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PROTECTION OF ORGANIC CUCUMBER PRODUCTION
AGAINST STRIPED CUCUMBER BEETLES USING TRAP CROPS

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PROTECTION OF ORGANIC CUCUMBER PRODUCTION AGAINST STRIPED CUCUMBER BEETLES USING TRAP CROPS

By

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ABSTRACT

PROTECTION OF ORGANIC CUCUMBER PRODUCTION AGAINST STRIPED CUCUMBER BEETLES USING TRAP CROPS

By

Vianney O M. Willot

Striped cucumber beetles, A*ccalymma vittatum* F. (Coleoptera: Chrysomelidae), are major pests of cucumber production in the North Eastern United States. The use of perimeter trap crops is an important striped cucumber beetle management tactic that has been used successfully in conventional cucumber production when insecticides are applied to the trap crop but has been less successfully applied in organic pest management. I assessed the potential of four winter squash varieties: blue hubbard (*Cucurbita maxima* Duchesne), burgess buttercup (*Cucurbita maxima* Duchesne), waltham butternut (*Cucurbita. moschata* Duchesne), table queen acorn (*Cucurbita moschata* Bailey) to be used as trap crops under green house and field conditions. Results showed burgess buttercup and blue hubbard are the most attractive varieties. Burgess buttercup has an advantage under low beetle population because of its good marketability. I also assessed the potential of the trap crop combination, blue hubbard (*Cucurbita maxima* Duchesne) with waltham butternut (*Cucurbita moschata* Poir), compared to each cultivar alone. Furthermore, I assessed the potential of Pyganic® (an OMRI approved insecticide) and insect vacuums to control cucumber beetles on trap crops. Results showed that blue hubbard combined with waltham butternut were as efficient as blue hubbard alone in attracting beetles. The experiments also demonstrated the importance of flowers in the attractiveness of the trap crops.

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CHAPTER 1

Literature review

Vegetable production in the United States and Michigan

The United States (USA) is the third largest vegetable producer worldwide after China and India (USDA 2008b). In 2008, the top five vegetable crops in the USA were potato, tomato, lettuce, onion and carrots with 18.7, 11.5, 5.1, 3.6, and 1.6 million tons, respectively (Jackson et al. 2005b, USDA 2008b). Cucumbers are also an important vegetable crop with 2008 USA fresh and pickled cucumber production estimated at 0.9 million tons. Michigan vegetable production in 2007 was around 763,820 tons with a value of $211 million and a crop surface of 110,100 acres (USDA 2008b). Pickling cucumbers represented the largest single 2007 vegetable production crop in Michigan, with 30,000 acres producing 156,350 tons of cucumbers, with a value of $35.961 million. Fresh cucumber production was the fourth largest vegetable production in Michigan in 2007, with 11,700 acres producing 38,919 tons of cucumbers, representing a value of $15.358 (USDA 2008b). Michigan's fresh cucumber production is the fourth largest in USA with 9.8% of national production. In 2008, 2,500 USA farms produced organic vegetables on a surface of 130,436 acres, representing a value of $685 million (USDA 2008a). Michigan organic vegetable production represented a surface of 1,730 acres for a value of $4.5 million (USDA 2008a).

Pest management is an important aspect of vegetable production. Vegetable fields are a resource for insects, diseases and also a good environment for weeds. In 1990, pest insects caused a loss of 4 to 21% of the farm-gate for USA vegetable production (Howard et al. 1994). The farm-gate cost was estimated to be between 8 and 23% for diseases and 8 and 13% for weeds, respectively (Howard et al. 1994). In 1987, crop losses for USA cucumber production, from insects and disease was estimated at 15% and 21%, respectively (Howard et al. 1994). Several diseases attack cucurbits crops such as: Angular leaf spot (*Pseudomonas syringae* pv. *Lachrymans* Smith & Bryan), bacterial wilt (*Erwinia tracheiphila* Smith), Anthracnose (*Colletotrichum orbiculare* Berk. & Mont.), powdery mildew (*Erysiphe cichoracearum* DC), and cucumber mosaic virus (Howard et al. 1994, Swiader and Ware 2002). There are also several insect species that attack cucurbits plants such as: squash bug (*Anasa tristis* De Geer), squash vine borer (*Melittia satyriniformis* Hübner), European earwing (*Forficula auricularia* L.), Melon aphid (*Aphis gossypii* Glover), Seedcorn maggot (*Delia platura* Meigen), Tarnished plant bug (*Lygus lineolaris* Palisot de Beauvois), and the cucumber beetle complex (Howard et al. 1994, Burgio et al. 1997, Swiader and Ware 2002, Jackson et al. 2005a).

The Cucumber Beetle Complex

The cucumber beetle complex (Coleoptera: Chrysomelidae) makes up the principal insect pests of cucurbits in the USA and consists of: the striped cucumber beetle (*Acalymma vittatum* F.), the spotted cucumber beetle (*Diabrotica undecimpuctata howardi* Barber), and the banded cucumber beetle (*Diabrotica balteat* Leconte). In

Michigan and Southern central Canada, the striped cucumber beetle is considered the most important of these species. Crop losses from striped cucumber beetles were estimated at 15% in Ontario Canada if no control methods were implemented (Howard et al. 1994). Adult striped cucumber beetles damage cucurbits by feeding on the flowers, fruits, leaves, and stems while larvae feed on the roots. At the seedling stage, feeding by adults can kill the plants. Older plants are more capable of tolerating defoliation. Brewer et al. (1987) showed that zucchini attacked at the second and third-leaf stages compensate for damage occurring before fruit production. When adult cucumber beetles feed on the fruits they cause scars that limit the cucumber's marketability. Furthermore, striped cucumber beetles can transmit bacterial wilt (*Erwinia tracheiphila* Smith) when feeding on the foliage (Brust and Rane 1995, Mitchell and Hanks 2009) and damaging the flowers (Sasu et al. 2010). This disease kills the plants and currently no curatives are available. Therefore, cucumber beetles must be maintained at very low levels in regions where this pathogen occurs. In Michigan, bacterial wilt occurrence is sporadic, allowing for higher tolerance of cucumber beetles and providing increased opportunities to manage them with certified organic tactics.

In the North Central region of the USA, the striped cucumber beetle is usually monovoltine. Adult beetles generally emerge from their overwintering sites at the end of May or beginning of June, and start to colonize the cucurbits fields when temperatures exceed 12^{o}C (Radin and Drummond 1994a). This often coincides with early growth of cultivated cucurbits and can have a severe impact on the production, leading to reduced stand or delayed plant maturation (Brewer et al. 1987, Ayyappath et al. 2002). The female beetles lay their eggs at the base of the plants. The larva then feed exclusively on the cucurbits roots, causing damage that reduces the development of the roots. Ellers-Kirk et al (2000) showed that reducing the population of cucumber beetle larvae increased the root length and density of cucumbers in organic and conventional systems. The summer generation emerges at the end of July or beginning of August. They are usually less damaging to crops, particularly cucumbers, because crops are often ready for harvest prior to peak beetle emergence.

Pest Management

High consumer expectations/aesthetic criteria for vegetables make their production challenging compared to field crops. This leads to a lower tolerance of pest damage and makes the implementation of Integrated Pest Management (IPM) challenging (Foster and Flood 2005). Conventional farmers rely principally on pesticides to achieve economic levels of pest control. Physical control methods such as trapping, vacuuming, flaming, and use of mulch are also useful methods, particularly for organic farmers (Vincent et al. 2003). Cucumber farmers can also use conservation or augmentative biological control (Fiedler et al. 2008). Cultural methods such as crop rotation, host plant resistance, or cover crops are also important pest management tactics (Way and van Emden 2000, Ngouajio and Mennan 2005). Integrated Pest Management emphasizes the use biological, physical, and cultural methods to limit the use pesticides, especially those that are harmful to both the environment and natural enemies. Conventional farmers have a variety of chemical options to protect cucurbit crops against striped cucumber beetles. Farmers are advised to use systemic soil insecticides before planting and foliar insecticides after planting if striped cucumber beetles are present (Howard et al. 1994, Swiader and Ware 2002). Active substances available in cucumber production are Carbaryl, Permethrin, or Bifenthrin (Foster and Brust 1995, Brust et al. 1996, Zehnder et al. 1997, MacIntyre-Allen et al. 2001, Jasinski et al. 2009, Bird et al. 2010). Farmers also have access to efficient physical methods against striped cucumber beetles. The physical method commonly use in cucurbit productions against cucumber beetles are traps, mulch, and row covers (Barrett et al. 1971a, Hoffmann et al. 1996b, Ibarra et al. 2001, Jackson et al. 2005b, Lam 2007, Cline et al. 2008). Traps are usually used to monitor cucumber beetle populations in fields (Hoffmann et al. 1996b, Jackson et al. 2005b, Lam 2007, Cline et al. 2008).

In organic production, pesticide use is limited due to a paucity of organic OMRI certified products available The list of the product available for organic farmers is available on the Organic Materials Review Insititute (OMRI)web site (OMRI Institut 2010). Available OMRI approved insecticides include: natural pyrethrums, neem oil, Citrus oil, kaolin film, garlic oil, hot pepper oil, and *Bacillus thuringiensis.* Organic pesticides are also typically much less efficient than conventional pesticides in controlling striped cucumber beetle (Karagounis et al. 2006, Cross et al. 2007, Kamminga et al. 2009) and there is abundant literature showing the variable efficacy of organic insecticides on pests (Abdel-Moniem et al. 2004, Barry et al. 2005, Glenn and Puterka 2005, Karagounis et al. 2006, Cross et al. 2007, Trdan et al. 2007, Cloyd et al. 2009, Gomez Jimenez and Poveda 2009, Kamminga et al. 2009). Organic pesticides also have shorter residual than conventional and thus require more frequent treatments compared to their conventional counterparts (Karagounis et al. 2006, Miresmailli and Isman 2006, Cross et al. 2007, Kamminga et al. 2009). The limited chemical tools available to organic farmers makes the solid understanding of pest and plant biology and ecology essential to economically viable organic pest management. Furthermore, a very low recommended threshold makes striped cucumber beetle management a primary concern for organic farmers (Brust and Foster 1999). Thus, organic farmers are forced to rely more on biological, physical, and cultural pest management tactics.

Biological control tactics ranging from conservation to augmentation can be used to manage striped cucumber beetles. A variety of research has been conducted on the natural enemies of cucumber beetles and manipulation of the environment (Gould 1944, Bach 1980, Dix et al. 1997, Platt et al. 1999, Ellers-Kirk et al. 2000, Snyder and Wise 2001, Cline et al. 2008). Gould (1944) observed that the parasite tachnid fly (*Jiaetophleps setosa*, Coq) is the most efficient natural enemy of striped cucumber beetles. Platt et al. (1999) showed that using a border of buckwheat increases the presence of tachnid flies, leatherwings and parasitic wasps while decreasing the presence of striped cucumber beetles. Snyder and Wise (2001) showed that lycosid spiders reduce the striped cucumber beetle density at the beginning of the season and that carabids affect the squash bug population by predation. They also showed that the presence of these two predators together reduced the effect of each one to control cucurbit pests suggesting the presence of intra-guild predation. Ellers-Kirk et al. (2000) showed that when applied to the soil, entomopathogenic nematodes had a significant impact on striped cucumber beetle emergence, however nematodes are expensive and their efficacy varies greatly depending on soil conditions (Kaya and Gaugler 1993). Dix et al. (1997) showed that the presence of shelter did not affect the presence of striped cucumber beetles.

Physical pest management tactics, such as plastic mulch and row covers (Vincent et al. 2003) have also been employed against striped cucumber beetle with fair success, especially in organic systems (Matthewsgehringer and Houghgoldstein 1988, Cline et al. 2008, Nair and Ngouajio 2010). Row covers are expensive but this tactic may also provide additional benefits beyond insect pest management such as increased humidity, increased air temperature that lessen plant growth, and increased soil temperature that lead to faster development. Ibarra et al. (2001) showed that the use of row covers and plastic mulch increased Muskmelon yield. Vacuuming can also be used to remove adult beetles (Kuepper and Thomas 2002). It has been used efficiently against Lygus bug in organic strawberries and Colorado potato beetles (*Leptinotarsa decemlineata)* in organic potato (Kuepper and Thomas 2002).

Cultural striped cucumber beetle management tactics are also available. Crop rotation is commonly used by organic farmers because adults overwinter in and around cucurbit fields (Russo and Kindiger 2007). Implementing perimeter trap cropping is also an efficient cultural method to manage cucumber beetles when combined with insecticides (MacIntyre-Allen et al. 2001, Boucher and Durgy 2004, Adler and Hazzard 2009, Cavanagh et al. 2009). However the perimeter trap cropping system has seen less success in organic agriculture compared to conventional agriculture (Boucher and Durgy 2004, Hazzard and Cavanagh 2005, Adler and Hazzard 2009, Cavanagh et al. 2009).

Perimeter Trap Crops

Shelton and Badenes-Perez (2006) define trap crops as: "plant stands that are, *per se* or via manipulation, deployed to attract, divert, intercept, and/or retain targeted insects or the pathogens they vector in order to reduce damage to the main crop." They further differentiate two types of trap crops as: the dead-end trap crop and the conventional trap crop. A dead-end trap crop refers to plants that are highly attractive to the pest but are not a sustainable host for the development of offspring. An example is the use of Yellow Rocketcress (*Barbarea vulgaris* var. arcuata Opiz ex J.& K. Presl) to protect cabbage production against diamondback moth, *Plutella xylostella* (Shelton and Nault 2004).

A conventional trap crop is a crop that is planted close to a high value crop to attract pest and limit damage. Conventional trap crops are the more commonly used. There are many examples of trap crop use in conventional production. For example, corn and wheat are used as trap crops to divert cabbage seedpod weevil (*Conoderus spp* Barber) in sweet-potatoes (Seal et al. 1992), squash is used in peanut production to protect against spotted cucumber beetles (Barbercheck and Warrick 1997), alfalfa is used in cotton production to protect against Lygus bugs (*Lygus hesperus* Knight) (Godfrey and Leigh 1994), eggplant and squash are used in bean production to protect against sweet potato whitefly (*Bemisia argentifolii* Bellows & Perring) (Smith et al. 2000, Smith and McSorley 2000), and winter squash are used in cucurbit production to protect against striped cucumber beetles, and spotted cucumber beetle (Radin and Drummond 1994b, Hoffmann et al. 1996a, Pair 1997, Boucher and Durgy 2004, Hazzard and Cavanagh 2005, Cavanagh 2008, Adler and Hazzard 2009, Cavanagh et al. 2009).

In cucurbit production, trap crops are usually implemented as perimeter trap crop. A perimeter trap crop consists of series of rows of trap crops that surround a field of the economic crop (Boucher and Durgy 2004, Hazzard and Cavanagh 2005, Cavanagh et al. 2009). The goal of this tactic is to contain the pest on the border of the field (Radin and

Drummond 1994b). Containment of the pest in the perimeter trap crop allows more precise application of insecticides. The reported advantages of perimeter trap crops are reduced damage to the main crop through the diversion of cucumber beetles, as well as reduced insecticide use (Boucher and Durgy 2004, Adler and Hazzard 2009, Cavanagh et al. 2009). Cavanagh et al (2009) showed that the use of perimeter trap crops can lead to a 94% reduction in insecticide use. However, trap crops alone typically do not provide sufficient damage control when cucumber beetles occur in large numbers (MacIntyre-Allen et al. 2001, Brewer et al. 2006).

In the case of striped cucumber beetles, winter squash cultivars are the most commonly used perimeter trap crops. Some varieties of winter squash that are particularly attractive to cucumber beetles include buttercup *Cucurbita pepo* Alef and blue hubbard *Cucurbita maxima* Wall (Caldwell and Stockton 1998, MacIntyre-Allen et al. 2001, Bellows and Diver 2002, Boucher and Durgy 2004, Cavenagh 2008, Adler and Hazzard 2009). The relative attractiveness of different cultivars has been attributed to the presence of cucurbitacin, which has been identified as a phagostimulant and an arrestant (Metcalf et al. 1980, Ferguson et al. 1983, Brust and Foster 1995, Schroder et al. 2001, Martin et al. 2002, Smyth et al. 2002, Jackson et al. 2005b), as well as volatile attractants from blossoms (Andersen and Metcalf 1986, Lewis et al. 1990, Metcalf et al. 1995, Mena Granero et al. 2004, Ferrari et al. 2006, Andrews et al. 2007, Theis et al. 2009, Sasu et al. 2010).

Interestingly, cucurbitacin has been proven to be very toxic and is a deterrent compound for most insects (Howe et al. 1976, Metcalf et al. 1980, Nishida and Fukami

1990, Walsh et al. 2008). However, striped cucumber beetles evolved closely with cucurbits and consuming cucurbitacin does not present any real physiological cost (Tallamy and Gorski 1997, Tallamy et al. 1997). Eben et al (1997) showed that diabroticine beetles in choice tests are more attracted to plants with cucurbitacin than plants without. All plants of the cucurbit family produce cucurbitacin and volatile attractants but the attractiveness among plant species is highly variable. This may be because plants can contain a great diversity of cucurbitacin molecules (Chen et al. 2009). Eben et al 1997 showed that diabroticine beetles have a preference for some types of cucurbitacin molecules (Eben et al. 1997). The striped cucumber beetles ability to detect cucurbit plants from a long range is primarily due to volatile attractant and not cucurbitacin because of its poor volatility (Branson and Guss 1983).

Volatile compound concentration can also vary within a single plant and may also affect the attractiveness of cucurbit varieties. Sasu et al (2010) showed variation of attractiveness within *C. pepo* plants, with male flowers attracting more cucumber beetles than female flowers. Insect feeding can also affect the attractiveness of plants. Theis et al. (2009) demonstrated that beetle feeding increases the floral fragrance in male flowers yet delays the appearance of flowers. The attractiveness of a plant is reinforced by the presence of male aggregation pheromone (Smyth and Hoffmann 2003, Morris et al. 2005). Smyth and Hoffmann (2003) showed that several males as lures are more efficient to attract conspecifics than one male alone.

Research has been conducted on the potential of winter squash varieties to attract striped cucumber beetles (Bellows and Diver 2002, Cavanagh 2008, Adler and Hazzard

2009). Much of this research has focused on the varieties available for conventional farmers and has usually concluded that blue hubbard has high trap crop potential. (Caldwell and Stockton 1998, MacIntyre-Allen et al. 2001, Bellows and Diver 2002, Boucher and Durgy 2004, Cavenagh 2008, Adler and Hazzard 2009). The identification of alternative varieties that can be used as trap crops limits risk of shortage for seeds, particularly for organic farmers.

The main limitation of perimeter trap crops for organic farmers is the lack of affordable and efficacious insecticides. Furthermore, the short residuals, typical of organically acceptable insecticides, lead to the need of multiple insecticide applications. Alternatives to currently available OMRI approved pesticides are needed. Methods to improve the efficiency of trap crops without use of insecticide could be useful for farmers. One potential way to increase the efficiency of trap crops is to mix different varieties of winter squash. To date, this possibility has not been explored. A better understanding of which parts of the plants attract the most striped cucumber beetles could also help to improve the trap crop management.

Objectives

1- Determine the attractiveness and trap crop potential of four varieties of winter squash, for management of striped cucumber beetles

2- Determine the potential of winter squash varietal mixtures to improve striped cucumber beetle trap crop performance in organic cucumber production

3- Determine the relative importance of different trap crop parts (i.e. flowers, leaves, fruit) to the attractiveness of trap crop varieties

CHAPTER 2

Attractiveness and trap crop potential of four varieties of winter squash to striped cucumber beetles (Coleoptera: Chrysomelidae)

Abstract:

Striped cucumber beetles, A*ccalymma vittatum* F. (Coleoptera: Chrysomelidae), are major pests in organic cucumber production. Trap crops are an important tool in management of striped cucumber beetles but have limits in organic pest management. In this study we assessed the trap crop potential of four winter squash varieties: blue hubbard (*Cucurbita maxima* Duchesne), burgess buttercup (*Cucurbita maxima* Duchesne), waltham butternut (*Cucurbita moschata* Duchesne), table queen acorn (*Cucurbita moschata* Bailey) under greenhouse and field conditions. Results show that burgess buttercup and blue hubbard are the most attractive varieties. No significant difference was observed between these two varieties. Burgess buttercup has an advantage under low beetle population with its good marketability. The study showed the importance of flowers in the attractiveness of the trap crops and thus the management of striped cucumber beetles.

Introduction

The cucumber beetle complex (Coleoptera: Chrysomelidae) makes up the principal insect pests of cucurbits in the USA and consists of: the striped cucumber beetle (*Acalymma vittatum* F.), the spotted cucumber beetle (*Diabrotica undecimpuctata howardi* Barber), and the banded cucumber beetle (*Diabrotica balteat* Leconte). In Michigan, the striped cucumber beetle is considered the most important of these three species. Adult striped cucumber beetles damage cucurbits by feeding on flowers, fruit, leaves, and stems while larvae are root feeders. At the seedling stage, feeding by adults can kill the plants. However, older plants are more able to tolerate some defoliation (Burkness and Hutchison 1998). Brewer et al. (1987) showed that zucchini attacked at the second and third-leaf stage compensate for growth delay before fruit production. Adult cucumber beetle feeding on fruit causes scars that limit cucumber marketability. Furthermore, striped cucumber beetle also transmits bacterial wilt (*Erwinia tracheiphila* Smith) (Mitchell and Hanks 2009). This disease kills the plants and currently no curatives are available. Thus, in regions where this pathogen occurs, cucumber beetles must be maintained at very low levels. Brust and Foster (1999) advise a threshold of one beetle/per plant if bacterial wilt is present. In Michigan, bacterial wilt occurrence is sporadic, allowing higher tolerance for cucumber beetles and providing increased opportunities to manage cucumber beetles with certified organic tactics.

In the North Central region of the USA, the pest is univoltine. The first generation of the striped cucumber beetle is initiated by overwintering adults with adult beetles spreading from overwintering sites to cultivated fields at the beginning of June. This often coincides with early growth of cultivated cucurbits and can have a severe impact on the production, leading to reduced stand or delayed plant maturation (Brewer et al. 1987, Ayyappath et al. 2002). Eggs are laid at the base of the cucurbit plants and larvae hatch and feed on the roots. Larval feeding is usually less damaging than feeding by overwintering adults because the plants are well established when the larvae begin feeding (Bellows and Diver 2002) The second generation of beetles emerges at the end of July beginning of August.

Trap crops function by attracting pests to a restricted area where the pest is either diverted from the protected plant, is more easily controlled, or both (Shelton and Badenes-Perez 2006). In the case of cucumber beetles, trap crops are usually varieties of winter squash. Some varieties of winter squash that are particularly attractive to cucumber beetles include *Cucurbita pepo* Alef and *Cucurbita maxima* Wall. The difference in attractiveness among varieties has previously been reported to be due to the concentration of cucurbitacin in the plants (Bellows and Diver 2002). Winter squash trap crops are usually planted on the edges of a cucumber field as perimeter trap cropping (Hokkanen 1991, MacIntyre-Allen et al. 2001, Hazzard and Cavanagh 2005, Cavanagh et al. 2009). The reported advantages of trap crops are reduced damage to the main crop through the diversion of cucumber beetles as well as reduced insecticide use (Boucher and Durgy 2004, Adler and Hazzard 2009, Cavanagh et al. 2009). However, trap crops alone typically do not provide sufficient damage control when cucumber beetles occur in large numbers (MacIntyre-Allen et al. 2001, Brewer et al. 2006).

In conventional cucumber production perimeter trap cropping is typically tied with use of an insecticide (Hazzard 2005, Adler and Hazzard 2009, Cavanagh et al. 2009). This method typically reduces the amount of insecticide necessary to achieve economic control. For example, Cavanagh and Hazzard (2009) showed that perimeter trap cropping reduced the use of insecticide by 94% compare with conventional methods. A surface of 15% of trap crop is recommended (Radin and Drummond 1994a).

Striped cucumber beetle management options available for certified organic production vary greatly in efficacy and cost and can be classified into low-input or high-input strategies. Examples of low-input strategies include use of different densities and varieties of trap crops (Hazzard and Cavanagh 2005), which may be integrated with: light traps (Barrett et al. 1971b) , vacuum removal of adult beetles (Smith 2000), and biological control (Reed et al. 1986, Barbercheck and Warrick 1997, Ellers-Kirk et al. 2000). High-input strategies include row covers on cucumber (Matthewsgehringer and Houghgoldstein 1988), organic insecticides, and trap crop plus organic insecticides, (Hazzard and Cavanagh 2005). These strategies may be more efficient than low-input strategies but are typically also more expensive. Perimeter trap crops are thus an attractive pest management option for organic farmers. However, the acquisition of organically produced attractive trap crop seeds can be challenging especially considering most of the available information on trap crops has been developed using conventional varieties.

Furthermore, the integration of organically acceptable insecticides with perimeter trap cropping is challenging because there are few effective organically approved insecticides and they typically require frequent treatment due to short residual activity. Thus, the potential for the effective use of perimeter trap crops in organic cucumbers depends on the use of highly attractive cultivars. The attractiveness of a cultivar is due to cucurbitacin which is a phagostimulant and an arrestant (Metcalf et al. 1980) and the volatile attractant from blossoms (Andersen and Metcalf 1986, Lewis et al. 1990, Metcalf et al. 1995). The attractiveness of a plant is reinforced by the presence of male aggregation pheromone (Smyth and Hoffmann 2003, Morris et al. 2005). Smyth and Hoffmann (2003) showed that several males as lures are more efficient to attract conspecifics that a male alone.

The primary objective of this study was to assess the potential of different winter squash varieties easily found as organic seeds. The second objective was to evaluate which parts of these potential trap crops (*i.e.* flower, fruit, leaves and stem) contribute the most to their relative attractiveness for striped cucumber beetles.

Materials and methods

Greenhouse Experiment: We measured the relative attractiveness of cucumbers to striped cucumber beetles versus four different varieties of squash at three time periods with three different simulated damage scenarios under greenhouse conditions. Cobra (*C. sativus* L.) (Seedway: Elizabethtown, PA) was selected as our cucumber cultivar while the four trap crop varieties used in the experiment were: Blue Hubbard (*Cucurbita maxima* Duchesne) (Fedco seeds Waterville, ME), Burgess Buttercup (*Cucurbita maxima* Duchesne), Waltham Butternut (*Cucurbita. moshata* Duchesne ex Lam) and table queen acorn (*Cucurbita. pepo* Bailey) (High Mowing Seeds Wolcott, VT). Plants were grown and the experiment conducted in greenhouses located at the Michigan State University (MSU), Center for Integrated Plant Studies (CIPS) (East Lansing, Michigan). Plants were grown in organic certified substrate, in 15.5 cm diameter 17.5 cm tall pots. Plants did not receive additional fertilizer but were watered three times a week. Plants were 12 d old when each experimental run took place.

The experimental design was a factorial randomized block design with two experimental factors: a five-way cucumber vs. trap crop factor and a three way damage factor. Four replications for each cultivar with three damage treatment were evaluated for each of the three experimental runs, yielding a total of eight replicates, with time and date used as a blocking factor. The five levels of the trap crop variety factor were established with experimental units consisting of a single cucumber (the protected crop) plant planted with one of each of the four trap crop plants or a second cucumber plant (control). For the damage factor either the trap crop plant was damaged, the trap crop plant and the cucumber plant were damaged, or both plants were left undamaged. Simulated damage was accomplished by scratching two leaves using a dissection probe without fully piercing the leaves. Plants were damaged 30 minutes prior to the initiation of each experimental run. A transparent plastic cage (14 cm diameter and 37 cm tall) was set over the two plants in each pot. Ten field collected striped cucumber beetles were placed in each cage. New beetles were collected for each run. The different experiments run were started at 1pm and terminated 24 hours later. Our response variable was the number of striped cucumber beetles on each plant or not on either plant within each cage at 1, 5, and 24 h after their release.

We calculated the percentage of beetles on the trap crop varieties by dividing the number of beetles on each the trap variety by the number of beetles release in each cage (10 beetles). We analyzed the percentage of beetles on trap crop using a three by three by three by eight (type of damage, time sample, date, repetition) factorial and post hoc Tukey's honest significant difference multiple comparison procedure was performed (R Development Core Team 2008).

Field experiment: The relative attractiveness of cucumber versus itself and four different varieties of squash with four different levels of artificial damage to striped cucumber beetles was assessed under field conditions. The squash varieties and cucumber cultivar employed were the same as those used in the greenhouse experiment. Plants were grown in the greenhouse and transplanted into a field located at the MSU, Horticulture Farm (Holt, Michigan). Pairs of squash seedling and cucumber seedlings were transplanted into the field with a spacing of 20 cm between plants within a pair and 2 m of bare soil between pairs. The control treatment paired two cucumber plants. Plots were manually weeded on a weekly basis. Plants were watered regularly but received no fertilization.

Two independent experiments were performed with transplants of different ages. The first experiment was done with 26 d old transplants and the second with 16 d old seedlings. Both experiments represented a full factorial randomized complete block consisting of two factors: a five-way cucumber versus trap crop factor and a four-way damage factor. There were six blocks of each cultivar combination and damage level. The five levels of the trap crop variety factor were established with experimental units consisting of a single cucumber (the protected crop) plant planted with one of each of the four trap crop plants (blue hubbard, burgess buttercup, waltham butternut, table queen acorn) or a second cucumber plant (control). For the artificial damage factor either the trap crop plant was damaged, the cucumber plant was damaged, the trap crop plant and the cucumber plant were damaged, or neither the cucumber nor the trap crops were damaged. Simulated damage was accomplished as in the greenhouse experiment.

Plants used in the experiment with 26 d old transplants were planted on 17 June 2008 while plants used in the experiment with 16 d old transplants were planted on18 June 2008. Artificial damage was applied on19 June 2008 in both experiments. Our response variable was the number of beetles present on flowers, fruit, leaves and stems twice weekly on cucumber (The protected crop) and trap crop plants. We also assessed percentage defoliation and mortality. Defoliation was estimated on a scale from 0% to 100% defoliation. Data were taken twice weekly between June 20 and August 11. Number of beetles present on plant, defoliation and mortality were recorded at each sample date between 7 am and 11am.

Mortality data was transformed using the arcsine transformation to normalize the data. The number of beetles across the field season was summed and normalized using a base 10 Logarithm transformation and analyzed using a six by five by four (block, cultivar, artificial damage) factorial and post hoc Tukey's honest significant difference multiple comparison procedure (R Development Core Team 2008, Team 2009).The ratio number striped cucumber beetles on flowers to the number of striped cucumber beetles on leaves, stems were also analyzed for each cultivar. Data were normalized using a base 10 Logarithm transformation and analyzed using a six by five (block, cultivar) ANOVA.

Results

Greenhouse experiment: We observed a significant difference in the percentage of beetles on trap crops among the five trap crop varieties (F = 50.01; df = 4, 307; P < 0.001) (Fig 1.1). The mean percentages of beetles observed on trap crop were 57%, 52%, 34%, 29%, and 23% on blue hubbard, burgess buttercup, waltham butternut, cucumber and table queen acorn, respectively. Significantly more beetles were observed on burgess buttercup than waltham butternut, table queen acorn and cucumber. Significantly more beetles were observed on blue hubbard than waltham butternut, table queen acorn and cucumber. Significantly more beetles were observed on cucumber and waltham butternut than table queen acorn. We observed a significant difference between the three sampling times (F = 4.78; df = 2, 307; P = 0.008). The mean percentages of beetles observed on trap crop were 40%, 43% and 36% at 1 hour, 5 hours and 24 hours after release, respectively. We did not observed a significant difference between repetition (F = 0.79; df = 7, 307; P = 0.59), dates (F = 2.47; df = 2, 307; P = 0.086) and artificial leaf damage treatments (F = 2.83; df = 2, 307; P = 0.061). Nor did we observe a significant interaction effect between times sampling time and trap crop varieties (F = 1.27; df = 8, 307; P = 0.26), between artificial leaf damage treatments and trap crop varieties (F = 1.43; df = 8, 307; P = 0.18) and between times sampling and artificial leaf damage treatments (F = 1.21; df = 4, 307; P = 0.31).

Field experiment: For the 26d transplant experiment we observed a significant difference in the total number of beetles on trap crop among the five trap crop varieties (F

= 62.16; df = 4, 107; P < 0.001) (Fig 1.2). The mean sum of beetles observed were 443, 278, 72, 62, and 37 on burgess buttercup, blue hubbard, table queen acorn, waltham butternut and cucumber, respectively. Significantly more beetles were observed on burgess buttercup than waltham butternut, table queen acorn and cucumber. Significantly more beetles were observed on blue hubbard than waltham butternut, table queen acorn and cucumber. Significantly more beetles were observed on table queen acorn than cucumber. We did not found any artificial damage effect on attractiveness of trap crop (F = 1.84; df = 3, 107; P = 0. 14).

Furthermore we observed a significant difference in the total number of beetles on the flowers among trap crop varieties (F = 95.24; df = 4, 107; P < 0.001) (Fig. 1.2) with mean sums of 395, 236, 55, 40 and 6 beetles observed on burgess buttercup, blue hubbard, table queen acorn, waltham butternut and cucumber, respectively. Significantly more beetles were observed on burgess buttercup than waltham butternut, table queen acorn and cucumber. Significantly more beetles were observed on blue hubbard than waltham butternut, table queen acorn and cucumber. Significantly more beetles were observed on table queen acorn than cucumber and significantly more beetles were observed on waltham butternut than cucumber. We also found a difference in the total number of beetles counted on leaves and stems among trap crop varieties (F = 9.70; df = 4, 107; P < 0.001) (Fig. 1.2) with mean sums of 48, 43, 18, 21 and 29 beetles observed on burgess buttercup, blue hubbard, table queen acorn, waltham butternut and cucumber, respectively. Significantly more beetles were observed on burgess buttercup than table queen acorn and waltham butternut. Significantly more beetles were observed on blue hubbard than table queen acorn and waltham butternut. We did not analyze the data on the number of beetles found on trap crop fruits due to the low number of beetles found (only 9 beetles were observed across all the season).

We did not observe a significant difference in the total number of beetles on cucumber among the five trap crop varieties ($F = 1.82$; $df = 4, 107$; $P = 0.13$) (Fig 1.2) nor any artificial damage effect on attractiveness of trap crop ($F = 0.28$; $df = 3, 107$; $P = 0.84$). Furthermore we did not observe difference in the total number of beetles observed on cucumber flowers among the five trap crop varieties ($F = 2.21$; $df = 4, 107$; $P = 0.073$) nor in the total number of beetles observed on cucumber leaves and stems among the five trap crop varieties ($F = 1.12$; $df = 4, 107$; $P = 0.35$). We found 46 beetles on cucumber fruits and no difference in the total number of beetles observed on cucumber fruits among the five trap crop varieties ($F = 1.69$; $df = 4, 107$; $P = 0.16$).

In the burgess buttercup vs. cucumber treatment we observed significantly more beetles on burgess buttercup ($t= 9.53$, $df= 23.85$, $P<0.001$) (Fig. 2.2). In the blue hubbard vs. cucumber treatment we observed significantly more beetles on blue hubbard ($t= 8.25$, $df= 24.8$, $P<0.001$) (Fig. 2.2). In the table queen acorn vs. cucumber treatment we observed significantly more beetles on table queen acorn ($t=2.04$, $df= 45.99$, $P= 0.047$) (Fig. 2.2). In the waltham butternut vs. cucumber treatment we did not observe any significant difference ($t= 1.92$, $df= 45.99$, $P= 0.061$) (Fig. 2.2). In the cucumber vs. cucumber control we did not observed any significant difference ($t= -0.15$, $df= 44.90$, $P= 0.88$) (Fig. 2.2).

We observed a significant difference in the mortality of plants among the five trap crop varieties at the end of the experiment ($F = 3.25$; $df = 4, 24$; $P =0.029$). The percentage mortality was 17%, 29%, 13%, 0% and 42% on burgess buttercup, blue hubbard, table queen acorn, waltham butternut and cucumber, respectively. Significantly more cucumber died than Waltham butternut. No significant difference was observed in the percentage of dead cucumber plants associated with the trap crops among the five trap crop varieties ($F = 2.66$; $df = 4, 24$; $P = 0.057$).

We observed a significant difference in the ratio of beetles on flowers to beetles on leaves, stems and fruits among the five trap crop varieties ($F = 28.09$; $df = 4, 20$; $P < 0.001$) (Fig. 2.1). The ratios of beetles on flowers to beetles on leaves, stems and fruits observed were 8.6, 5.8, 3.4, 2.3 and 0.18 on burgess buttercup, blue hubbard, table queen acorn, waltham butternut and cucumber, respectively. The ratio calculated for the cucumber treatment was significantly lower than for burgess buttercup, blue hubbard and table queen acorn. The ratio calculated for the table queen acorn and waltham butternut treatments was significantly lower than for burgess buttercup, blue hubbard and table queen acorn (Fig. 2.2).

For the 16d transplant experiment we found a difference in the total number of beetles observed on trap crop among the five trap crop varieties ($F = 47.89$; $df = 4, 107$; $P < 0.001$) (Fig 2.3). The mean sum of beetles observed were 224, 212, 79, 40, and 47 on burgess buttercup, blue hubbard, table queen acorn, waltham butternut and cucumber, respectively. Significantly more beetles were observed on burgess buttercup than waltham butternut, table queen acorn and cucumber. Significantly more beetles were observed on blue hubbard than waltham butternut, table queen acorn and cucumber. Significantly more beetles were observed on table queen acorn than cucumber and waltham butternut. We did not found any artificial damage effect on attractiveness of trap crop ($F = 0.79$; $df = 3, 107$; $P = 0. 50$).

Furthermore, we observed a significant difference in the total number of beetles counted on the flowers among trap crop varieties ($F = 70.14$; $df = 4, 107$; $P < 0.001$) (Fig. 2.3) with mean sums of 192, 174, 66, 30 and 2 beetles observed on burgess buttercup, blue hubbard, table queen acorn, waltham butternut and cucumber, respectively. Significantly more beetles were observed on burgess buttercup than waltham butternut, table queen acorn and cucumber. Significantly more beetles were observed on blue hubbard than waltham butternut, table queen acorn and cucumber. Significantly more beetles were observed on table queen acorn than cucumber and waltham butternut and significantly more beetles were observed on waltham butternut than cucumber. We also found a difference in the total number of beetles counted on leaves and stems among trap crop varieties ($F = 19.10$; $df = 4, 107$; $P < 0.001$) (Fig. 2.2) with mean sums of 32, 38, 14, 10 and 43 beetles observed on burgess buttercup, blue hubbard, table queen acorn, waltham butternut and cucumber, respectively. Significantly more beetles were observed on burgess buttercup than table queen acorn and waltham butternut. Significantly more beetles were observed on blue hubbard than table queen acorn and waltham butternut. Significantly more beetles were observed on cucumber than table queen acorn and waltham butternut. We did not analyze the data on the number of beetles found on trap crop fruits due to the low number of beetles found (only 13 beetles were observed across all the season).

We did not find a difference in the total number of beetles observed on cucumber among the five trap crop varieties ($F = 2.40$; $df = 4, 107$; $P = 0.055$) (Fig 1.2) nor any artificial damage effect on the attractiveness of trap crops ($F = 0.16$; $df = 3, 107$; $P = 0.92$). Furthermore we did not observe differences in the total number of beetles on cucumber flowers among the five trap crop varieties (F = 1.23; df = 4, 107; P = 0.30). We did observe a difference in the total number of beetles on cucumber leaves and stems among the five trap crop varieties (F = 2.84; df = 4, 107; P = 0.028). Significantly more beetles were observed on burgess buttercup with 38 beetles than waltham butternut with 20 beetles. We did not analyze the data on the number of beetles found on cucumber fruits as only 22 beetles were observed across all treatments.

In the burgess buttercup vs. cucumber treatment we observed significantly more beetles on burgess buttercup (t= 8.80, df= 28.89, P<0.001) (Fig. 2.2).In the blue hubbard vs. cucumber treatment we observed significantly more beetles on blue hubbard (t= 13.73, df= 27.43, P<0.001) (Fig. 2.2). In table queen acorn vs. cucumber treatment we observed significantly more beetles on table queen acorn (t=6.56, df= 43.24, P<0.001) (Fig. 2.2). In the waltham butternut vs. cucumber treatment we observed significantly more beetles on waltham butternut (t= 3.31, df= 42.09, P=0.002) (Fig. 2.2). In the cucumber vs. cucumber control we observed significantly more beetles on trap crop cucumber (t= 2.25, df= 34.31, P=0.031) (Fig. 2.2).

We observed a significant difference in the percentage mortality of plants among the five trap crop varieties at the end of the experiment (F = 8.85; df = 4, 24; P<0.001). The percentage mortality was 17%, 13%, 8%, 0% and 63% on burgess buttercup, blue hubbard, table queen acorn, waltham butternut and cucumber, respectively. Significantly more cucumber died than waltham butternut and table queen acorn. However, no significant difference was observed in the percentage of dead cucumber associated with the trap crops among the five trap crop varieties (F = 2.66; df = 4, 24; P =0.057).

We observed a significant difference in the ratio of beetles on flowers to beetles on leaves, stems and fruits the five trap crop varieties ($F = 8.72$; $df = 4, 20$; $P < 0.001$) (Fig. 2.1). The ratios of beetles on flowers to beetles on leaves, stems and fruits observed were 6.4, 5.7, 5.2, 3.5 and 0.03 on burgess buttercup, blue hubbard, table queen acorn, waltham butternut and cucumber, respectively. The ratio calculated for the cucumber treatment was significantly lower than for burgess buttercup, blue hubbard and table queen acorn (Fig. 2.3).

Discussion

Burgess buttercup is as efficient as blue hubbard in attracting striped cucumber beetles and may have the advantage of being marketable. The greenhouse experiment showed that blue hubbard and burgess buttercup are both considerably more attractive to striped cucumber beetles than cucumbers (Fig. 2.1). In contrast, waltham butternut and table queen acorn did not show any potential to be used as trap crops in cucumber production (Fig. 2.1). The two field experiments did not show a difference in attractiveness between burgess buttercup and blue hubbard. Thus, both varieties showed potential to be used as trap crops (Fig.2.2 and 2.3). These results confirmed the higher attractiveness of the blue hubbard and burgess buttercup squash (Caldwell and Stockton 1998, Bellows and Diver 2002, Boucher and Durgy 2004, Cavenagh 2008). These results also suggest that blue hubbard and burgess buttercup may have the potential to be used as trap crops in waltham butternut and table queen acorn production. Furthermore, we did not observe a higher mortality of burgess buttercup compared to blue hubbard in either field experiments. The greenhouse experiment and the field experiments showed that simulated damage did not affect the attractiveness of trap crops.

One advantage of burgess buttercup over blue hubbard is the relative ease in finding organic seeds. Another advantage is that buttercup provides an alternative marketable crop, thus reducing the cost of perimeter trap cropping. Burgess buttercup is a more easily marketable squash compared to blue hubbard, which produces very large squash that are difficult to sell (Whalen et al. 2000, Cavanagh 2008). Furthermore, even when beetles feed on the trap crops, the squash fruits are not frequently attacked. Only 0.2% and 0.4% striped cucumber beetles were found on fruits in the 26d old transplant and the 16d old transplant experiment, respectively.

These results also highlight that the attractiveness of varieties within the same species can be highly variable. For example, burgess buttercup showed high attractiveness while table queen acorn showed low attractiveness for striped cucumber beetles, although both are *C. pepo* (Fig. 2.1, 2.2 and 2.3). This result is very meaningful because it clearly indicates that describing the trap crop potential of variety by its species can be misleading.

Our data also suggest that it is very important to provide a floral resource on trap crops to manage striped cucumber beetles. The presence of flowers has a large impact on the attractiveness of the trap crops to the striped cucumber beetle (Andersen and Metcalf 1986, Lewis et al. 1990, Metcalf et al. 1995, Ferrari et al. 2006). The ratio of beetles on flowers to beetles on leaves and stems observed in the field experiments varies between 5.7 to 8.5 for blue hubbard and burgess buttercup, 2.3 to 5.2 for waltham butternut and table queen acorn, and 0.03 to 0.2 for cucumbers. The low flower/vegetative plant part ratio on cucumbers may be explained by the very small size of cucumber flowers compared to the winter squash flowers. Whereas variation in the concentration of volatiles between waltham butternut and table queen acorn may explain the lower attractiveness of thiese two cultivars compared to blue hubbard and burgess buttercup. Sasu et al (2010) showed variation of attractiveness inside plant for *C.pepo*, with male flowers more attractive to cucumber beetles than female. Figure 2.4 shows the position of the striped cucumber beetles on the plants and the effect of flowers in the number of beetles found. The two experiments are independent but took place during the same time and in the same field. They showed the importance of the age of the plant in the appearance of the flowers. In the experiment with 26d transplants, flowers appeared around July 1, more than two weeks sooner than in the 16d transplants. Striped cucumber beetles started to appear in the field around June 26. Furthermore, Theis and al (2009) demonstrated that flowers attract striped cucumber beetles and feeding delays the appearance of flowers. Older transplants ensure earlier appearance of flowers in the field, thus increasing the protection potential of trap crops. Cucurbitacin may also play a role in the difference of attractiveness observed between varieties (Metcalf et al. 1980, Andersen and Metcalf 1986, Schroder et al. 2001).

This study showed that burgess buttercup has the same potential to be used as a trap crop as blue hubbard in cucumber, table queen acorn, or waltham butternut production. Burgess buttercup could be more financially beneficial for farmers than using blue hubbard (Cavanagh 2008). Lastly, the study showed the importance of the transplant age to ensure an optimal protection of the cucumbers through continuous provisioning of floral resources on the trap crop.

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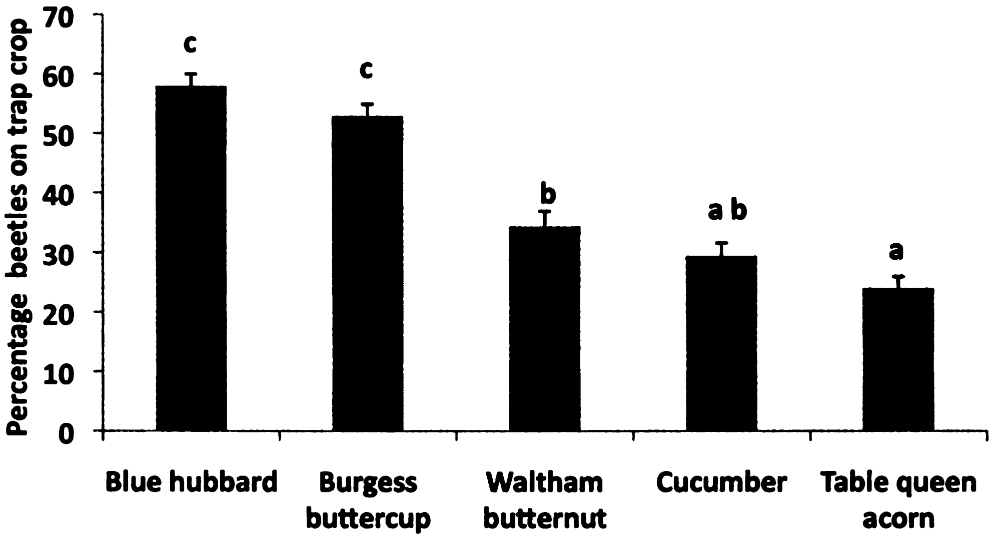
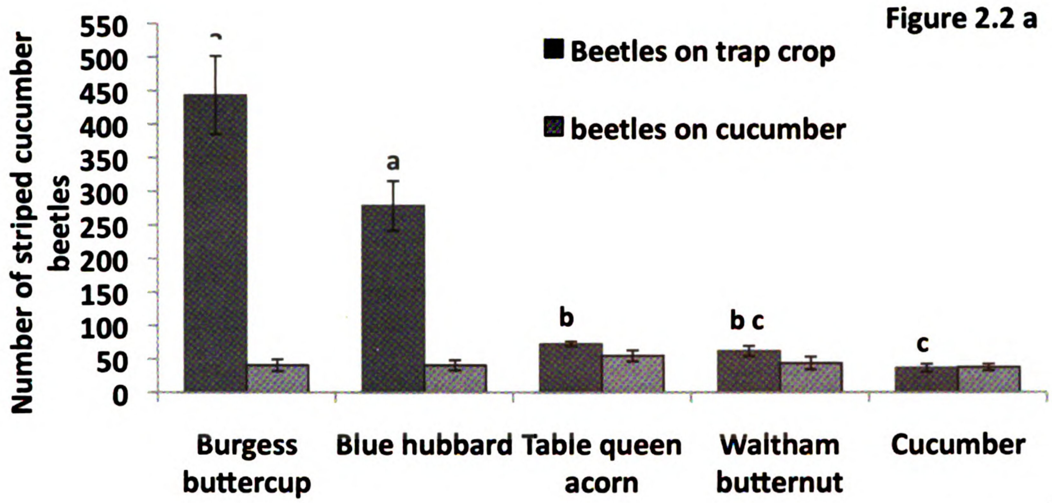


Figure 2.1: Mean percentage of striped cucumber beetles (±SEM) found on trap crops versus cucumbers. Bars with different letters are significantly different (Tukey's honest significant difference test alpha = 0.05).



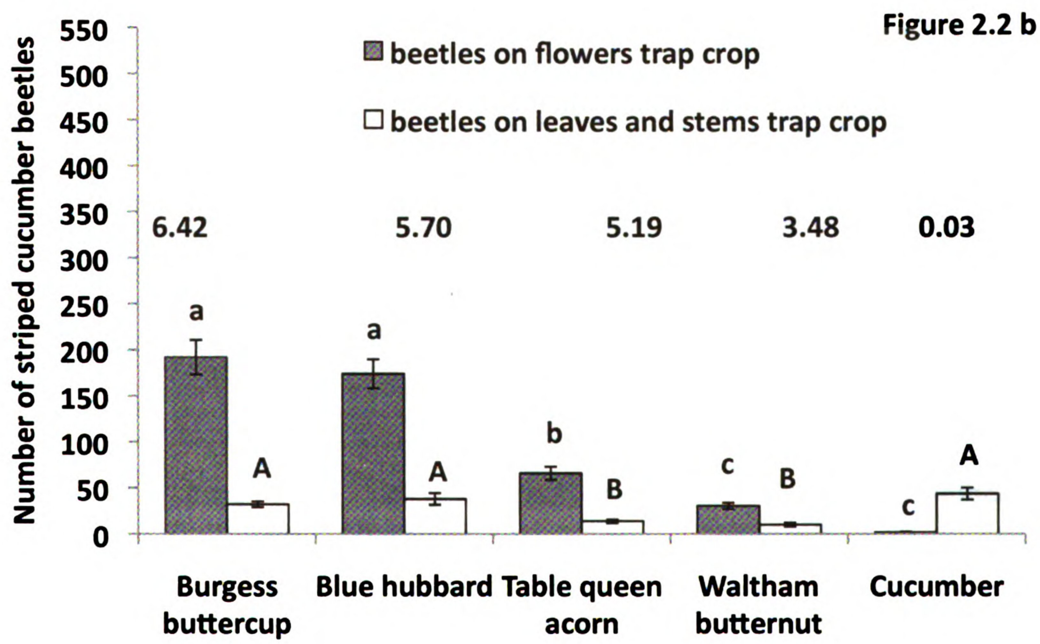


Figure 2.2: Average number of striped cucumber beetles (±SEM) observed on trap crops, across all observation dates for the 26 day transplants a) on trap crop variety and cucumber pairs b) on trap crop flowers or leaves, fruits and stems. Numbers above bars represent the ratio of beetles on flowers to leaves and stems. Bars with different letters are significantly different (Tukey's honest significant difference alpha=0.05).

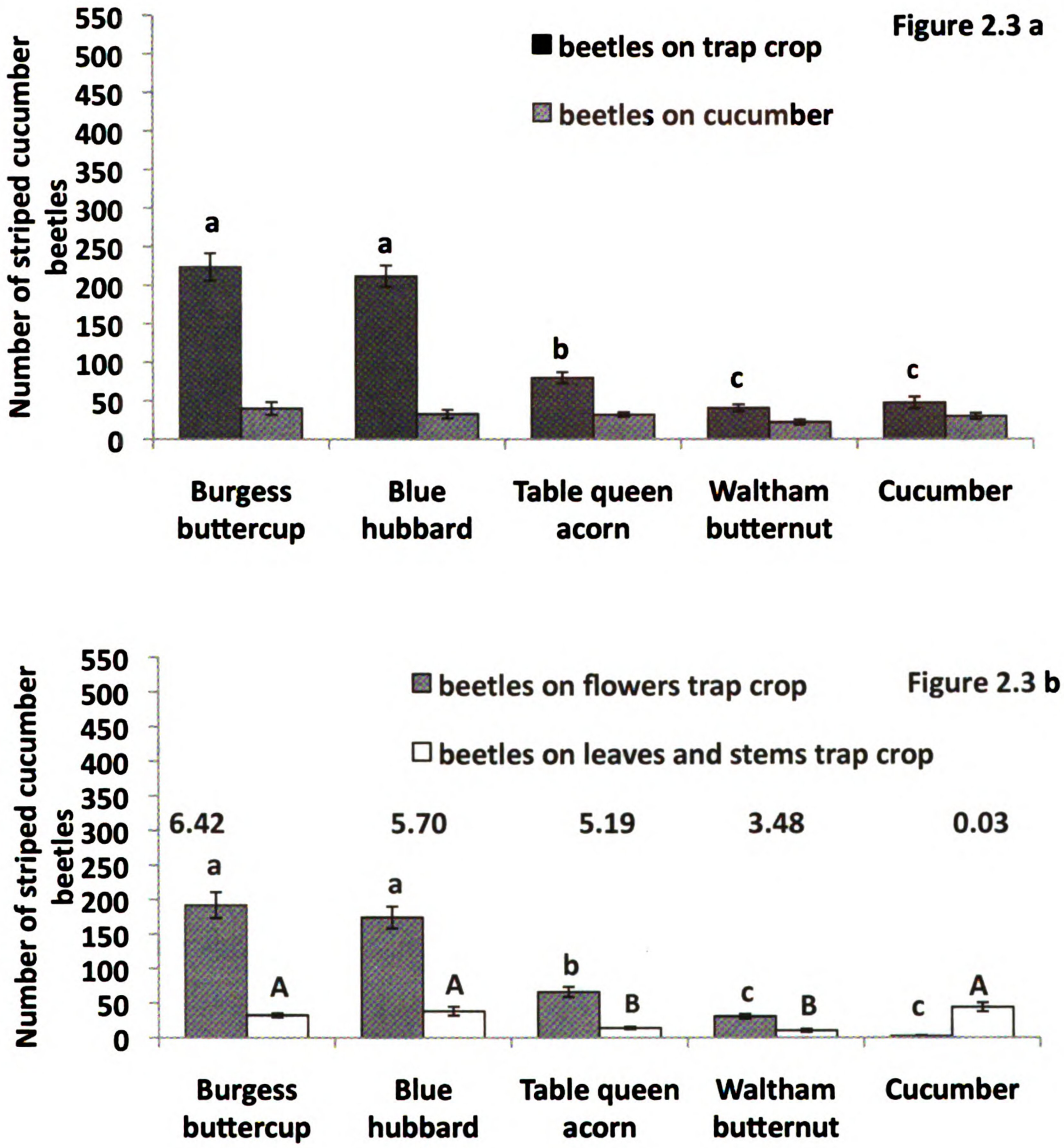


Figure 2.3: Average number of striped cucumber beetles (±SEM) observed on trap crops, across all observation dates for the 16 day transplants a) on trap crop variety and cucumber pairs b) on trap crop flowers or leaves, fruits and stems. Numbers above bars represent the ratio of beetles on flowers to leaves and stems. Bars with different letters are significantly different (Tukey's honest significant difference alpha=0.05).

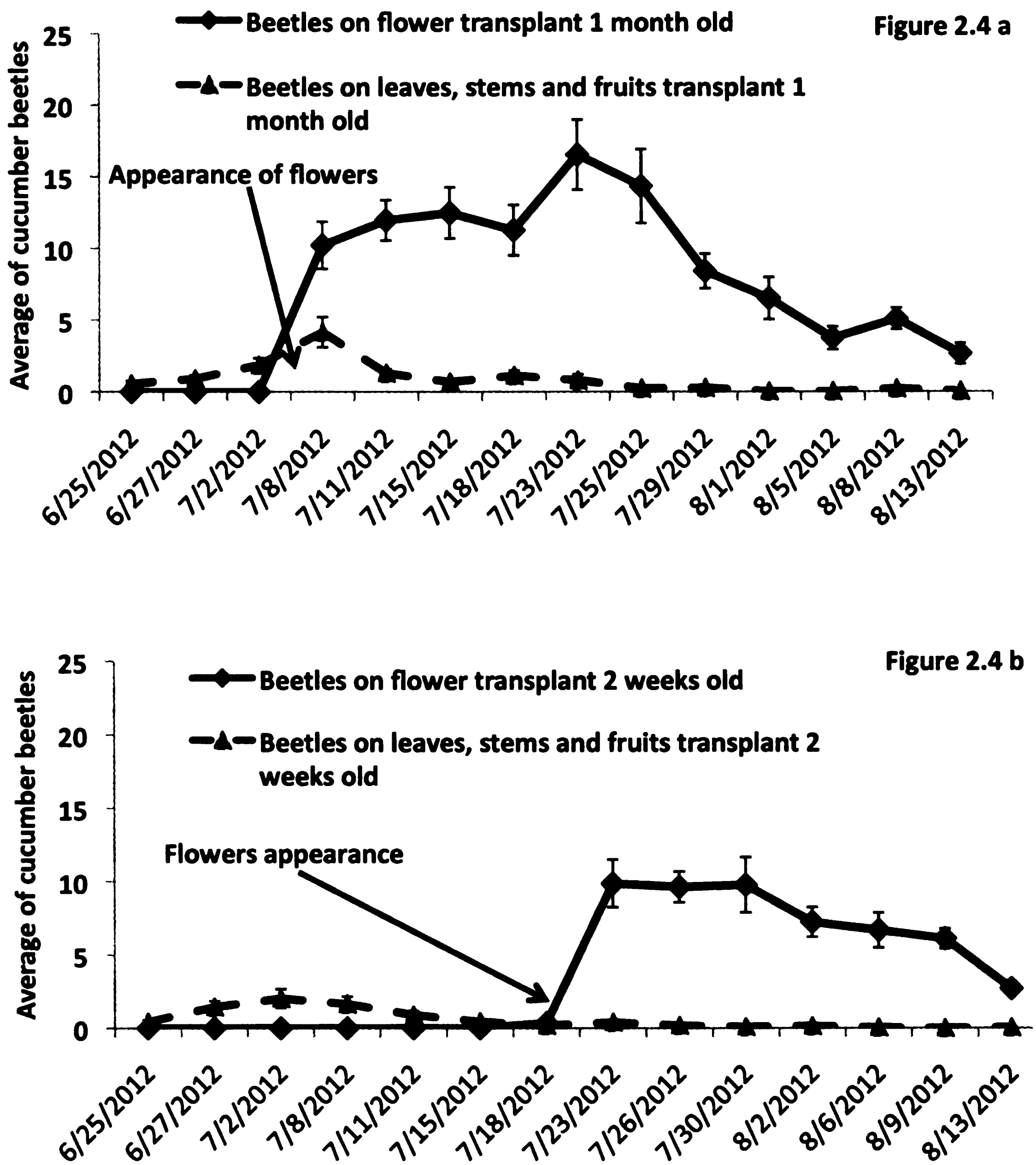


Figure 2.4: Average number of striped cucumber beetles observed on burgess buttercup flowers or leaves, stems, and fruits (±SEM) using (a) 26 day old or (b) 16 day old transplants.

CHAPTER 3

Potential of winter squash varietal mixtures to improve striped cucumber beetle trap crop performance in organic cucumber production

Abstract:

Striped cucumber beetles, A*ccalymma vittatum* F. (Coleoptera: Chrysomelidae), are major pests in organic cucumber production. Trap crops are an important tool in management of striped cucumber beetles but have limited efficacy in organic pest management. In this study we assessed the trap crop potential of combinations blue hubbard (*Cucurbita maxima* Duchesne) with waltham butternut (*Cucurbita moschata* Poir), compared to each cultivar alone. We also assessed the potential of Pyganic® insecticide and vacuum applications to control cucumber beetles on trap crops. Results showed that blue hubbard combined with waltham butternut is as efficient as blue hubbard alone. The waltham butternut has an advantage in the case of low beetle population with its good marketability. No differences were observed between treatments where insecticide and vacuum were used compared to control. The study also showed the importance of flowers in the attractiveness of the trap crops and thus the management of striped cucumber beetles.

Introduction

The striped cucumber beetle (*Acalymma vittatum* F.) is a member of the cucumber beetle complex that also includes: the spotted cucumber beetle (*Diabrotica undecimpunctata howardi* Barber), banded cucumber beetle (*Diabrotica balteata* Leconte), western spotted cucumber beetle (*Diabrotica undecimpunctata undecimpunctata* Mannerheim), and western corn root worm (*Diabrotica virgifera virgifera)*(Bellows and Diver 2002). This complex makes up the most prevalent and serious pests of cucurbit crops in the mid-west. In Michigan, where this research was conducted, striped cucumber beetles are the most common pest found on cucurbitaceous crops. Michigan's fresh cucumber production is the fourth largest in US with 9.8% of national production. Around 4,900 acres were planted in 2007, with total sale of 15.4 million dollars (Kleweno and Matthews 2008).

The striped cucumber beetle's host range is primarily plants in the family Cucurbitacea (McKinlay. Roderick. G 1992) and adult beetles feed on the leaves, stems, and fruits. Damage resulting from adult feeding can kill the plant, decrease yields, or reduce fruit value through scarring. Brewer et al (1987) showed that although plants at the third true leaf stage were able to resist and compensate for foliar feeding, younger plants often died. Adult cucumber beetles also transmit Bacterial Wilt (*Erwinia tracheiphila* Smith) by feeding on foliage (Brust and Rane 1995, Mitchell and Hanks 2009) or damaging flowers (Sasu et al. 2010). Larva feed exclusively on cucurbits roots, causing damage that reduces the development of the roots. (Ellers-Kirk et al. 2000) showed that reducing the population of cucumber beetle larvae increased the root length and density of cucumbers in organic and conventional systems.

In the North Central region of the USA, the striped cucumber beetle is typically monovoltine. Adult beetles usually emerge from their overwintering sites at the end of May or beginning of June, and start to colonize cucumber fields when temperatures exceed 12°C (Radin and Drummond 1994a). This often coincides with early growth of cucumbers and can have a severe impact on production through reduced stand and/or delayed plant maturation (Brewer et al. 1987, MacIntyre-Allen et al. 2001, Ayyappath et al. 2002). Female beetles lay their eggs at the base of the plants and the next generation emerges at the end of July or beginning of August. The summer generation is usually less damaging to crops, particularly cucumbers, because crops are often ready for harvest prior to peak beetle emergence.

Brust and Foster (1999) recommend an economic threshold of one beetle per plant if bacterial wilt is present, making striped cucumber beetle management a primary concern for farmers. Organic striped cucumber beetle management tactics are limited compared to conventional methods. Organic farmers have access to very few insecticides, most of which contain natural pyrethrums and are much less efficacious than their pyrethroid, carbamate, or organophosphate counterparts used in conventional cucumber plantings (Barry et al. 2005, Karagounis et al. 2006, Cross et al. 2007, Kamminga et al. 2009). Ellers-Kirk et al. (2000) showed that entomopathogenic nematodes applied to the soil had a significant impact on striped cucumber beetle emergence, however nematodes are expensive and their efficacy varies greatly depending on soil conditions (Kaya and

Gaugler 1993). Organic farmers also have access to physical management methods, such as plastic mulch and row covers. These are important to organic growers and have been employed with fair success (Matthewsgehringer and Houghgoldstein 1988, Cline et al. 2008, Nair and Ngouajio 2010). (Ibarra et al. 2001) showed that the use of row covers and plastic mulch increases Muskmelon yield compared to treatment without. Vacuuming can also be used to remove adult beetles (Smith 2000). Finally, the perimeter trap cropping system with organic insecticides is also used by organic farmers but with less success compared to conventional agriculture (Boucher and Durgy 2004, Hazzard and Cavanagh 2005, Adler and Hazzard 2009, Cavanagh et al. 2009). Cavanagh et al (2009) showed that in conventional agriculture, perimeter trap cropping can lead to a 94% reduction in insecticide use.

Trap crops function by attracting pests to a restricted area where the pest is either diverted from the protected plant, more easily controlled, or both (Shelton and Badenes-Perez 2006). In the case of cucumber beetles, the trap crop is usually a winter squash (*Cucurbita maxima* Duchesne) variety. Some varieties of winter squash that are particularly attractive to cucumber beetles include burgess buttercup and blue hubbard (Willot 2010). The difference in attractiveness among varieties has previously been reported to be due to the concentration of cucurbitacin in the plants (Metcalf et al. 1980, Ferguson et al. 1983, Brust and Foster 1995, Schroder et al. 2001, Martin et al. 2002, Smyth et al. 2002, Jackson et al. 2005b), but flowers have also been shown to play an important role in the attraction of the cucumber beetles to the cucurbits (Andersen and Metcalf 1986, Lewis et al. 1990, Ferrari et al. 2006) (Willot et al. 2010).

Winter squash trap crops are often planted around the edges of the cucumber field in a tactic referred to as perimeter trap cropping (Hokkanen 1991, Hazzard and Cavanagh 2005, Cavanagh et al. 2009). The reported advantages of perimeter trap crops are reduced damage to the main crop through the diversion of cucumber beetles, as well as reduced insecticide use (Boucher and Durgy 2004, Adler and Hazzard 2009, Cavanagh et al. 2009). However, trap crops alone typically do not provide sufficient damage control when cucumber beetles occur in large numbers (Brewer et al. 2006).

The lack of affordable and efficacious insecticides has severely limited the use of perimeter trap crops in organic cucumber production. One possible way to increase the efficiency of trap crops is to mix different varieties of winter squash. To date, this possibility has not been explored. Our hypothesis is that mixing varieties of winter squash with different flowering periods and different attractiveness can increase the efficiency of trap crops compared to a highly attractive variety of winter squash alone. Thus the main objectives were to determine whether different trap crop combinations might reduce the incidence of striped cucumber beetles on commercial cucumbers. In addition, we assessed the impact of flowers on the efficiency of trap crops as well as the potential of vacuum and organic insecticide applications to assist trap crops in managing striped cucumber beetles.

Materials and Methods

2007 Field experiment: We evaluated the effects of mixing different trap crop varieties with or without Pyganic® or insect vacuum applications on the striped cucumber beetle management provided by trap crops for cucumbers. We used blue hubbard (*Cucurbita maxima* Wall) (Fedco seeds Waterville, ME) and waltham butternut (*Cucurbita moshata* Poir) (High Mowing Seeds Wolcott, VT) as our two trap crops. The experimental design was a full factorial randomized complete block consisting of one factor with four treatments. Treatments one through three alternated three blue hubbard with three waltham butternut repeated four times to form a row of 24 plants. Pyganic® (McLaughlin Gormley King Company, MN) insecticide or an insect vacuum were applied in treatments two and three, respectively. Treatment four was 24 blue hubbard plants without insecticide or vacuum treatments. Each treatment was repeated four times, yielding a total of four blocks.

The experiment was performed at the Michigan State University (MSU) Horticulture Farm (Holt, Michigan). Trap crop transplants were grown at the MSU Center for Integrated Plant Studies (CIPS) greenhouse. Plants were grown in certified organic substrate, in 10.5cm by 10.5cm by 12.5 cm tall pots with no additional fertilizers or other inputs. Each experimental unit was composed of one central row of 24 trap crop plants, spaced 30 cm apart with three rows of cucumbers on either side of the central row. One m of bare soil was maintained between rows and each replicate was separated by 6 m of bare soil. Trap crops were transplanted in the field at the three leaves stage on May 30, 2007 while cultivar Cobra cucumbers (*C. sativus* L.) (Seedway: Elizabethtown, PA) were planted by direct seedling on June 7, 2007. Insecticide or vacuum treatments were applied when a threshold of two beetles per plant was reached. Weeding was done mechanically and manually to keep the field as clean as possible. Pyganic® was applied by back pack sprayer (16.8 ml per Liter) and is a certified organic product. Vacuuming was performed using a hand leaf blower (STIHL BG55, VA) converted to a vacuum (STIHL vacuum kit).

We counted the number of beetles present on the trap crops, the number of beetles on the two rows of cucumber closest of the treatments and assessed the mortality of the trap crops twice weekly. The number of beetles on the trap crops and on the rows surrounding the treatments across the field season were summed and analyzed using four by four (treatment, block) ANOVA. We analyzed plant mortality using a four by four (treatment, block) ANOVA. For treatment one, two and three (blue hubbard + waltham butternut, blue hubbard + waltham butternut + insecticide, blue hubbard + waltham butternut + vacuum) we calculated the ratio: number of striped cucumber beetles on blue hubbard to the number of striped cucumber beetles on blue hubbard + waltham butternut for two time periods of seven consecutive samples. Sample dates prior to July 2 were excluded because less than 10 beetles were collected per plot. Ratios were normalized using a base 10 Logarithm transformation. A T test was used to compare differences between the two time periods. All data were analyzed using the R statistical language (R Development Core Team 2008).

2009 Field Experiment: In the 2009 experiment we shifted our focus to assess the efficacy of mixing two trap crop varieties compared to a single variety or cucumber alone. The winter squash varieties and the cucumber cultivar used were the same as in the 2007 experiment, and the agronomic details of the experiment identical to the 2007 experiment. The experimental design was a full factorial randomized complete block consisting of four blocks of one treatment factor with four levels. Treatment one alternated three blue hubbard with three waltham butternut squash repeated four times to form a row of 24 plants. Treatment two was composed of 24 blue hubbards, treatment three of 24 waltham butternuts and treatment four of 24 cucumbers. Each treatment was repeated four times, yielding a total of four blocks.

The cucumbers were planted on June 5th but a heavy rain flooded the fields, thus, we reseeded the field on June 24th, 2009. The trap crops were transplanted on June 11th, 2009. We counted the number of beetles present on flowers and leaves, stems and fruits of trap crops, the number of beetles on the two rows of cucumber closest of the treatments twice weekly and assessed the mortality of the trap crops. At the end of the season, we harvested the cucumbers within each plot and classified them as saleable or not saleable by visually assessing the number of scars and by measuring cucumber weight.

The number of beetles on the flowers, leaves, stems and fruits of trap crops trap crops and on the rows surrounding the treatments across the field season was summed and normalized using a base 10 Logarithm transformation and analyzed using a four by four (block, treatment) ANOVA and post hoc Tukey's honest significant difference multiple comparison procedure. Percentage trap crop mortality data was transformed using the arcsine transformation to normalize the data and analyzed using a four by four (treatment, block) ANOVA. The number and weight of saleable cucumbers and non-saleable cucumbers were normalized using a base 10 Logarithm transformation and analyzed using a four by four (block, treatment) ANOVA.

We calculated the ratio of the number of striped cucumber beetles on blue hubbard to the number of striped cucumber beetles on blue hubbard + waltham butternut for two time periods consisting of eight consecutive sampling dates in the waltham butternut + blue hubbard treatment. Sample dates prior to July 2 were excluded because fewer than 10 beetles per treatment were collected. A T test was used to compare differences between the two time periods. All data were analyzed using the R statistical language (R Development Core Team 2008, Team 2009).

Results

2007 Field experiment: We did not observe a difference in the number of striped cucumber beetles found on the trap crops among the four treatments ($F = 1.34$; $df = 3, 9$; $P = 0.32$) with 394, 456, 502, 492 beetles observed on blue hubbard, blue hubbard + waltham butternut, blue hubbard + waltham butternut + vacuum and blue hubbard + waltham butternut + insecticide, respectively (Fig. 3.1). Similarly, we did not observe differences in the number of beetles counted in the cucumber rows surrounding the treatments ($F = 0.503$; $df = 3, 9$; $P = 0.689$), nor in plant mortality among treatments ($F = 0.909$; $df = 3, 9$; $P = 0.47$). The ratio of striped cucumber beetles on blue hubbard to blue hubbard + waltham butternut among the two time periods assessed in 2007 was significant ($F = 24.31$; $df = 17, 1$; $P < 0.001$) with 0.84 (±0.006) and 0.66 (±0.036) observed for the first and second time period, respectively (Fig. 3.5). No difference was observed in the ratio of striped cucumber beetles on blue hubbard to blue hubbard + waltham butternut among treatments ($F = 0.027$; $df = 17, 2$; $P = 0.204$).

2009 experiment: In 2009 we found a significant difference in the total number of beetles observed on trap crops among the four treatments ($F = 28.49$; $df = 3, 9$; $P < 0.001$) (Fig. 3.2) with 1051, 743, 503, 246 beetles observed on blue hubbard, blue hubbard + waltham butternut, waltham butternut and cucumber, respectively. Significantly more beetles were observed on the blue hubbard, waltham butternut, and combined trap crop treatments compared to the cucumber alone treatment and more beetles were observed on the blue hubbard compared to the Waltham butternut treatment (Fig. 3.1).

We also found a significant difference in the total number of beetles observed among the four treatments on the leaves, stems and fruits ($F = 4.257$; $df = 3, 9$; $P = 0.039$) (Fig. 3.1) with 162, 120, 91, 207 beetles observed on blue hubbard, blue hubbard + waltham butternut, waltham butternut and cucumber, respectively. Significantly more beetles were counted on the leaves, stems and fruits of the cucumber alone treatment vs. waltham butternut alone treatment.

Furthermore we observed a significant difference in the total number of beetles found on flowers among treatments ($F = 31.45$; $df = 3, 8$; $P < 0.001$) (Fig. 3.1) with 890, 622, 412, and 33 beetles observed on blue hubbard, blue hubbard plus waltham butternut, Waltham butternut and cucumber, respectively. Significantly more beetles were observed on flowers in the blue hubbard alone treatment vs. the cucumber alone treatment and the waltham butternut alone treatment, and significantly more beetles were observed on the blue hubbard plus waltham butternut treatment vs. to the cucumber alone treatment (Fig.3.1). As in the 2007 experiment, we did not observe difference in the number of beetles counted in the cucumber rows surrounding the treatments (F = 0.93; df = 3, 9; P = 0.465).

We did observe a difference in the mortality of trap crops between treatments at the end of the experiment (F = 25.96; df = 3, 9; P < 0.001), we also analyzed the mortality on July 17, 2009 corresponding to the maturity of cucumbers and did not observe difference among treatments (F = 2.47; df = 3, 9; P = 0.13) (Fig. 3.3).

We harvested the squash at the end of the experiment and obtained 201 kg, 114 kg and 102 kg of squash for the treatments Waltham butternut, blue hubbard, blue hubbard + waltham butternut, respectively. For the treatment blue hubbard + waltham butternut we harvested 51 kg for each variety.

No differences were found among the number of saleable cucumbers (F = 0.58; df = 3, 9; P = 0.64) and non-saleable cucumbers per treatment (F = 2.03; df = 3, 9; P = 0.179). Additionally, we did not observe a difference in the total weight of saleable cucumbers among the treatments (F = 0.1180; df = 3, 9; P = 0.947), nor in the non-saleable cucumbers (F = 2.597; df = 3, 9; P = 0.125).

The ratio of striped cucumber beetles on waltham butternut to the number striped cucumber beetles found on blue hubbard for the treatment waltham butternut + blue hubbard varied among the two time periods assessed in 2009 was significant (t= 6.32, df= 3, P= 0.008) (Fig. 3.6).

Discussion

Although neither experiment showed a difference in the number of striped cucumber beetles found in the 'blue hubbard alone' compared to the 'blue hubbard mixed with waltham butternut' treatments mixing the two trap crops may provide a benefit compared with the use of either variety alone by providing an alternative saleable crop, reducing the cost associated with establishing a perimenter trap crop and/or by extending the useful life of the perimeter trap crop (Fig. 3.1). In the 2009 experiment, the 'waltham butternut alone' treatment attracted significantly less beetles than 'blue hubbard plus waltham butternut' or 'blue hubbard alone' treatments (Fig. 3.1). This confirmed the higher attractiveness of the blue hubbard compared to the waltham butternut squash (Willot et al.2010, Bellows and Diver 2002, Caldwell and Stockton 1998).

An advantage of mixing blue hubbard with waltham butternut is that butternut provides an alternative crop, thus reducing the cost of perimeter trap cropping. Butternut is a more easily marketable squash compared to blue hubbard, which produces very large squash that are difficult to sell (Zandstra et al. 1986, Whalen et al. 2000) Furthermore, even when beetles feed on the trap crops, the squash fruits are not frequently attacked (Willot 2010) (Fig. 3.1). In 2009, we obtained 51 kg of marketable waltham butternut squash, without any input, from 'blue hubbard + waltham butternut' from a total of 48 butternut plants.

Another potential advantage of mixing the two trap crop varieties is that the addition of a lesser attractive trap crop may extend the useful life of the trap crop rows due to differences in the temporal pattern of mortality and/or flowering period between the two varieties. In both experiments the blue hubbard variety was the most attractive but we observed a movement of the beetles from the blue hubbard to the waltham butternut later in the season (Fig. 3.5 and 3.6). In the 2009 experiment, there was a substantial variation observed between June 15 and beginning of July due to the absence of flowers and a low number of beetles observed during this time (Fig. 3.6). One explanation for why we did not observe the same phenomenon in the beginning of the 2007 experiment is that the beetles arrived when both trap crops were already blooming. In 2009, we observed a movement of beetles from the blue hubbard to the waltham butternut between the two time periods (Fig 3.6). In 2007, we observed the same phenomenon between the two time periods (Fig. 3.5). Two hypotheses to explain the movements of the beetles are: either there is a difference of mortality between the blue hubbard and waltham butternut (Fig. 3.2), or the flowering period of these two varieties are temporally divergent (Fig. 3.6).

The fact that none of the plants in the 'waltham butternut alone' treatment died during the 2009 experiment and only one out of 48 waltham butternut plants died in the waltham butternut + blue hubbard treatment while 20% of blue hubbard plants died and 26% of plants died in the blue hubbard alone treatment supports the first hypotheses (Fig. 3.2). The observed numerical difference in mortality might be explained by the blue hubbard's higher attractiveness and susceptibility to bacterial wilt (Yao et al. 1996). We noticed higher mortality of plants in the 'cucumber alone' treatment, with an average rate of 67% (Fig. 3.2). However, this result is a bit deceptive as the cucumber cultivar 'cobra' reaches maturity after 60d and by the end of the experiment the cucumbers were 97d old. In contrast, blue hubbard squash reach maturity at 95d and the waltham butternut at 105d. When cucumber mortality was measured on July 17' 2009, their point of maturity, the average mortality was only of 6% and no significant differences were observable among treatments (Fig. 3.2).

Another explanation for the movement of the beetles to the waltham butternut from the blue hubbard is the slightly longer cycle of butternut. Waltham butternut start flowering later and therefore attract beetles later (Fig. 3.6). The tangle of the plants could also play a role. Squash plants totally cover the ground and form an edge at the end of the season. So bigger the plants grow and harder it must be for the beetles to distinct between the two varieties, particularly because the two varieties are sustainable hosts.

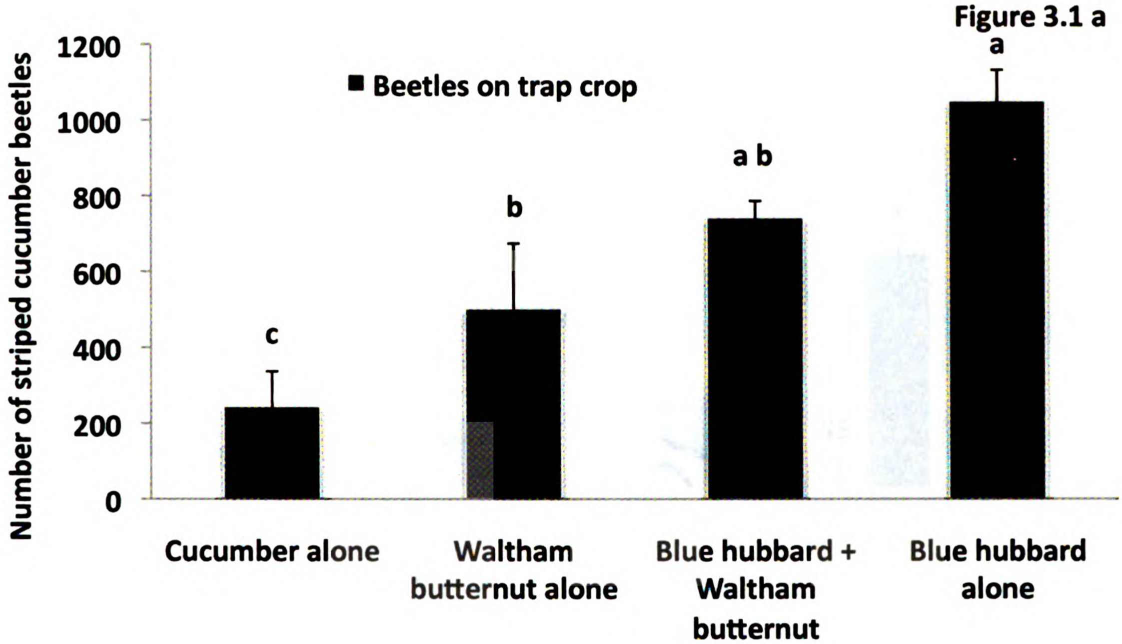
Our data suggest that it is very important to ensure a floral resource to manage striped cucumber beetles. The presence of flowers has been shown to have a large impact on the attractiveness of the trap crops to the striped cucumber beetle (Willot 2010, Ferrari et al 2006, Lewis et al 1990, Andersen and Metcalf 1986). Greater than 75% of the beetles observed in the 'blue hubbard alone', 'waltham butternut alone', and 'blue hubbard plus waltham butternut' treatments were found on the flowers. In contrast, in the 'cucumber alone' treatment, only 15% of the beetles were found on the flowers (Fig. 3.1). This may be explained by the very small size of cucumber flowers compared to the winter squash flowers. Figure 3.4 shows the movement of the beetles from the leaves and stems to the flowers when flowers started to appear in the field.

No detectable pest management benefit was observed when we combined Pyganic® or vacuum applications with the trap crops. This failure might be explained by a low population of striped cucumber beetles. To illustrate, in 2007, we began to observe beetles in the field around the June 25th, while in 2009 we had already recorded a substantial number of beetles by June 15th. There are three other possible explanations for these findings: limited effect of vacuum application, effect of the Pyganic® on the entire experimental plot and not only in the treated areas, or a failure of the insecticide to kill striped cucumber beetles. Vacuum applications were likely not effective at removing sufficient numbers of beetles relative the entire plot. Furthermore, beetles were primarily observed in the flowers where the vacuum was unable to capture them. Pyganic® applications may have reduced the number of beetles in every treatment, not only those where the insecticide was applied. Figure 3.3 shows that after each insecticide application there is a decrease of the beetle population in all treatments. This is likely due to the high mobility of the cucumber beetles and their tendency to change plants regularly (Dudley and Searles 1923, Radin and Drummond 1994a, b), pyrethrum repellency could also affect the movements of beetles (Kamminga et al. 2009).

In conclusion our study demonstrates that trap crop mixtures of blue hubbard and waltham butternut have the potential to provide increased protection of cucumber. This effect is likely due to either the lower mortality of waltham butternut as well as its later flowering period. Furthermore, a trap crop mixture including waltham butternut might financially benefit farmers by providing an alternative salable crop. An interesting future study would be to combine waltham butternut with another very attractive variety, such as burgess buttercup, that also has good marketability, to see if a similar complementary effect is observed.

Acknowledgment: Thanks to Bill Chase and all the worker of the horticulture farm for their help, the several undergraduate students that assisted me, particularly Jonathan

Landis and Aristarque Djoko. Thanks to Mathieu Ngouajio for his help and advices to prepare this work and Ed grafius for his comments.



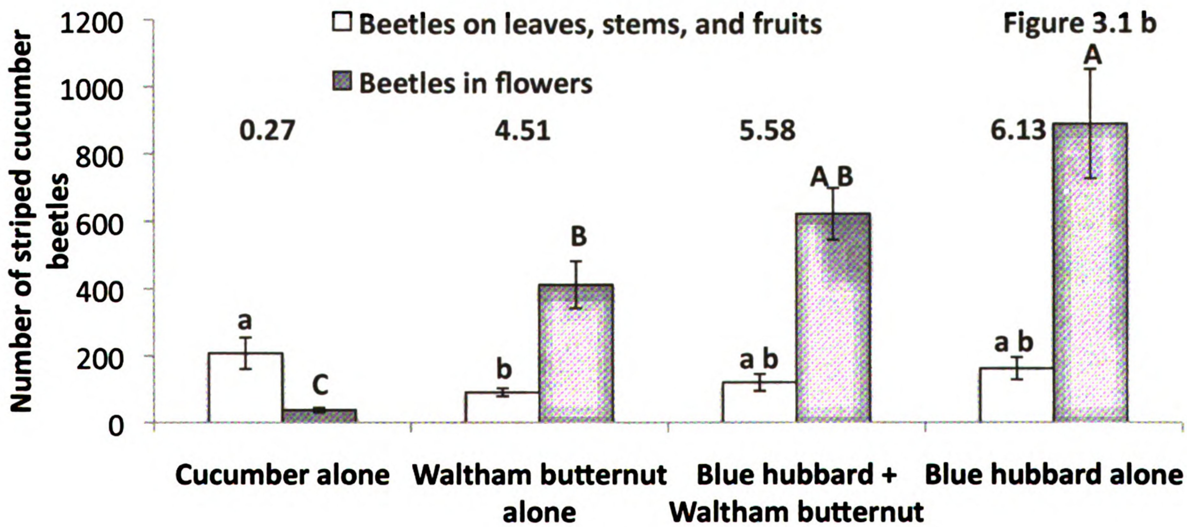


Figure 3.1: Average number of striped cucumber beetles (±SEM) observed on trap crops across all observation dates for the 2009 experiment. a) On flowers. b) On flowers and leaves, stems and fruits. Numbers above bars represent the ratio of beetles on flowers to leaves and stems. Bars with different letters are significantly different (Tukey's honest significant difference alpha=0.05).

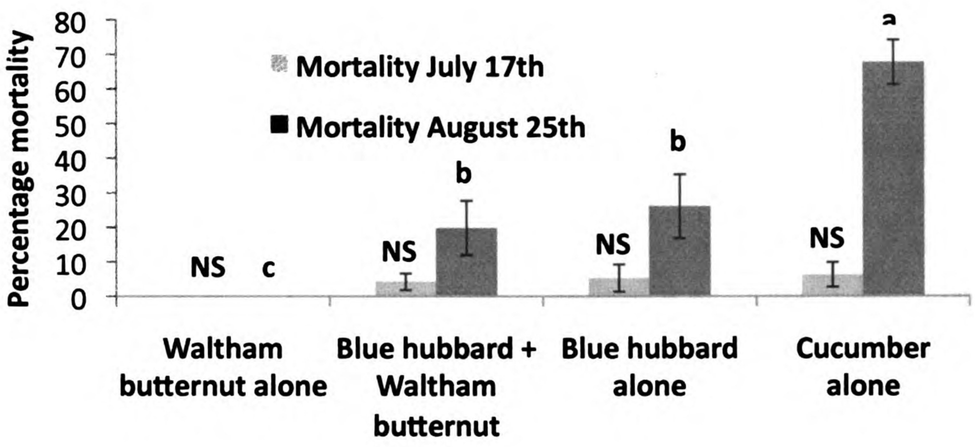


Figure 3.2: Average percentage plant mortality (±SEM) on July 17^{th} and August 25^{th}. Bars with different letters are significantly different (Tukey's honest significant difference alpha=0.05).

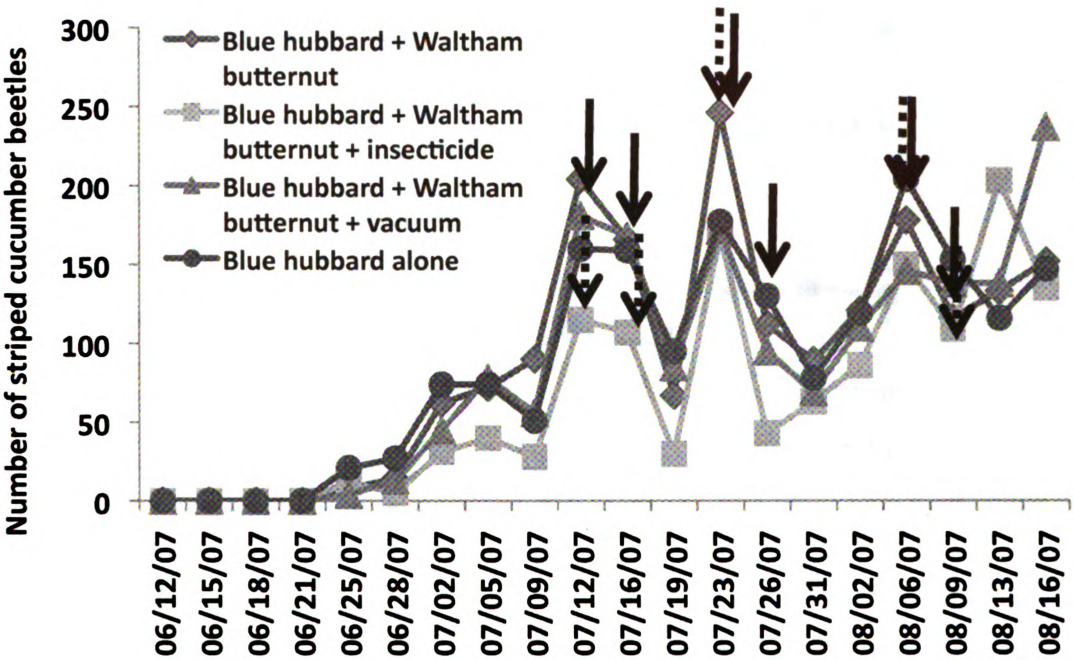


Figure 3.3: Average number of striped cucumber beetles by treatment at each sample date for the 2007 experiment. The black and dotted arrows indicate dates of vacuum and Pyganic® applications, respectively.

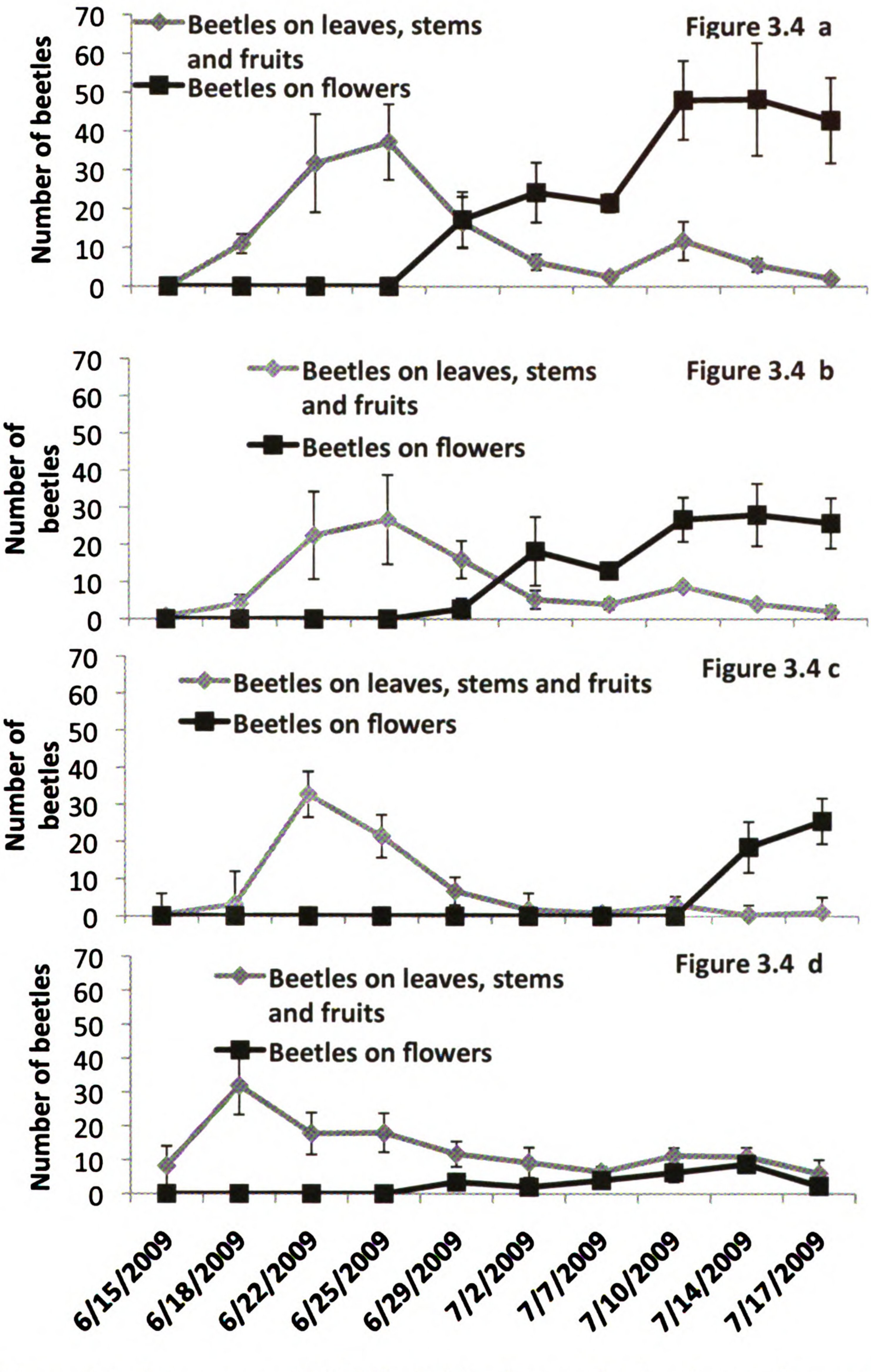


Figure 3.4: Average sum (±SEM) of striped cucumber beetles on flowers or leaves stems and fruits for each sample date between June 15 and July 17 for the 2009 experiment. a) blue hubbard alone, b) blue hubbard + waltham butternut, c) waltham butternut alone, d) cucumber alone.

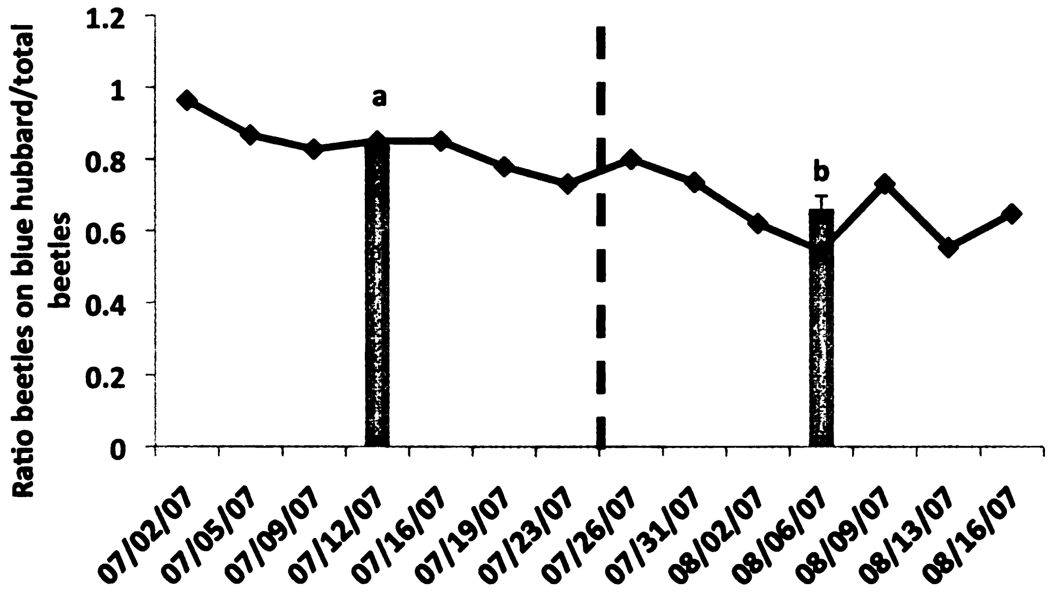


Figure 3.5: Ratio of striped cucumber beetles found on blue hubbard to total beetles found in the blue hubbard + waltham butternut, blue hubbard + waltham butternut + vacuum, and blue hubbard + waltham butternut + Pyganic® treatments in the 2007 experiment. Bars provide the ratio over seven sampling periods. Bars with different letters are significantly different (T test alpha = 0.05).

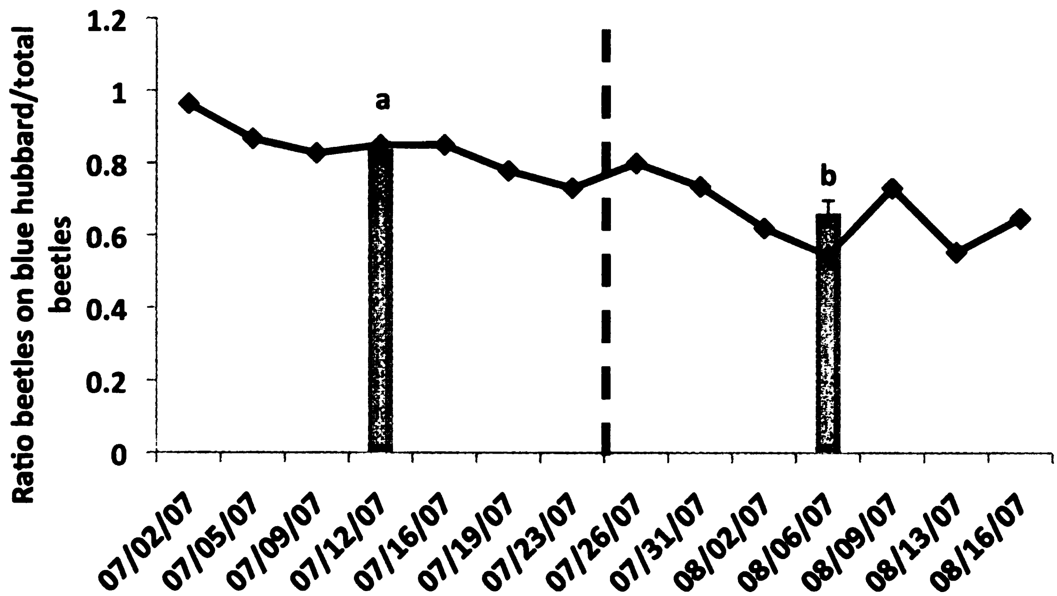


Figure 3.5: Ratio of striped cucumber beetles found on blue hubbard to total beetles found in the blue hubbard + waltham butternut, blue hubbard + waltham butternut + vacuum, and blue hubbard + waltham butternut + Pyganic® treatments in the 2007 experiment. Bars provide the ratio over seven sampling periods. Bars with different letters are significantly different (T test alpha = 0.05).

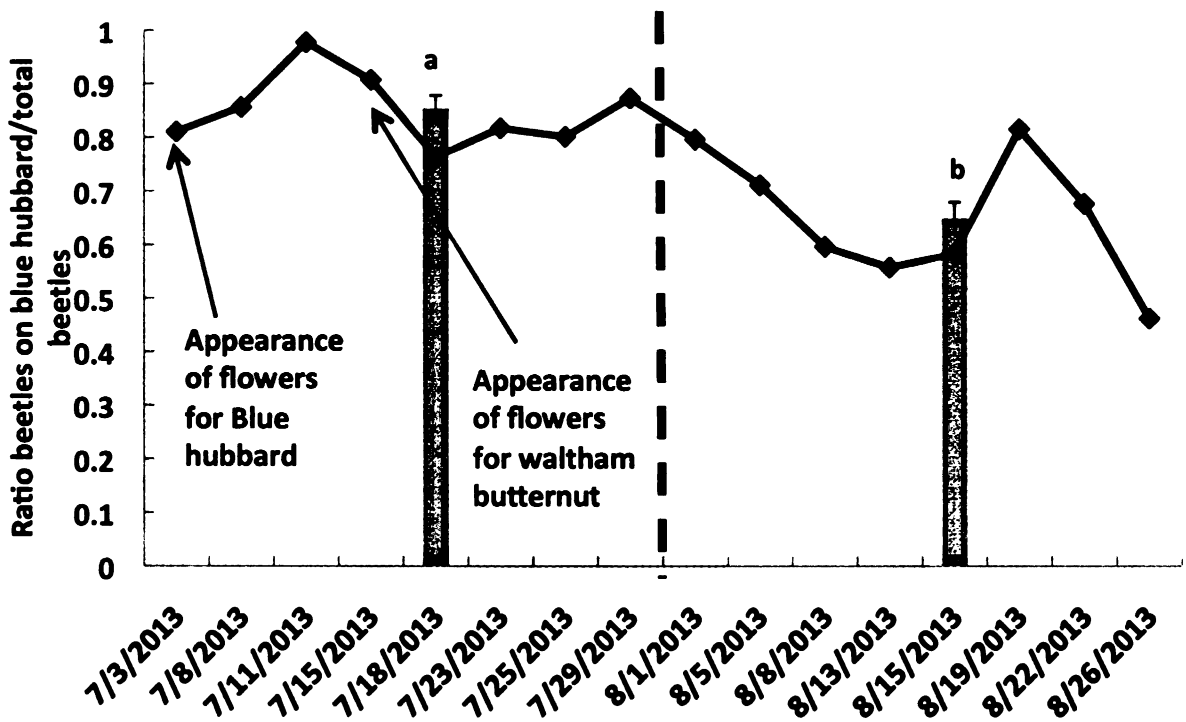


Figure 3.6 Ratio of striped cucumber beetles found on blue hubbard to total striped cucumber beetles observed in the blue hubbard + waltham butternut plots in the 2009 experiment. Bars provide the ratio over eight sampling periods. Bars with different letters are significantly different (T Test alpha = 0.05).

CHAPTER 4

Perimeter Trap Crops for Striped Cucumber Beetles: Conclusions and Future Research

Synthesis

The application of Integrated Pest Management (IPM) is essential to successful and profitable cucumber production in the Northeastern US (Cavanagh 2008, Cavanagh et al. 2009). This is especially true for organic farmers who have limited pest management options, two of which are row covers and perimeter trap cropping. Row covers ensure protection of plants until blooming thus limiting the need for insecticides. However, at the start of the flowering stage, row covers must be removed to allow for pollination, requiring careful monitoring of pests thereafter. Trap cropping is another important management method for farmers, leading to a substantial reduction of insecticides use (Cavanagh et al. 2009). The usual variety of trap crop employed is blue hubbard which can be difficult for farmers to find, particularly if they require certified organic seed. Thus, farmers need alternative squash varieties that are as efficient as blue hubbard yet readily available in certified organic seed.

My results showed that burgess buttercup is as efficient as blue hubbard in attracting striped cucumber beetles in cucumber production (Fig. 2.1, 2.2 and 2.3) and therefore is a viable alternative. Burgess buttercup is also more marketable than blue hubbard (Whalen et al. 2000, Cavanagh 2008). This is a potential advantage for farmers because trap crop squash fruits are not commonly attacked by striped cucumber beetles. The observation of the position of the beetles on plant showed that flowers are the most attractive part of the trap crop with approximately 80%, 19.6%, and 0.4% of the total beetles observed on flowers, leaves and stems, and fruit, respectively. Furthermore, because fruits are the least attractive part of the plants, they might be harvest regularly without decreasing the efficacy of trap crops.

Trap crops alone typically do not provide sufficient damage control when cucumber beetles occur in large numbers (Brewer et al. 2006). In conventional agriculture, trap crops are usually assisted by insecticide to reduce the pest pressure (Radin and Drummond 1994b, Boucher and Durgy 2004, Adler and Hazzard 2009, Cavanagh et al. 2009). However, in organic agriculture, insecticide options are limited, expensive, and less efficient. Thus, alternative methods that increase the efficiency of trap crops are needed. My results showed that mixing blue hubbard with waltham butternut as trap crops may provide a benefit compared with the use of either variety alone. Neither experiment in chapter 3 showed a difference in the number of striped cucumber beetles found in the 'blue hubbard alone' compared to the 'blue hubbard mixed with waltham butternut' treatments (Fig.3.1). Like burgess buttercup, waltham butternut provides an alternative crop, thus reducing the cost of perimeter trap cropping (Zandstra et al. 1986, Whalen et al. 2000). Waltham butternut has a slightly longer cycle than blue hubbard, and therefore, begins flowering later (Fig.3.6). This leads to a longer flowering period when blue hubbard and waltham butternut are mixed together compared to each cultivar alone.

The results show the importance of the presence of flower in the attractiveness of trap crops (Fig 2.2; 2.3; 2.4; 3.1and 3.6). The majority of the beetles were found on the flowers of the winter squash. The highest ratio beetles on flower to beetles on leaves and stems were found on the most attractive varieties, such as blue hubbard and burgess buttercup (Fig 2.2; 2.3 and 3.1). Figure 1.4 shows that the number of beetles on burgess buttercup increased when the flowers appeared. When flowers were not present, the number of beetles found on the attractive trap crops was only slightly higher than found on the cucumbers. This suggests that management of the trap crop flowering period is crucial to ensure adequate protection of cucumbers. Cucumbers have a short cycle, arriving at maturity after only 60 d. In comparison, squash have a life cycle of 90-110 d. Thus, it is important to use trap crop transplants that are old enough to guarantee a protection of the cucumber in their most sensitive stages.

In the experiment presented in chapter three testing the potential benefit to use vacuum and Pyganic® insecticide we did not observe a significant difference between treatments. This might be due to the experimental design or the limited residual activity of the insecticide. The vacuum utilized did not prove effective at removing beetles within flowers.

Future research

Flowering period management appears to be critical in ensuring the efficiency of perimeter trap cropping systems. Additional research needs to be conducted on the affect of using different ages of transplants of the same variety compared to a mixture of varieties. It would also be interesting to assess the impact of harvesting the squash fruits from the trap crops on the number of flowers and the attractiveness of trap crops. Another potential area of study would be using a combination of row covers and trap crops in organic farming to assess the benefits provided by the two tactics relative to their costs.

My experiment on the potential of using Pyganic® with trap crops was largely inconclusive. Data are needed on the efficiency of organic insecticides for striped cucumber beetles. This will help to optimize the use of trap crops with organically approved insecticides. Furthermore, some organic pesticides are known to have a deterrent effect. Using these could be beneficial if applied as part of a Push and Pull strategy (Durmusoglu et al. 2003, Riba et al. 2003, Green et al. 2004, Cook et al. 2007, Gomez Jimenez and Poveda 2009). On the other hand, repellant insecticides might be incompatible with perimeter trap crops if they lead to the movement of the pest into the cash crop.

Finally, much work remains to be done on striped cucumber beetle foraging and host selection behavior. Striped cucumber beetles appear to be very attracted to flowers but they are also easily attracted by yellow sticky traps. A better understanding of the relative importance of visual olfactory cues could lead to improved of pest management and offer new solution for pest control. This could help to develop more efficient traps to control striped cucumber beetles and improved trap crops management.

Appendix 1.1

Record of Deposition of Voucher Specimens*

The specimens listed on the following sheet(s) have been deposited in the named museum(s) as samples of those species or other taxa, which were used in this research. Voucher recognition labels bearing the Voucher No. have been attached or included in fluid-preserved specimens.

Voucher No.: 2010-02

Title of thesis or dissertation (or other research projects):

PROTECTION OF ORGANIC CUCUMBER PRODUCTION AGAINST STRIPED CUCUMBER BEETLES USING TRAP CROPS

Museum(s) where deposited and abbreviations for table on following sheets:

Entomology Museum, Michigan State University (MSU)

Other Museums:

Investigator's Name(s)

Vianney Willot

Date June 10 2010

*Reference: Yoshimoto, C. M. 1978. Voucher Specimens for Entomology in North America.

Bull. Entomol. Soc. Amer. 24: 141-42.

Deposit as follows:

Original: Include as Appendix 1 in ribbon copy of thesis or dissertation.

Copies: Include as Appendix 1 in copies of thesis or dissertation.

Museum(s) files.

Research project files.

This form is available from and the Voucher No. is assigned by the Curator, Michigan State University Entomology Museum.

Appendix 1.1

Voucher Specimen Data

Page___of___Pages

Species or other taxon	Label data for specimens collected or used and deposited	Number of: Eggs	Larvae	Nymphs	Pupae	Adults ♀	Adults ♂	Other	Museum where deposited
Acalymma vittatum	MI: Ingham co. Horticulture Farm MSU College road 18vi2009							20	MSU

(Use additional sheets if necessary)

Investigator's Name(s) (typed)

Vianney Willot

Date June 10 2010

Voucher No. 2010-02

Received the above listed specimens for deposit in the Michigan State University Entomology Museum.

Curator Date 6/23/2010

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