sector=CROPS&group=FIELD%20CROPS&comm=CORN

United States Department of Agriculture, National Agricultural Statistics Service. (2018). Vegetables 2019 summary Retrieved from https://www.nass.usda.gov/Quick_Stats/Ag_Overview/stateOverview.php?state=INDIANA

United States Department of Agriculture, National Agricultural Statistics Service (2017 ). Rank among states Retrieved from https://www.nass.usda.gov/Statistics_by_State/Indiana/Publications/Annual_Statistical_Bulletin/1718/pg2.pdf

Van der Sluijs, J. P., Amaral-Rogers, V., Belzunces, L. P., Bijleveld van Lexmond, M. F. I. J., Bonmatin, J. M., Chagnon, M., Downs, C. A., Furlan, L., Gibbons, D. W., Giorio, C., Girolami, V., Goulson, D., Kreutzweiser, D. P., Krupke, C., Liess, M., Long, E., McField, M., Mineau, P., Mitchell, E. A. D., Morrissey, C. A., Noome, D. A., Pisa, L., Settele, J., Simon-Delso, N., Stark, J. D., Tapparo, A., Van Dyck, H., van Praagh, J., Whitehorn, P. R., & Wiemers, M. (2015). Conclusions of the worldwide integrated assessment on the risks of neonicotinoids and fipronil to biodiversity and ecosystem functioning. Environmental Science and Pollution Research, 22(1), 148-154. doi:10.1007/s11356-014-3229-5

Van Lenteren, J. C. (2012). The state of commercial augmentative biological control: plenty of natural enemies, but a frustrating lack of uptake. Biocontrol, 57(1), 1-20. doi:10.1007/s10526-011-9395-1

Vincent, P. L. D. (2001). Zea mays (maize, corn). eLS.

Walters, S. A. . (2003). Suppression of watermelon mosaic virus in summer squash with plastic mulches and rowcovers. HortTechnology horttech, 13(2), 352-357. doi:10.21273/HORTTECH.13.2.0352

Waterfield, G., & Zilberman, D. (2012). Pest management in food systems: an economic perspective. Annual Review of Environment and Resources, 37(1), 223-245. doi:10.1146/annurev-environ-040911-105628

Wehner, T. C. (2008). Watermelon. In Jaime Prohens & Fernando Nuez (Eds.), Vegetables I: Asteraceae, Brassicaceae, Chenopodicaceae, and Cucurbitaceae (pp. 381-418). New York, NY: Springer New York.

Welbaum, G. E. (2015). Vegetable production and practices: CABI.

Weyman, G. S. (1993). A review of the possible causative factors and significance of ballooning in spiders. Ethology Ecology & Evolution, 5(3), 279-291. doi:10.1080/08927014.1993.9523016

Whitford, F., Showers, W. B., & Edwards, G. B. (1987). Insecticide Tolerance of Ground- and Foliage-dwelling Spiders (Araneae) in European Corn Borer (Lepidoptera: Pyralidae) Action Sites1. Environmental Entomology, 16(3), 779-785. doi:10.1093/ee/16.3.779

Wiles, J. A., & Jepson, P. C. (1992). In situ bioassay techniques to evaluate the toxicity of pesticides to beneficial invertebrates in cereals. Aspects of Applied Biology (United Kingdom).

Williams, J. L., & Wise, D. H. (2003). Avoidance of wolf spiders (Araneae Lycosidae) by striped cucumber beetles (Coleoptera: Chrysomelidae): laboratory and field studies. Environmental Entomology, 32(3), 633-640.

Zaher, M. A., El-Hennawy, H. K., Hassan, M. F., Hussein, A. K. M., & Ahmad, N. F. R. (2005). Survey and populations of spiders and other arthropods in cucurbit and legume fields in Al-Kanater (Egypt). Serket, vol. 9(3), 91-100.