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CUCUMBER BEETLE IN CUCUMERS**

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**EVALUATING ORGANIC-COMPLIANT MANAGEMENT STRATEGIES  
FOR STRIPED CUCUMBER BEETLE IN CUCUMBERS**

By

Matthew E. Kaiser

**A THESIS**

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## **ABSTRACT**

### **EVALUATING ORGANIC-COMPLIANT MANAGEMENT STRATEGIES FOR STRIPED CUCUMBER BEETLE IN CUCUMBERS**

By

Matthew E. Kaiser

The use of a squash trap crop, row covers and a polyculture of cucumbers and tomatoes for managing striped cucumber beetle, *Acalymma vittatum* Fabricius (Coleoptera: Chrysomelidae), was studied in mid-Michigan in 2006 and 2007. The trap crop had a greater effect in reducing beetle presence and injury to cucumber than a cucumber monoculture early in the season, but the benefits were reduced later in the season. Early in the season, striped cucumber beetles reached densities up to three times greater in the cucumber monoculture than in cucumber with a trap crop, and up to six times more beetles on the trap crop than on the cucumbers. The polyculture of cucumber and tomato added to the trap crop treatment provided little to no additional protection. Row covers provided complete striped cucumber beetle exclusion until they were removed to allow for pollination. Other factors tested included distance from the trap crop, and the potential for foliar applications of the biological attractant, cucurbitacin, to enhance the trap crop effect. While there was early season protection of cucumber with these organic-compliant and non-insecticidal management methods, late season protection did not occur, greatly reducing marketable yield due to fruit scarring and reduced fruit production. This study supports the use of trap crops and, when economical, row covers for early season protection of cucumbers from striped cucumber beetle and discusses potential methods for extending protection later in the growing season.

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## **Key Words**

trap crop

polyculture

biological attractants

IPM

organic

row covers

**CHAPTER ONE:**

**GENERAL INTRODUCTION**

## Overview of Cucumber Production

Michigan is one of the leading states in cucumber, *Cucumis sativus* L., production (Swiader and Ware 2002) with 759,000 Cwt of cucumbers produced statewide in 2008 (Agricultural Statistics Board 2009). Cucumber, along with other vine crops, is a member of the Cucurbitaceae plant family, which consists of some 96-120 genera and over 800 species (Decker 1988, Swiader and Ware 2002, Teppner 2004, Jeffrey 2008). Of those genera, there are three of commercial importance in the United States: *Cucumis* (cucumbers and muskmelon), *Citrullus* (watermelon), and *Cucurbita* (pumpkins and squash). There are 40 species in the *Cucumis* genus, many of which are grown commercially. Cucumber is both a leading commercial crop and a popular home garden vegetable in the United States (Meglic et al. 1996, Swiader and Ware 2002). Immature cucumber fruits are harvested and sold fresh or processed into pickles, relishes and other condiments.

Cucumbers are believed to be native to India, although there is evidence of their cultivation in western Asia for over 3,000 years (Whitaker and Davis 1962, Meglic et al. 1996, Meglic and Stuab 1996, Swiader and Ware 2002). There is also some evidence that wild cucumbers were used by humans in Thailand around 9750 B.C., some 2000 years before true agriculture began in either the Near East or Central America (Meglic et al. 1996, Meglic and Stuab 1996). From India, the cucumber is thought to have spread to Western Asia, Greece and Italy before reaching China (Meglic et al. 1996, Meglic and Stuab 1996, Swiader and Ware 2002). Cucumbers were most likely spread to the rest of Europe by the Romans. Historical records show the presence of cucumber cultivation in France in the 9th century, in England during the 14th century and in North America as

early as the mid-16th century (Meglic and Stuab 1996, Swiader and Ware 2002). Among the first to cultivate cucumbers in the Americas were New England colonists and the Iroquois Indians (Meglic and Stuab 1996).

Cucumber is an annual warm season crop and young plants can be easily injured by frost. The plants grow along the ground or up trellises in a vining structure. The main stem branches into several trailing laterals exhibiting determinate, indeterminate, or compact growth depending on the cultivar. Cucumbers grow best in warm, rich and limey soils but can grow well in any well-drained fertile soil (Coleman 1995, Swiader and Ware 2002, Lijuan et al. 2008). Proper fertilization increases yield and reduces pest problems with sheep, horse and dairy compost being favored soil amendments (Coleman 1995).

Cucumbers are either directly seeded or transplanted into the field. Transplants are typically sown in a greenhouse in 5 cm (2") plug trays with 3 seeds planted per cell between 4 and 5 wk after the years first frost free date to avoid frost damage to the plants (Swiader and Ware 2002). Cucumber production is divided almost equally into two major groups. "Slicer cucumbers" varieties are usually fresh-marketed. "Pickling cucumbers" are produced primarily for processing into pickles, relishes and other condiments, usually by cooking in a solution of various seasonings and preservatives such as salt and vinegar before canning and preserving. Direct-seeded cucumber crops are typically planted in rows with in-row spacing around 5-13 cm (2"-5") for pickling varieties and 46 cm (18") for slicer cucumbers with a distance between 1.5 m and 1.8 m (5-6 ft.) between rows. Plastic mulches are commonly used to reduce weed populations and row covers are sometimes used to provide protection from insect pests, particularly in smaller scale operations. Both plastic mulches and row covers also increase the temperature at which

the cucumber plants are grown by retaining more heat and thus accelerating plant growth (Motsenbocker and Bonanno 1989, Wolfe et al. 1989, Ibarra et al. 2001).

Most cucumber varieties are monoecious, with separate male and female flowers on the same plant, while some varieties are gynoeceous, containing almost exclusively female blossoms (Nandgaonkar and Baker 1981, Swiader and Ware 2002). Most cucumber varieties require insect pollination, so row covers, if used, must be removed once the vines begin to flower. Poor pollination leads to fruit abortion, misshapen fruit, poor fruit sets and decreased yield (Swiader and Ware 2002). Slicing cucumbers are typically hand harvested five to ten times during the season once the first fruit have grown to a marketable size. Most pickling cucumbers are machine harvested when about half of them have reached the appropriate size.

## **Description of Striped Cucumber Beetle Biology and Damage**

The striped cucumber beetle, *Acalymma vittatum* Fabricius (Coleoptera: Chrysomelidae), is a major pest of cucumbers, and a top concern of cucumber growers in the United States. These beetles have been a threat worthy of investigation by the Department of Agriculture since 1915 (Chittenden 1923). They overwinter as adults, emerging early in the growing season when temperatures exceed 10° C. They seek out and immediately begin to feed on cucumbers in the plant's early growth stages when the risk of plant death from feeding damage is highest (Pitblado and Lucy 1994). Beetles may enter fields before the cucumber plants emerge and crawl into soil crevices to damage the seedlings. Striped cucumber beetles damage cucumber plants by feeding on cotyledons, shoots, stems and leaves. Later in the season they also feed on cucumber blossoms and fruit. Damage reduces both yield in the form of biomass production and fruit marketability (Capinera 2001). Feeding on young plants leads to stand reduction and delays in growth of surviving plants, both leading to reduced biomass production. Fruit scarring affects fruit size and marketability. Striped cucumber beetle adults also transmit diseases such as bacterial wilt and cucumber mosaic virus. In addition, adults lay eggs in the soil around the bases of cucumber plants. After hatching, larvae burrow through the soil to feed on cucumber roots and stems, although this damage is rarely as severe as that caused by the adults (Brewer et al. 1987).

Adult striped cucumber beetles measure approximately 0.5 cm long and 0.2 cm wide. They have black heads and abdomens as well as striped black and yellow wing covers. The legs are mostly yellow and the antennae, tarsi and tibia are black (Foster et al. 2005). Larvae are creamy white in color with darkened areas at the head and posterior

tip of the abdomen (Bellinder 1994). It is important to distinguish striped cucumber beetles from the western corn rootworms, *Diabrotica virgifera* LeConte (Coleoptera: Chrysomelidae), which also occasionally feeds on cucurbits. Western corn rootworms have a similar appearance, but their central black stripe does not extend all the way to the tip of the abdomen and their abdomens are yellow instead of black (Foster et al. 2005). Despite the similarity to the striped cucumber beetle, western corn rootworms are less damaging to cucurbits. The adults are only present in the field in the mid to late summer, they do not transmit cucurbit diseases, and their larvae can only develop on the roots of corn, *Zea mays* L. (Foster et al. 2005).

Striped cucumber beetles are native to the United States, inhabiting all regions east of the Rocky Mountains from southern Canada to Mexico (Chittenden 1923, Capinera 2001). Cucurbits are the only known food source for striped cucumber beetle larvae, but the adults occasionally attack other crops, including peas (*Pisum sativum* L.), apples (*Malus domestica* Borkh) and corn (*Z. mays* L.). Adults also feed on goldenrod (*Solidago* sp. L.), aster (*Aster* sp. Shirokujaku), sunflower (*Helianthus annuus* L.), great ragweed (*Ambrosia* sp. L.), chokeberry (*Aronia melanocarpa* Elliot), Juneberry (*Amelanchier alnifolia* Nutt), cherry (*Prunus* sp. L.) and related plants, feeding primarily on flowers and fruits (Chittenden 1923, Flint 1990, Capinera 2001).

In the northern United States, the striped cucumber beetle is univoltine due to the climate (Chittenden 1923, Davidson & Lyon 1979, Lewis 1992, Capinera 2001). Females lay between 400 and 500 eggs on average, with up to 1,457 eggs/female recorded. Eggs are laid in the soil around the base of cucurbits and usually hatch within 1 – 2 wks depending on temperature. The larvae burrow through the soil to feed on roots,

occasionally also feeding on the stems and fruit where they come into contact with the earth. The larval stage lasts 2 – 6 wk before the beetle enters the pre-pupa stage, lasting 2 – 5 d. The pupa lasts from 5 – 8 d in warmer weather or up to 2 wk in colder temperatures. The new generation of adults emerges as early as the first week in July, with continued emergence staggered over the next few weeks (Chittenden 1923, Capinera 2001, Ellers-Kirk and Fleisher 2006). The previous generation of beetles usually lives through the end of July, so there is overlap between the two generations of adults (Chittenden 1923). They may be multivoltine in the southern states, with as many as four generations per year recorded in Texas (Chittenden 1923, Godfrey 1999).

## **Conventional Production Solutions**

In conventional cucumber production, striped cucumber beetle control often involves using systemic insecticides such as carbofuran (Furadan 4F®), imidacloprid (Admire Pro®, Nuprid®), or thiamethoxam (Platinum®) at planting and/or spraying foliar insecticides as soon as beetles are detected (Foster et al. 2005, Bird et al. 2008). Insecticides registered as foliar sprays to control striped cucumber beetle in conventional production include several formulations of carbaryl, Asana, Baythroid, bifenthrin (Bifenture, Brigade, Capture), endosulfan, Lannate, permethrin (Ambush, Perm-UP, Pounce), or Warrior (Foster et al. 2005, Bird et al. 2008). In areas where striped cucumber beetles transmit bacterial wilt, the economic threshold for spraying is less than one beetle per plant (Foster et al. 2005), which means growers generally spray as soon as striped cucumber beetles are detected and at regular intervals afterwards, usually without continuing to monitor beetle numbers. Some growers may simply spray their cucumber crop regularly to avoid monitoring carefully for the first appearance of striped cucumber beetles in their fields. Conventional growers try to avoid adverse effects on pollination by selecting insecticides with limited toxicity to honey bees and other pollinators (Johansen 1977, Lewis 1992). Some insecticides in conventional use combine insecticide with cucurbitacins as a feeding stimulant to increase efficiency and selectivity, while requiring a smaller amount of the active ingredient (commonly carbaryl [Sevin<sup>TM</sup>]). (Brust and Foster 1995, Cranshaw 1998, Foster et al. 2005). These products are not approved for organic use.

## **Organic Production Solutions and Challenges**

Organic cucumber production has more restrictions on chemical inputs than conventional production in order to meet organic labeling requirements. Since the varieties and amounts of chemical inputs are limited in organic systems, control of pest insects often requires more detailed knowledge of the biology of both host plant and insect pest. In addition, the market price for organic cucumbers is not significantly higher than the price for conventionally produced cucumbers. Thus organic control methods cannot cost much more than conventional control methods for organic cucumber production to be commercially and economically viable (Heissenhiber and Ring 1992, Estes et al. 1999, Miles and Peet 2000). Current organic approaches for managing cucumber beetles focus on population monitoring, cultural practices, trapping, natural enemies and organically approved insecticides and protectants.

Population monitoring determines when overwintering cucumber beetles in an area emerge to better time control measures taken to prevent crop damage. For example, Cornell University entomologists recommend surveying a field twice weekly by checking the undersides of the leaves of at least five plants in five different locations in a field, including field edges, particularly when plants have fewer than five true leaves (Petzoldt 2001). Midwest guidelines similarly recommend scouting fields two to three times weekly, paying particular attention to field edges (Foster et al. 2005).

Cultural practices include any form of land or crop management which adversely affects pest reproduction, the time and level of, or crop exposure to, the pest insect. Cultural practices used for the management of striped cucumber beetles include delayed planting, row covers, mulching, plant trellising, cultivation, residue removal,

intercropping, and insect vacuuming. Delaying planting of cucurbits until after cucumber beetles lay their eggs (mid-June in the Midwest) is an effective control measure, but may be impractical for growers targeting the higher sale prices of early-season cucurbits, including cucumbers (Foster et al. 2005). Row covers provide a physical barrier between pest and plant, but must be removed once the crop flowers to allow access by pollinators. Smaller-scale operations may also produce cucumbers in greenhouses which also provide a physical barrier to pests. Greenhouse production requires the use of special parthenocarpic cultivars that produce fruit without pollination, although many of the parthenocarpic varieties must be sprayed with a fruit growth hormone such as chlorflurenol in order to obtain normal fruit growth (Coleman 1995, Swiader and Ware 2002). Heavy mulching can deter cucumber beetles from laying their eggs around the base of a plant and may protect vines and fruit from larval feeding, but does nothing to protect the leaves, flowers and fruit from feeding damage by adults (Cranshaw 1998). Trellising plants makes leaves and fruit less accessible to larvae and decreases egg laying, but does not protect against adult feeding. Cultivation and residue removal after harvest may reduce overwintering populations of striped cucumber beetles (Chittenden 1923). Intercropping one crop variety with other crop types to form a polyculture can lead to a 10 to 30 fold reduction in striped cucumber beetle populations compared to a monoculture (Bach 1980). A tomato crop, *Solanum lycopersicum* L., added to a field of cucurbits can reduce the number of striped cucumber beetles present (Lawrence and Bach 1989). Vacuuming allows growers to mechanically remove adult striped cucumber beetles from their host plants, but is highly labor intensive (Power 1987).

Several kinds of traps can be employed to help manage striped cucumber beetles,

including trap crops, trap baits, and sticky traps, which attract the striped cucumber beetles away from the protected crop with a combination of scent, color and pheromones (Radin and Drummond 1994, MacIntyre-Allen et al. 2001, Jackson et al. 2005, Lam 2007). Trap crops are plant varieties that the pest finds more attractive than the protected crop. Striped cucumber beetles are attracted to plants which produce high levels of cucurbitacin, a feeding stimulant, as well as a variety of floral volatiles. To be an effective lure, a trap crop usually needs to have a higher level of these chemicals than the protected crop (Metcalf 1985, Andersen and Metcalf 1989, Andrews et al. 2007). Organic botanical insecticides may then be applied to the trap crop to kill the striped cucumber beetles that are gathered there (Caldwell et al. 2005). Trap baits combine pest-attracting pheromones, kairomones, and other chemical attractants with insecticides. Cucurbitacins are used in various forms in trap baits for the control of striped cucumber beetle (Metcalf 1985). Yellow sticky traps attract and trap striped cucumber beetles by virtue of their color (Levine and Metcalf 1988, Levine and Oloumi-Sadeghi 1991). Some also have chemical attractants added for added effectiveness.

Natural enemies such as predators, parasitoids, and pathogens can be exploited as a natural means of biologically controlling an insect pest. Natural enemies of striped cucumber beetle include soldier beetles (Coleoptera: Cantharidae), tachinid flies (*Celatoria diabroticae* Shimer, Diptera: Tachinidae), braconid wasps (Hymenoptera: Braconidae), certain nematodes (Lyon and Smith 2000, Reed et al. 1986, Ellers-Kirk 2000), and some species of bats (Snyder and Wise 2000). Studies show that many insect natural enemies are attracted to a field with a flowering border of buckwheat (Platt et al. 1999). However, striped cucumber beetles often reach high infestation levels far above

the economic threshold in cultivated cucurbits, even in the presence of these natural enemies (Godfrey 1999).

A number of organic insecticides and protectants, such as the botanical insecticides sabadilla and pyrethrum, are recommended for cucumber beetle control. However, sabadilla and pyrethrum are highly toxic to honeybees, *Apis mellifera* L. (Hymenoptera: Apidae), and should not be used when pollinators are present in the field (Shepherd et al. 2003). Some organic growers use pyrethrum in combination with a particle film barrier called Surround WP™ (Engelhard Corp., Iselin, NJ) Crop Protectant (Caldwell et al. 2005). Rotenone is another moderately effective insecticide used by organic growers in the past, but no formulations are currently approved by the Organic Materials Review Institute (OMRI) in organic production (Caldwell et al. 2005). Rotenone also poses a risk to pollinators. Recent research showed that plant-growth-promoting rhizobacteria decreased striped cucumber beetle feeding. Both cucumber beetle feeding and incidence of bacterial wilt were reduced by the addition of soil drenches composed of a mixture of the rhizobacteria *Pseudomonas putida*, *Serratia marcescens*, *Flavomonas oryzae*, and *Bacillus pumilis*, although inoculum for this treatment method is not yet commercially available (Zehnder et al. 2001).

Of these organic techniques, this experiment focuses on assessing and comparing the ability of row covers and trap crops to control striped cucumber beetle. Methods for enhancing the trap crop by adding attractants or a tomato intercrop are also analyzed.

## **CHAPTER 2**

### **EVALUATING ORGANIC-COMPLIANT MANAGEMENT STRATEGIES FOR STRIPED CUCUMBER BEETLE IN CUCUMBERS**

## Introduction

In recent years there has been an increasing interest in, and demand for, organic produce (Tavernier 2003). Organic production faces many of the same pest challenges as conventional production, but often cannot incorporate conventional pest management solutions, which commonly focus on spraying crops with pesticides. Organic growers need to satisfy organic labeling restrictions which limit the types and amounts of chemical inputs (Phelan et al. 1995, Caldwell et al. 2005), often requiring them to employ different pest management techniques than conventional growers. In addition, some growers have a desire to grow fresh produce free of pesticide inputs, whether organic-compliant or not.

Cucumbers, *Cucumis sativus* L., are a major vegetable crop in the United States (Swiader and Ware 2002). The striped cucumber beetle, *Acalymma vittatum* Fabricius (Coleoptera: Chrysomelidae), is a major pest of cucumber. This pest is of great concern to vegetable growers in both organic and conventional production due to the feeding damage that adult beetles cause to the plant's seeds, foliage, flowers, and fruit; the adults' ability to vector bacterial wilt; and the larvae feeding on plant roots (Chittenden 1923, Foster et al 2005). Striped cucumber beetles overwinter as adults and emerge to feed early in the growing season, badly damaging or killing young cucurbit seedlings or new transplants. After emergence the adults feed and lay eggs in the soil around the base of their host plant. Striped cucumber beetles are univoltine in the north central United States, and can be bivoltine in the warmer southern gulf states (Chittenden 1923, Davidson & Lyon 1979, Capinera 2001). The larvae feed on roots, but they are less of a threat to cucumber production since they do not begin feeding until the plants are large

and they do not transmit bacterial wilt (Chittenden 1923, Foster et al. 2005). The larva does not cause fruit scarring as long as the fruits are not in direct contact with moist soil (Chittenden 1923). The striped cucumber beetle host range covers most cultivated Cucurbitaceae, including squash, melons, and cucumbers.

While there are several insecticides available for striped cucumber beetle control (Bird et al. 2008), few are certified for use in organic production systems and, like other insecticides, they can harm beneficial organisms such as natural enemies and pollinators (Johansen 1977). In areas where bacterial wilt is infrequent, such as in many parts of the north central United States (Hayward 1991), cucumber plants can withstand up to 25% defoliation without exhibiting significant yield loss (Burkness and Hutchison 1998). In these conditions, organic-compliant techniques to manage cucumber beetle are possible and some, such as trap cropping, are employed with varying degrees of success.

Trap cropping is used in commercial settings for striped cucumber beetle management, but the technique commonly relies on the application of an insecticide to the trap crop once beetles are detected, which is not desirable for some organic producers (Hokkanen 1991, Javaid and Joshi 1995, Shelton and Badenes-Perez 2006). On muskmelons, *C. melo* L., 82% of northern corn rootworm, *Diabrotica howardi* Barber (Coleoptera: Chrysomelidae), and striped cucumber beetles were found on the trap crop rather than on the muskmelon crop (Metcalf 1985). In another study, striped cucumber beetle densities were 42% to 81% higher in an NK530 squash perimeter trap crop, *Cucurbita maxima* Duchesne, than in the main melon crop, *C. melo* L. (Caldwell and Stockton 1998, Caldwell et al. 1998). In an extension program, all participating growers stated that their pest control using a perimeter trap crop of Blue Hubbard squash, *C.*

*maxima* Duchesne, around their green and yellow summer squash, *C. pepo* L., was “much better” than in previous years without a trap crop (Boucher and Durgy 2004). Radin and Drummond (1994) recorded that at least 70% of striped cucumber beetles were in a squash trap crop, *C. maxima* cv. ‘Sweet Mama’, compared to 30% in a cucumber crop. Squash trap crops also protect watermelon, *Citrullus* sp., and muskmelon, *C. melo*, from striped cucumber beetle (Cline 2004, Hoffman 1999). Blue Hubbard squash is a particularly promising candidate for a trap crop because striped cucumber beetles prefer it over most other cucurbit species (Reed et al. 1984, Pair 1997, Boucher and Durgy 2004, Shelton and Badenes-Perez 2006).

Increasing plant diversity in the field through intercropping and polyculture is an organic-compliant approach which can cause a 10 to 30 fold reduction in striped cucumber beetle populations compared to a monoculture (Bach 1980). The addition of a non-host tomato crop, *Solanum lycopersicum* L., to a field of cucurbits in some cases reduces the number of striped cucumber beetles present (Lawrence and Bach 1989). In comparison, trap cropping tends to be more effective at reducing phytophagous insect pest populations than intercropping (Banks and Ekbohm 2004), but it is not clear whether in combination the effects are additive.

A trap crop’s attractiveness to an insect pest can sometimes be enhanced with biological attractants such as kairomones (Hokkanen 1991, Javaid and Joshi 1995, Shelton and Badenes-Perez 2006). The addition of biological attractants can significantly enhance trap crops in the control of the Colorado potato beetle, *Leptinotarsa decemlineata* Say (Coleoptera: Chrysomelidae) (Martel 2005). Kairomones that attract striped cucumber beetle and which may be useful in trap crop enhancement have been

identified and are commercially available (Lewis et al. 1990, Fleischer and Kirk 1994, Brust and Foster 1995, Jackson et al. 2005). Attractive kairomones were used to enhance the attractiveness of sticky traps to reduce cucumber beetle populations by 50% by placing 40 kairomone enhanced sticky traps per acre around field edges (Hoffmann 1996). Such kairomones were also used in several different striped cucumber beetle baits (Fleischer and Kirk 1994, Brust and Foster 1995, Schroder et al. 2001, Martin et al. 2002, Jackson et al. 2005).

This study focuses on investigating organic-compliant non-insecticidal methods for managing striped cucumber beetles in cucumber production by increasing the level of plant diversity using a trap crop and an intercrop. Specifically, a comparison was made between the effectiveness of a squash trap crop, a cucumber and tomato polyculture added to the trap crop, and a squash trap crop with added biological attractants in reducing striped cucumber beetle densities on cucumbers. Floating row covers placed over the cucumbers and use of an organically approved insecticide were also included in the comparison of organic-compliant techniques.

## Materials and Methods

This study was conducted in 2006 and 2007 at an organic transition research plot (Fig. 2.1) and at the nearby student organic farm (Fig. 2.2) located at the Michigan State University Horticulture Teaching and Research Center in East Lansing, MI (42° 41' N, 84° 30' W). In the organic transition field site, 'Cobra' slicing cucumber and 'Mountain Fresh Plus' tomatoes (commonly used in commercial production) were grown in a 90 m x 34 m field in raised beds covered with plastic mulch and drip irrigation. In 2006, the tomatoes were sown in transplant trays in a greenhouse on 11 May, 2006 and the Blue Hubbard trap crop transplant trays were sown in the greenhouse on 18 May, 2006. The tomato and Blue Hubbard plants were transplanted into the field on 6 June, 2006 at the same time that the 'Cobra' slicing cucumbers were direct-seeded. In 2007, the Blue Hubbard trap crop was sown in transplant trays on 6 May, 2007 and the tomatoes and cucumbers were sown in transplant trays on 15 May, 2007 in the greenhouse. All plants were transplanted into the field on 7 June, 2007. The rows were 7.6 m-long and spaced 1.8 m apart with an in-row plant spacing of 0.5 m. The field site was planted with a rye, *Secale cereale* L., cover crop in the fall of 2006 and 2007 which was mowed and plowed into the soil before planting the field with cucumber and tomato, and had been in a soybean, *Glycine max* L., monoculture in 2003, 2004 and 2005. The student organic farm site (ca. 800 m from the organic transition plot) was a 91 m x 17 m field of assorted cucurbits planted in raised beds and drip irrigated. Rows were 1.5 m apart and in-row plant spacing was 0.8 m. This field previously contained a potato, *Solanum tuberosum* L., monoculture in 2005. Weeds were managed with plastic mulch at the organic transition research field site and hand hoeing at the student organic farm field site.



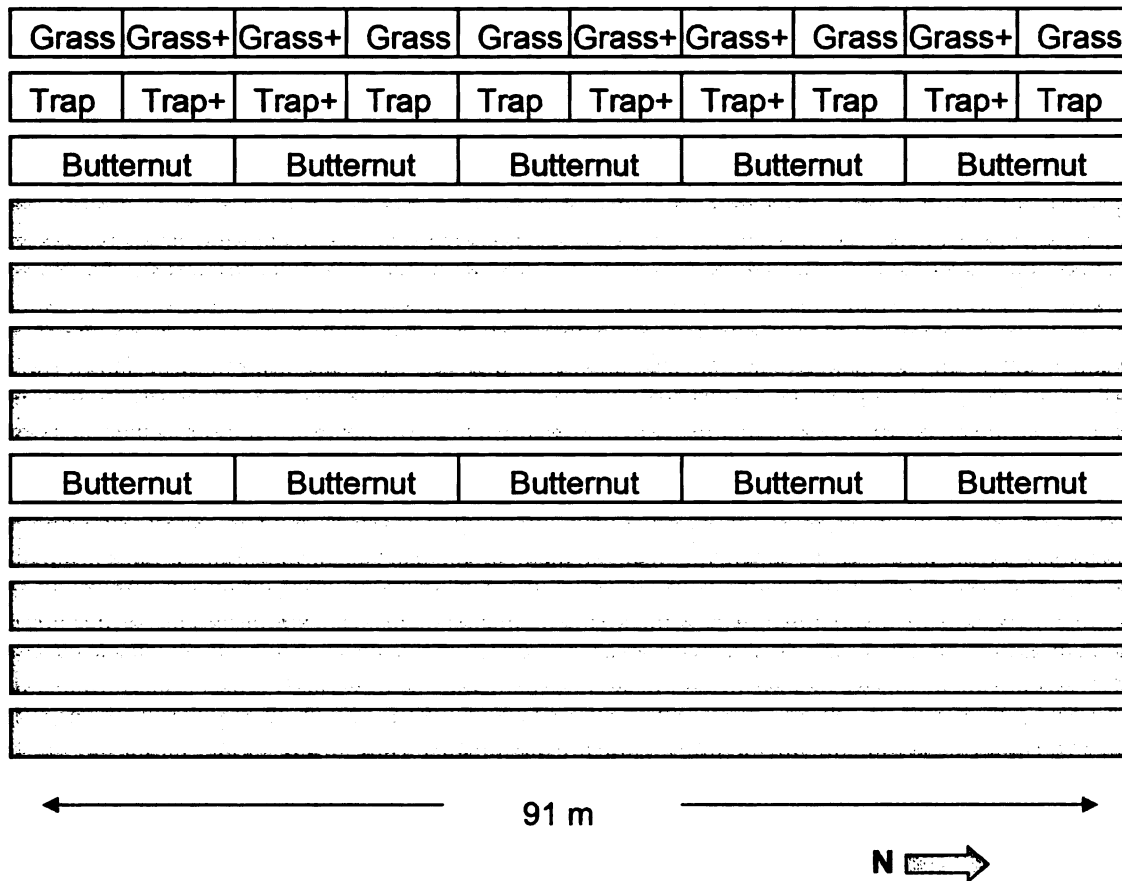


Figure 2.2: Field layout of the attractants field site at the student organic farm. Grass = untreated grass. Grass+ = grass with a cucurbitacin spray. Trap = an untreated Blue Hubbard trap crop. Trap+ = a Blue Hubbard trap crop with a cucurbitacin spray. Butternut = Butternut squash rows sampled at 1.5m and 9m from the trap crop. Unlabeled grey bars represent rows of other assorted cucurbits that were not sampled.

Each site was visually scouted bi-weekly for the first appearance of striped cucumber beetles. The first detection of striped cucumber beetles at the organic transition field site was 20 June in 2006 and 27 June in 2007, and first detection was on 12 June in 2006 at the Student Organic Farm site. In both settings, striped cucumber beetle densities were measured visually by counting the total number of beetles on randomly selected plants.

**Increasing levels of plant diversity to protect cucumber.** In 2006 at the organic transition field site, three treatments differing in their level of plant diversity were tested for their effect on striped cucumber beetle density and plant damage. The treatments were replicated plots of cucumber alone (cucumber monoculture), cucumber with a squash trap crop, and cucumber and tomato polyculture with a squash trap crop. The cucumber monoculture plots were separated from the plots containing trap crops by a 3 m alley of bare soil. For treatments with a squash trap crop, the trap crop was placed in its own row in the center of the plot 2 m from the nearest rows. The trap crop was Blue Hubbard squash. While squash trap crops protecting cucumber are usually placed on the field perimeter, our trap crop was placed in the field interior for this study to focus on the relative attractiveness of the trap crop and cucumber crop, separating the effect of the trap crop from field edge effects. For the cucumber and tomato polyculture with a squash trap treatment replicates, two sets of four raised beds alternated with cucumbers and tomatoes. The treatments were replicated four times in a randomized complete block design (Fig. 2.1). A row of cucumbers covered with a floating row cover was also placed in each treatment to serve as a positive control. The row covers were removed once the cucumber plants began to flower (17 July in 2006 and 11 July in 2007) to allow pollinator access.

This study was a subcomponent of a larger experimental plot that also explored effects of tomato planting strategies and cover crops on soil building.

*Data collection.* While adult beetles were active, beetles were visually counted and percent defoliation was visually estimated approximately twice per week on eight randomly selected cucumber plants in internal rows of the cucumber monoculture and cucumber with trap crop treatment replicates, four randomly selected cucumber plants on internal rows of the cucumber and tomato polyculture with trap crop treatment, four squash trap crop plants for appropriate treatments, and four cucumber plants in the rows with floating row cover by manipulating and observing the plants through the transparent row cover without removing it. Cucumbers were harvested on a weekly basis for five weeks and marketable yield was recorded. Marketable yield was based on visually assessing the damage and fruit quality and sorting the total yield into marketable and unmarketable fruit.

*2007 modifications.* In 2007, the experimental design remained the same except that the cucumbers were transplanted instead of direct seeded, and a foliar spray of PyGanic EC 1.4 (pyrethrum, 1.17 liters/ha, McLaughlin Gormley King Company, Minneapolis, MN), an organically certified insecticide, was applied to the Blue Hubbard trap crop. Both these changes were aimed at relieving cucumber beetle feeding pressure on the seedling cucumber plants. Spraying was triggered whenever striped cucumber beetle counts exceeded 2 per plant in the trap crop. To supplement the marketable yield data, beetle damage on fruit was measured as percent scarring per fruit for cucumber on the vine on eight randomly selected plants per replicate in all treatments.

*Data analysis.* A repeated measures analysis of variance (ANOVA) for a randomized complete block design was conducted using PROC MIXED (SAS Institute 2004) to compare striped cucumber beetle densities, percent defoliation and percent fruit scarring among the three plant diversity treatments across all dates of observation. All data were  $\log(x + 1)$  transformed to stabilize variances and meet the assumptions of ANOVA. Based on the ANOVA, the interaction between plant diversity treatment and date was significant in both years of the study (see Results and Discussion). Therefore a post hoc ANOVA was performed for each individual sample date, and plant diversity treatments were compared using *t*-tests of least squares means ( $P < 0.05$ ) (SAS-Institute 2004). The same procedure was also used to test plant diversity treatment differences in total marketable yield for each year, except accumulated yield was analyzed and date was not a factor in the analysis. Means and standard errors of beetle densities, defoliation, and yield data that were taken on the squash trap crop and cucumber under the row covers were also calculated as a reference for the ANOVA results comparing the plant diversity treatments.

**Trap crop enhancement to protect cucumber.** In 2006 at the student organic farm, a 90 m-long trap crop of Blue Hubbard squash was planted along the edge of a 90 m x 17 m field of assorted cucurbits to test the potential of enhancing trap crop effectiveness by adding cucurbitacins. Beyond the Blue Hubbard squash (away from the crop) was a 90 m-long swath of unmowed grass. These paired rows were divided into five 18 m-long replicates. In each replicate, half of the trap crop and half of the grass strip was randomly assigned to be treated with an attractant while the other half was left untreated in a two by two factorial design of five replicated blocks (Fig. 2.2).

The attractant was a twice weekly spray of cucurbitacin (2 liters of water mixed with 2.3 grams of powdered buffalo root per liter [*Cucurbita foetidissima* HBK, Cidetrak®, Trécé Incorporated, Salinas, California]). The relative attractiveness of these treatments to striped cucumber beetles was measured by counting the number of beetles twice weekly 1 day after spraying the cucurbitacin on four randomly selected plants per replicate in the Blue Hubbard squash treatments and, for one sampling date, on an equivalent ground surface area in the unmowed grass. A visual estimate of percent defoliation of the blue hubbard was also taken. Defoliation was not recorded in the unmowed grass. Beetles were also counted on four randomly selected Butternut squash, *C. moschata* Duchesne, plants within each of two 90 m-long rows of Butternut squash in the field. Plants in these rows were paired with the nearest treatment replicate; one row was 1.5 m from the trap crop at the edge of the field and the other was near the center of the field, 9 m from the trap crop. Data were taken bi weekly.

A repeated measures analysis of variance (ANOVA) for a randomized two by two factorial design was conducted using PROC MIXED (SAS Institute 2004) to compare striped cucumber beetle densities and percent defoliation among the Blue Hubbard squash and unmowed grass treatments with and without cucurbitacin sprays, across dates of observations. A separate repeated measures (date) single factor (distance from the trap crop row) ANOVA was used to compare cucumber beetle densities and percent defoliation on the two 90 m-long rows of Butternut squash in the field. Based on the ANOVA results, a date interaction with the main treatments was significant (see Results and Discussion); therefore a post hoc ANOVA was performed

as in the plant diversity experiment (SAS-Institute 2004).

## Results and Discussion

**Increasing levels of plant diversity to protect cucumber.** The effect of the increasing levels of plant diversity with an emphasis on use of trap crops was tested by comparing the striped cucumber beetle densities in the cucumber monoculture to the densities found in the cucumber plots protected by a trap crop and a polyculture of cucumber and tomato protected by a trap crop. For each year of the study at the organic transition field site the plant diversity treatment by date interaction was significant for the cucumber beetle count variable (2006,  $F = 2.38$ ,  $df = 28, 621$ ,  $P = 0.0001$ ; 2007,  $F = 14.85$ ,  $df = 26, 579$ ,  $P < 0.0001$ ). Samples were pooled by date for further analysis in a post hoc ANOVA of individual sampling dates separately to compare plant diversity treatment effects within each date.

In early 2006 striped cucumber beetle density was low and there were no significant differences between the cucumber monoculture and the cucumber plots protected by a trap crop (Fig. 2.3, 23-27 June,  $df = 9$ ,  $P > 0.05$ ). As overall beetle densities in the field increased in late June and early July, significantly more striped cucumber beetles were found in the cucumber monoculture than in the cucumbers containing the Blue Hubbard trap crop (Fig. 2.3, 30 June,  $df = 9$ ,  $t = 3.70$ ,  $P = 0.0049$ ; 3 July,  $df = 9$ ,  $t = 3.52$ ,  $P = 0.0065$ ; 6 July,  $df = 9$ ,  $t = 2.96$ ,  $P = 0.016$ ; 10 July,  $df = 9$ ,  $t = 3.53$ ,  $P = 0.0064$ ). Later in the growing season, around the time the cucumber plants started flowering, beetle counts stabilized at about 4 to 5 per plants across both these treatments (Fig. 2.3, 13 July and later,  $df = 9$ ,  $P > 0.05$ ). The addition of a tomato polyculture to the trap crop system provided no measurable benefit in reducing striped cucumber beetle densities. The polyculture of cucumber and tomato protected by a trap

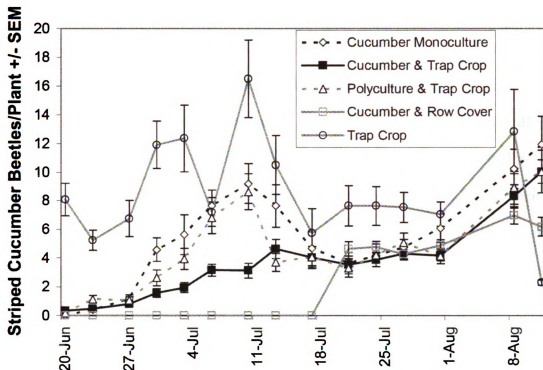


Figure 2.3: Mean number of beetles per plant across the cucumber growing season taken in cucumbers grown in three plant diversity treatments: monoculture, cucumbers grown next to a squash trap crop, a cucumber and tomato polyculture with a squash trap crop. Counts were also taken on cucumbers under a row cover and the squash trap crop found within the plant diversity treatments. Row cover was removed on 17 July. Organic transition site, East Lansing, MI, 2006.

crop did not have beetle densities significantly lower than the cucumber plots protected by a trap crop (Fig. 2.3,  $df = 9$ ,  $P > 0.05$ ). During a few dates, there were significantly higher numbers of beetles in the polyculture with a trap crop compared with the cucumber only protected by a trap crop (Jun 23,  $df = 9$ ,  $t = -2.37$ ,  $P = 0.042$ ; Jul 3,  $df = 9$ ,  $t = -2.24$ ,  $P = 0.044$ ; Jul 6  $df = 9$ ,  $t = -2.60$ ,  $P = 0.029$ , Jul 10,  $df = 9$ ,  $t = -3.35$ ,  $P = 0.0086$ ). The early to mid-season benefits that the trap crop provided can also be seen by comparing the densities of beetles on the Blue Hubbard trap crop and the cucumber crop it was protecting. The cucumber beetle density in the Blue Hubbard trap crop was much higher than the density on the cucumbers it was protecting (Fig. 2.3, 20 June, 23 June, 27 June, 30 June, 3 July, 10 July, 21 July, and 27 July).

Percent defoliation of the cucumber monoculture rose through 6 July, 2006 at which time defoliation was greater in the monoculture than on cucumber protected by the trap crop (Fig. 2.4,  $df = 9$ ,  $t = 4.34$ ,  $P = 0.0019$ ). As with the cucumber beetle counts, the cucumber-tomato polyculture with a trap crop showed no advantage in reducing defoliation compared to the cucumber and trap crop treatment (Fig. 2.4). There was also no significant difference in cumulative season-long marketable yield between the treatments (Fig. 2.5,  $P > 0.05$ ). In summary, the Blue Hubbard trap crop provided some protection to the cucumber growing adjacent to it early to mid-growing season. However, the trap crop effect broke down late in the season, resulting in no season-long protection to the cucumber fruit.

In 2007 when Pyganic was applied to the trap crop as additional protection, there tended to be more beetles in the cucumber monoculture than in the cucumber plot protected by the trap crop from 8 July through 11 July (Fig. 2.6, 8 July,  $df = 9$ ,  $t =$

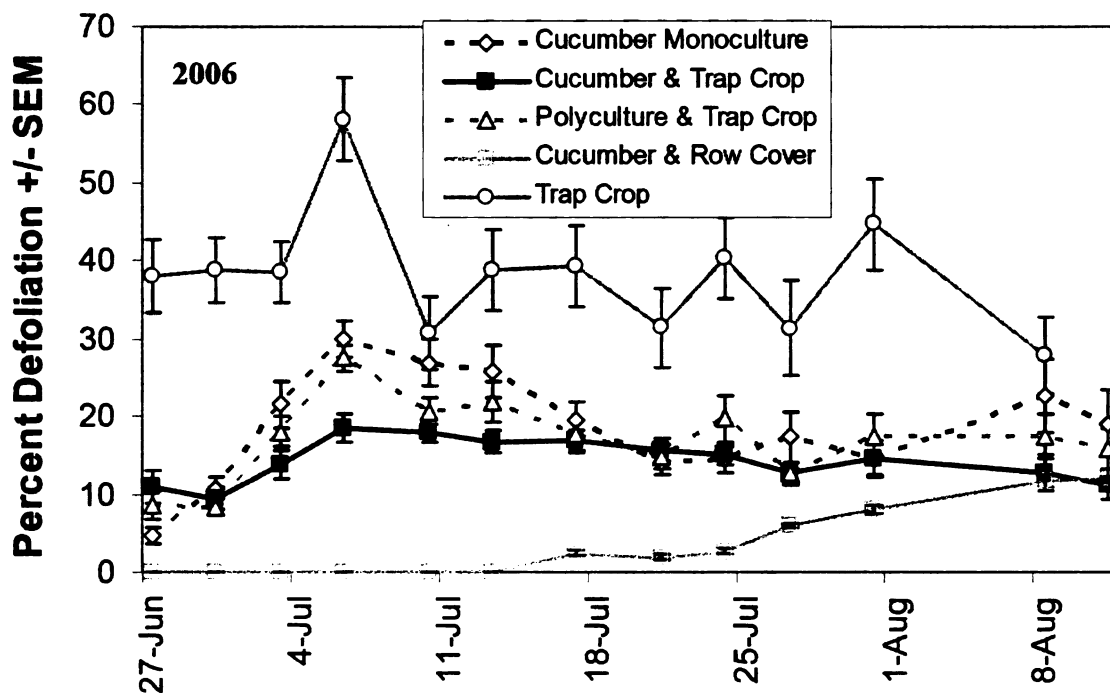


Figure 2.4: Mean percent defoliation across the cucumber growing season taken in three plant diversity treatments: monoculture, cucumbers grown next to a squash trap crop, a cucumber and tomato polyculture with a squash trap crop. Defoliation was also taken on cucumbers under a row cover and the squash trap crop found within the plant diversity treatments. Row cover was removed on 17 July. Organic transition site, East Lansing, MI, 2006.

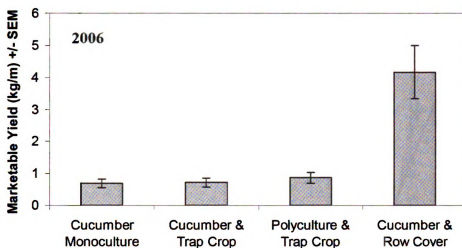


Figure 2.5: Mean marketable cucumber yield in cucumbers grown in three plant diversity treatments: monoculture, cucumbers grown next to a squash trap crop, a cucumber and tomato polyculture with a squash trap crop. Yield of cucumber under a row cover was also taken. Organic transition site, East Lansing, MI, 2006.

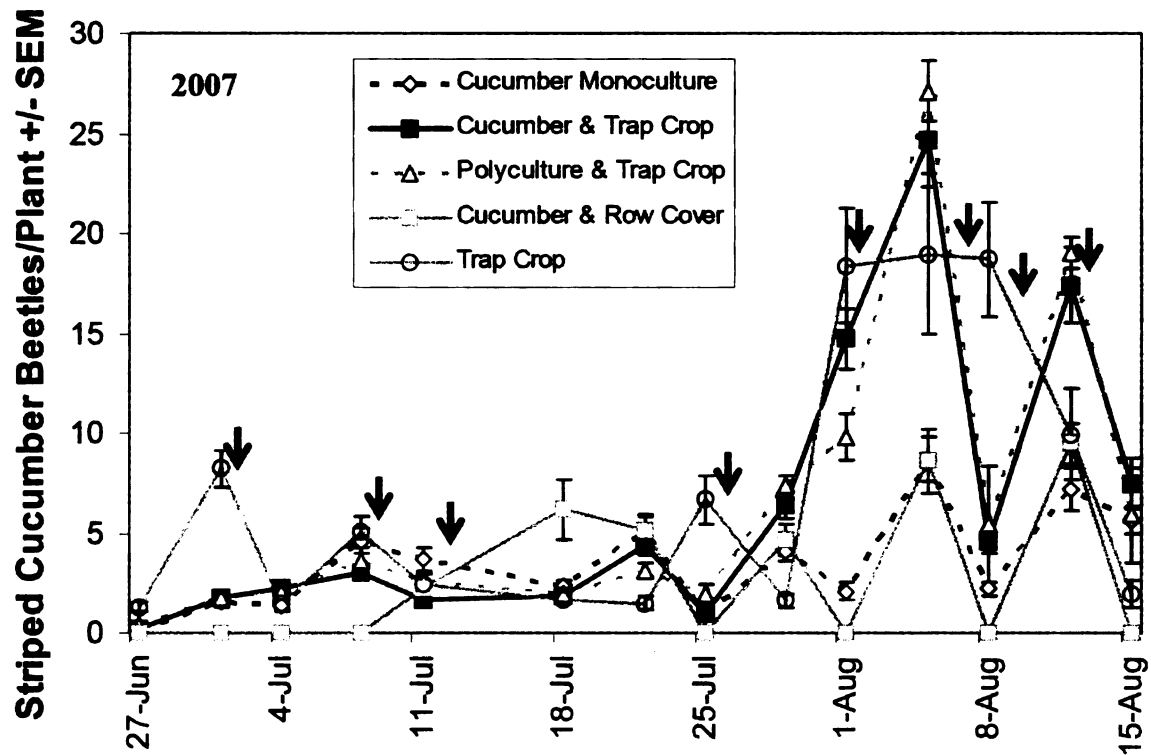


Figure 2.6: Mean number of beetles per plant across the cucumber growing season taken in three plant diversity treatments: monoculture, cucumbers grown next to a squash trap crop, a cucumber and tomato polyculture with a squash trap crop. Counts were also taken on cucumbers under a row cover and the squash trap crop found within the plant diversity treatments.. Row cover was removed on 11 July. PyGanic insecticide was applied to the trap crop rows when beetle counts exceeded two per plant (arrows). Organic transition site, East Lansing, MI, 2007.

2.92,  $P = 0.017$ ; 11 July,  $df = 9$ ,  $t = 3.43$ ,  $P = 0.0076$ ). But as the season progresses, the counts were similar from 18 July through 25 July (Fig. 2.6, 18 July-25 July,  $df = 9$ ,  $P > 0.05$ ), and then a significantly larger number of beetles occurred in cucumber with a trap crop from 29 July through 12 August (Fig. 2.6, 29 July,  $df = 9$ ,  $t = -3.28$ ,  $P = 0.0095$ ; 1 Aug,  $df = 9$ ,  $t = -9.91$ ,  $P < 0.0001$ ; 5 Aug,  $df = 9$ ,  $t = -13.70$ ,  $P < 0.0001$ ; 8 Aug,  $df = 9$ ,  $t = -3.42$ ,  $P = 0.0076$ ; 12 Aug,  $df = 9$ ,  $t = -4.66$ ,  $P = 0.0012$ ). Despite the use of Pyganic, there were high densities of beetles in the trap crop mid- to late-season (Fig. 2.6).

Following this pattern, defoliation was significantly greater in the cucumber monoculture than the cucumber plot protected by the trap crop early in the season (Fig. 2.7 1 July,  $df = 9$ ,  $t = 2.81$ ,  $P = 0.020$ ; 4 July,  $df = 9$ ,  $t = 2.52$ ,  $P = 0.033$ ). This difference was not significant later in the month of July (Fig. 2.7 8-29 July,  $df = 9$ ,  $P > 0.05$ ), and in August defoliation was significantly greater in the cucumber with a trap crop treatment than in the cucumber monoculture (Fig. 2.7, 5 Aug,  $df = 9$ ,  $t = -6.71$ ,  $P < 0.0001$ ; 8 Aug,  $df = 9$ ,  $t = -6.75$ ,  $P < 0.0001$ ; 12 Aug,  $df = 9$ ,  $t = -5.08$ ,  $P = 0.0007$ ; 15 Aug,  $df = 9$ ,  $t = -9.76$ ,  $P < 0.0001$ ). As reference, defoliation on the squash trap crop itself led to percent defoliation of 25% by late July, and plant death of 50% and higher thereafter (Fig. 2.7) Fruit scarring in the cucumber monoculture and cucumber protected by a trap crop was similar early season, but later it was higher in the cucumber with a trap crop than the cucumber monoculture in August (Fig. 2.8, 5 Aug,  $df = 9$ ,  $t = -5.72$ ,  $P = 0.0003$ ; 12 Aug,  $df = 9$ ,  $t = -5.82$ ,  $P = 0.0003$ ). As in the previous year, there was no significant difference in yield between the cucumber monoculture and the cucumber protected by a trap crop (Fig 2.9,  $P < 0.0001$ ). As in 2006, the

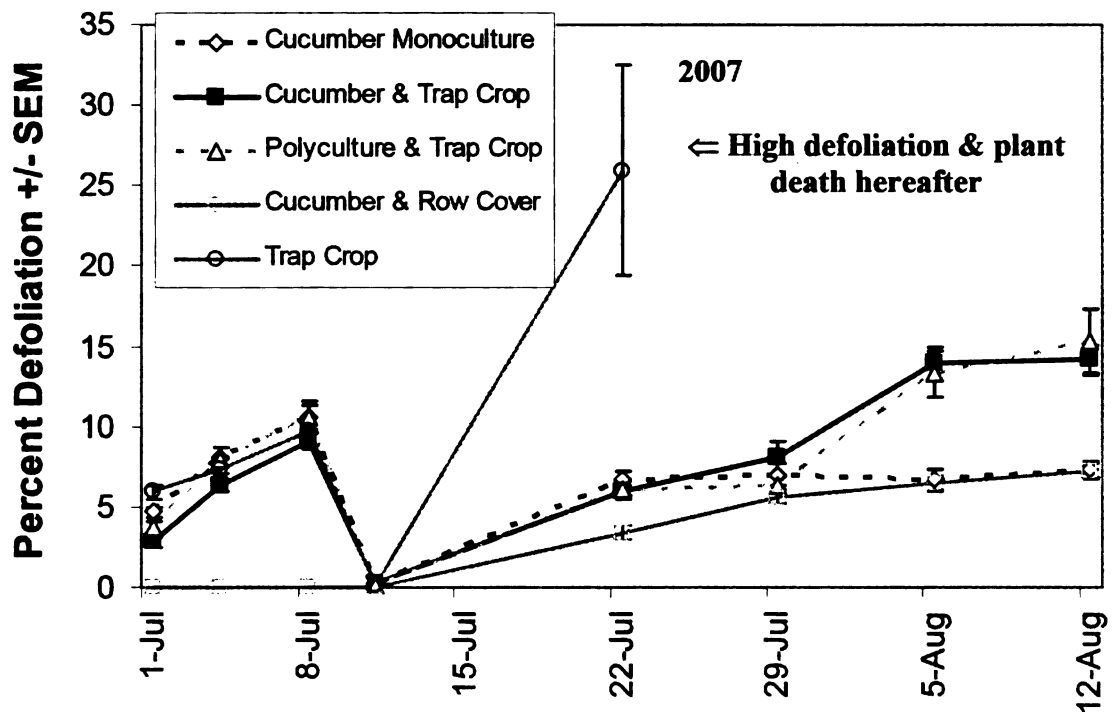


Figure 2.7: Mean percent defoliation across the cucumber growing season taken in three plant diversity treatments: monoculture, cucumbers grown next to a squash trap crop, a cucumber and tomato polyculture with a squash trap crop. Defoliation was also taken on cucumbers under a row cover and the squash trap crop found within the plant diversity treatments. Row cover was removed on 11 July. PyGanic insecticide was applied to the trap crop rows when beetle counts exceeded two per plant. Organic transition site, East Lansing, MI, 2007.

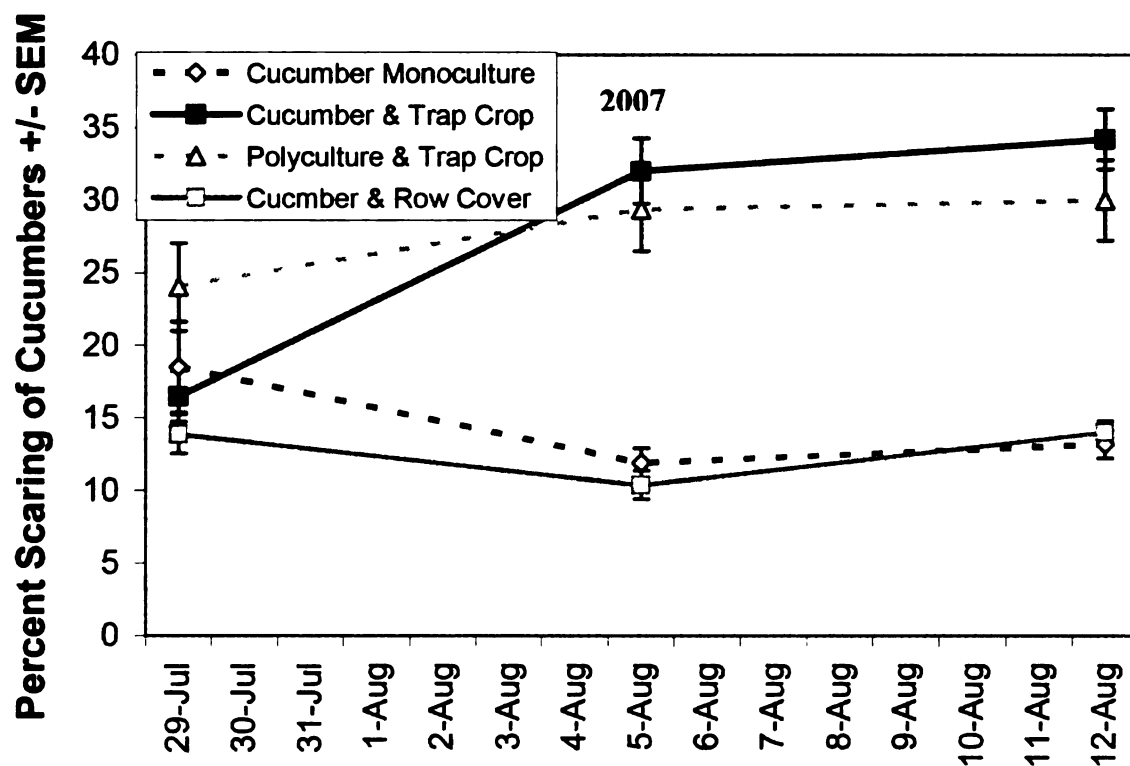


Figure 2.8: Mean percent scarring of cucumber fruit surface across the cucumber growing season taken in three plant diversity treatments: monoculture, cucumbers grown next to a squash trap crop, a cucumber and tomato polyculture with a squash trap crop. Estimates of scarring was also taken on cucumbers under a row cover. Row cover was removed on 11 July. Organic transition site, East Lansing, MI, 2007.

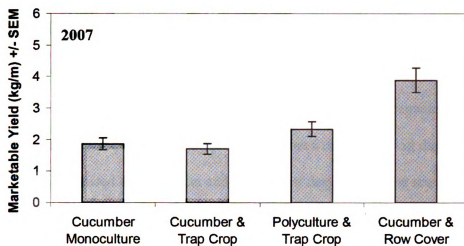


Figure 2.9: Mean marketable cucumber yield in cucumbers grown in monoculture, cucumbers grown next to a squash trap crop, a cucumber and tomato polyculture with a squash trap crop, and cucumbers under a row cover at the organic transition site, East Lansing, MI, 2007.

cucumber-tomato polyculture continued to show no advantage in reducing striped cucumber beetle density (Fig. 2.6) or defoliation (Fig. 2.7) compared to the cucumber with trap crop treatment.

The gradual decrease in the difference between beetle densities in the trap crop and in the protected cucumber crop may have been due to feeding damage to the trap crop, which caused deterioration and some plant death late in the season in both years. This deterioration probably reduced the trap crop's relative attractiveness as a food source. The attractiveness of the cucumber plants may also have increased as blossoms opened coinciding with decline in the trap crop. To reduce this feeding pressure, a PyGanic spray was applied to the trap crop in 2007 when beetles exceeded two per plant on the trap crop. Use of PyGanic appeared effective in reducing feeding pressure early to mid-season, but as beetles densities increased to over 10 per plant (Fig. 2.6 on 27 June, 4 July, 11 July, 18 July, 22 July and 29 July), the trap crop deteriorated quickly and the beetles spread throughout the field. Striped cucumber beetles are highly mobile and strong flyers (Chittenden 1923), they are preferentially attracted to the squash trap crop over cucumber early through mid-season (Fig. 2.3, Fig. 2.6) and those that survive the PyGanic may move due to the irritant characteristics of this and other pyrethrins (Gould 1991). These combined factors present a significant challenge in managing cucumber beetle and its ability to scar fruit mid- to late-season during years when beetle populations are high. The few available organic insecticides present a significant challenge to growers who wish to supplement a trap crop with insecticide. Other potential supplements to the trap crop, such as use

of cucurbitacins to enhance the attractions of the trap crop or replace the need for the trap crop may better maintain protection to the protected crop mid- to late-season.

Used as a positive control reference nested in the plant diversity treatments, the floating row covers excluded striped cucumber beetles until they were removed, as determined by visual inspection and sticky cards inside the row covers in both years (Fig. 2.3, 23 June through 17 July; Fig. 2.6, 27 June through 11 July). Defoliation was much lower under the row covers than on the plant diversity treatments (Fig. 2.4, 27 June through 17 July; Fig. 2.7, 22 July through 12 Aug). This resulted in considerably better yield and less fruit scarring (Figs. 2.5, 2.8, and 2.9). The cucumber plants under the row covers were also noticeably larger than those growing outside of the row covers. Less stress from striped cucumber beetle feeding along with higher temperature and humidity under the row covers likely benefitted yield under the row covers (Motsenbocker and Bonanno 1989, Wolfe et al. 1989, Ibarra et al. 2001).

**Trap crop enhancement to protect cucumber.** For the trap crop enhancement experiment, a date interaction with the main treatments was significant ( $F = 2.02$ ,  $df = 13, 470$ ,  $P = 0.0175$ ); therefore, post hoc ANOVAs were run separately for each sampling date to compare treatment effects as in the previous experiment. Comparing squash trap crop and unmowed treatments with and without cucurbitacin spray, adding cucurbitacin to the squash trap crop resulted in more beetles in the trap crop compared with the squash trap crop alone on three dates (Fig. 2.10, 3 July,  $df = 6$ ,  $t = -4.51$ ,  $P = 0.0041$ ; 7 July,  $df = 6$ ,  $t = -4.66$ ,  $P = 0.0035$ ; and 11 July,  $df = 6$ ,  $t = -7.12$ ,  $P < 0.0001$ ). The unmowed grass treatments attracted very few striped cucumber beetles with or without the cucurbitacin spray, averaging  $0.20 \pm 0.20$  and  $0.60 \pm 0.24$  on

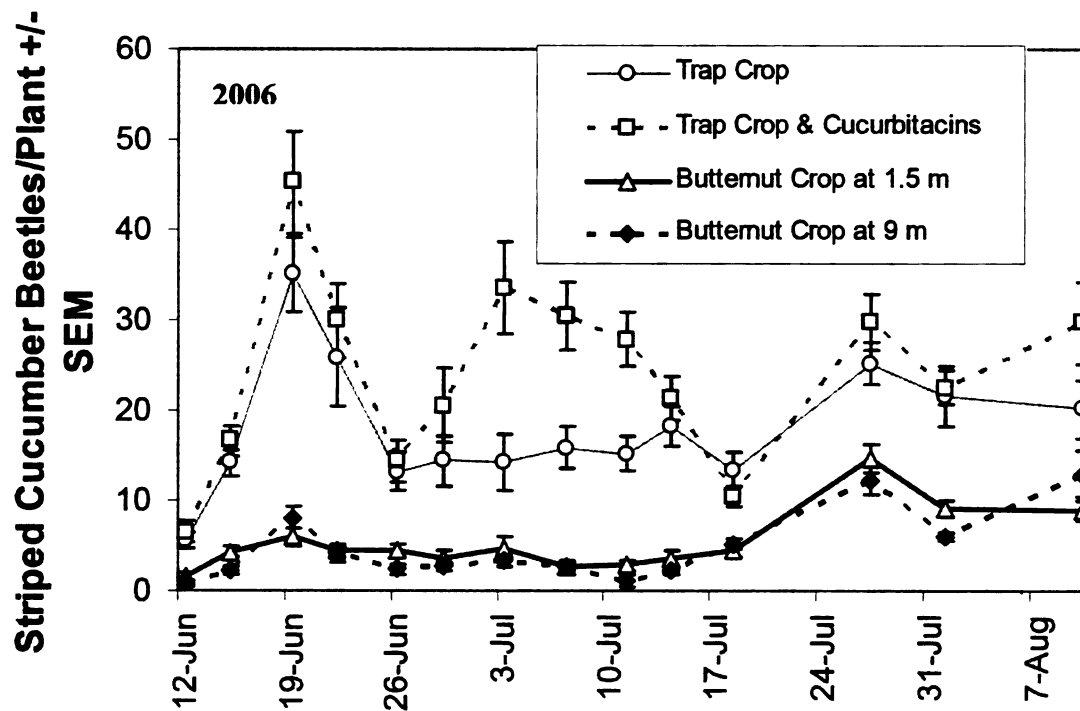


Figure 2.10: Mean number of beetles per plant across the growing season in the Blue Hubbard squash trap crop, a Blue Hubbard squash trap crop with added cucurbitacins, a row of Butternut squash 1.5 m from the trap crop and a row of Butternut squash 9 m from the trap crop at the Student Organic Farm field site, East Lansing, MI, 2006.

July 11, without and with cucurbitacins respectively ( $P > 0.05$ ). There was no difference in defoliation in the trap crop with and without cucurbitacin spray during all observation dates (Fig. 2.11,  $P > 0.05$ ). The addition of a cucurbitacin spray provided some additional attractiveness to the Blue Hubbard squash, but the Blue Hubbard squash are already quite attractive resulting in only modest benefits to adding the cucurbitacin to the trap crop on some dates. The almost complete lack of beetles in the unmoved grass with and without cucurbitacins confirms the strong attractiveness of the squash trap crop. At this field site, the protection afforded by the trap crop remained fairly strong throughout the growing season without breaking down towards the end as occurred in the other field site (Fig. 2.10). This may be due in part to the size that these plants reached before striped cucumber beetle infestation occurred (0.6 m in height vs. 0.4 m at the organic transition field site).

The value of using the trap crop on the field edge as recommended by others (Hokkanen 1991, Javaid and Joshi 1995, Boucher and Durgy 2004, Shelton and Badenes-Perez 2006) was seen in this plot. The protection the Blue Hubbard trap crop provided, as measured by these beetle densities and defoliation data, was not consistently different on the Butternut squash rows 1.5 m or 9 m from the trap crop (Fig. 2.10 and 2.11). The Blue Hubbard trap crop on the field edge had consistently higher striped cucumber beetle densities than the Butternut squash rows that it was protecting as far as 9 m from the trap crop. Although this difference declined as the season progressed as in the other experiment, the decline was not as severe (compare Figs. 2.3 and 2.10). The trap crop in this experiment was much larger when the beetles first appeared, and trap crop did not deteriorate as the season progressed.

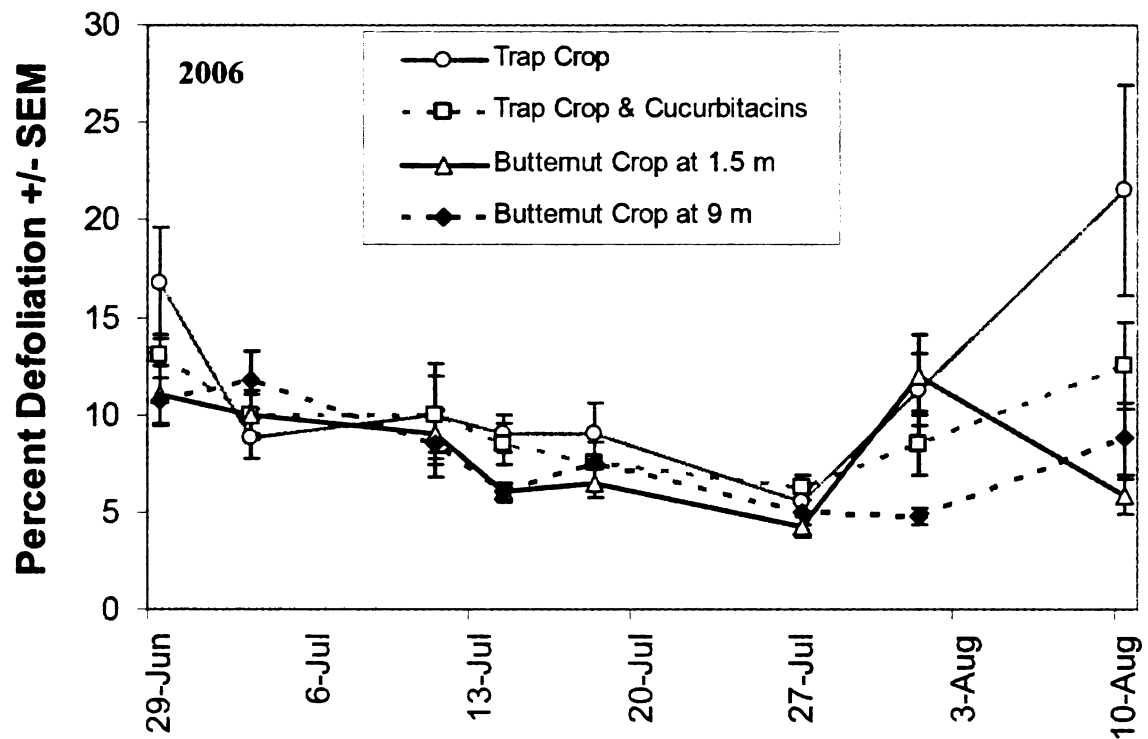


Figure 2.11: Mean Percent defoliation in a Blue Hubbard squash trap crop, a Blue Hubbard squash trap crop with added cucurbitacins, a row of Butternut squash 1.5 m from the trap crop and a row of Butternut squash 9 m from the trap crop at the Student Organic Farm field site, East Lansing, MI, 2006.

Overall these data provide evidence that adding plant diversity in the form of a Blue Hubbard squash trap crop can provide a cucumber crop with protection from striped cucumber beetle, particularly early in the season. But without another form of added protection to supplement the trap crop benefit in attracting beetles does not translate to improved yield. The traditional form of added protection is the use of an insecticide once beetles are detected in the trap crop (Hokkanen 1991, Javaid and Joshi 1995, Shelton and Badenes-Perez 2006). A polyculture system or spray of cucurbitacins may be more viable for organic production and more suitable for those organic producers wishing to avoid use of insecticides. Unfortunately, neither of these alternatives provided substantial addition to the attractiveness of the squash trap crop, as compared with the high level of protection provided by the row covers. The use of an organic certified insecticide the second year of our experimentation did reduce a high beetle population early in the season, confirming the advise to use insecticides once beetles are detected, but high beetle populations encountered and placement of the trap crop within the field may have prevented seeing the full value of using an insecticide to a trap crop grow on a field edge as seen by others (Hokkanen 1991, Javaid and Joshi 1995, Shelton and Badenes-Perez 2006). Given the good mobility of cucumber beetles, addition of a feeding deterrent to the protected crop along with the attractiveness of the squash trap crop may be another approach to consider (Miller and Cowles 1990) for those organic producers who wish to avoid use of insecticides and cannot use row covers due to cost or other factors.

## **CHAPTER THREE:**

### **GENERAL SUMMARY AND CONCLUSIONS**

## **General Findings and Implications**

*Adding plant diversity in the form of a trap crop:* This study found evidence that a Blue Hubbard trap crop, *Cucurbita maxima* (Duchesne), can provide early season protection to a cucumber crop, *Cucumis sativus* L., from striped cucumber beetle, *Acalymma vittatum* Fabricius (Coleoptera: Chrysomelidae). The protection can break down later in the season, resulting in feeding damage to the cucumber fruits which reduces marketable yield. Ways to prolong the life and benefits of the trap crop were explored.

**Cucumber in polyculture protected by a trap crop:** The addition of a tomato polyculture, *Solanum lycopersicum* L., to the cucumber crop with a trap crop did not further reduce cucumber beetle densities on the cucumbers compared to cucumber with a trap crop alone. This evidence suggests that while increased plant diversity in the field can aid in pest control as stated in previous studies (Bach 1980), increasing the number of species may not always have an additive effect.

**Addition of a cucurbitacin foliar spray:** Enhancing the attractiveness of the Blue Hubbard trap crop through the addition of a cucurbitacin foliar spray occurred during some observations, but not consistently. This may simply be because the plants are already very attractive to the beetles, making it difficult to improve attraction.

Other methods of increasing the attractiveness or longevity of the trap crop may be worthy of investigation. For example, a secondary trap might disperse the stress the striped cucumber beetles placed on the trap crop. The use of a secondary trap crop that is significantly less attractive than the primary trap crop, but still more attractive than the protected crop can also serve as a buffer in case the main trap crop deteriorates or beetle

numbers overflow the primary trap crop (Shelton and Badenes-Perez 2006). Insecticide can be applied to the trap crop to increase its longevity, but such applications may cause these highly mobile beetles to move elsewhere, a behavior that may have obscured treatment differences in the second year of this study.

If making the trap crop more attractive to striped cucumber beetles proves difficult, it may be better to turn efforts to trying to decrease the attractiveness of the main cucumber crop to the striped cucumber beetles.

**Row covers:** Floating row covers provided an excellent physical exclusion barrier against striped cucumber beetles. This finding is not new (Adams et al. 1990, Bextine et al. 2001, Mueller et al. 2006) but the comparison of its effectiveness with the other methods used in this study is striking and may provide incentive for growers who are not already using them to seriously consider floating row covers as a control method.

## **Recommended Methods of Organic Management of Striped Cucumber Beetle**

Based on the results presented here, this study strongly supports the use of floating row covers to growers so long as they are an economically viable option for the scale of their cucumber production operation. The caveat for this control method is that the row covers must be removed once the cucumber plants begin flowering to allow pollination, and their benefits can be minimized by late season feeding damage to and subsequent scarring of the cucumber fruits. This method would be most effective when combined with some other control measure that provides protection later in the growing season after the row covers have been removed.

The use of a trap crop is also recommended based on this study's results, but does not appear to be sufficient to provide striped cucumber beetle protection on its own. I would recommend using a Blue Hubbard trap crop in addition to row covers over the protected crop. To minimize breakdown of the Blue Hubbard trap crop later in the season, use transplants. The more time they have to grow before the beetles arrive, the better their chances are of surviving to provide protection later in the growing season. The use of a secondary trap crop may also help as a backup in case the primary trap crop fails to contain the striped cucumber beetles throughout the growing season (Shelton and Badenes-Perez 2006) and should be investigated in this system.

The trap crop effect might well be enhanced through the use of the stimulo-deterrent strategy by decreasing the attractiveness of the cucumber crop to the striped cucumber beetles with some form of deterrent (Miller and Cowles 1990). Known deterrents of striped cucumber beetles include: tetrahydropyranyl ethers (Reed and Jacobson 1983), an ethanol extract of *Trewia nudiflora* (Euphorbiaceae) seed (Freedman

et al. 1982), an ether extract of the defatted nuts of tung, *Aleurites fordii* Hemsl. (Jacobson et al. 1978), the extracts of *Piper* spp., Piperaceae, (Scott et al. 2004 and 2008), and several botanical derivatives (Reed and Jacobson 1989). Kaolin clay dust and other particle film barriers have also been shown to have repellent effects on striped cucumber beetle feeding (Chittenden 1923).

Pesticide use is limited in an organic system, but it could prove an important tool for reducing striped cucumber beetles late in the season once the row covers have been removed, particularly if the other control measures such as the perimeter trap crop are not diverting enough of the striped cucumber beetles away from the cucumber crop's developing fruit. Pesticide use should be limited as much as possible to reduce impacts on pollinators and other beneficial insects.

## **Obstacles Encountered**

During the course of this study a number of obstacles presented themselves. The addition of the PyGanic spray during the second year was meant to lower stress on the trap crop and prevent its deterioration later in the season, thereby enhancing our treatment differences. The PyGanic spray did reduce overall density of the beetles through mid-season, but later seemed to lead to redistribution of striped cucumber beetle densities and ended up obscuring many of the treatment differences apparent in 2006. This result may be due to the PyGanic acting as an irritant as well as a toxin to the striped cucumber beetles (Gould 1991) thereby decreasing the relative attractiveness of the Blue Hubbard squash trap crop compared to the unsprayed cucumber crop.

While this study tested several methods of organic and sustainable control of striped cucumber beetle, those that showed promise were most effective early in the growing season and provided much less protection after the plants had flowered and fruits began to form. Scarring of the fruit from striped cucumber feeding damage reduced marketable yield to suboptimal levels and is an issue that will have to be dealt with in any successful striped cucumber beetle control program.

Other problems included the tendency of striped cucumber beetles to aggregate on some plants in much higher numbers than on others. This is a well know attribute (Carroll and Hoffman 1980, Smyth and Hoffman 2003). Comparing attractiveness of damaged and undamaged squash and cucumber is advisable to determine the effect of damaged plants on their relative attractiveness to the beetles.

This field study was originally intended to be correlated with a set of laboratory studies to present striped cucumber beetles in an olfactory chamber a choice between

various plant volatiles, but attempts to establish a laboratory colony of striped cucumber beetles were unsuccessful. The rearing method in Howe and Zdarkova (1971) was used, but problems arose, including mould, drying out of eggs and larvae, low fecundity rates and unexplained adult death.

## Further Research

There are a number of lines of inquiry which further research might take. Research focusing on the trap crop element of this study could look at assessing other kinds of trap crop enhancements, since it may be that other methods of adding more cucurbitacins to the Blue Hubbard trap crop or the use of other chemical attractants might prove more effective than the method tested in this study. Other potential attractants include striped cucumber beetle aggregation pheromones and cucurbit flower volatiles (Metcalf 1985, Andersen and Metcalf 1989, Smyth and Hoffman 2003, Andrews et al. 2007). Sex pheromones have been isolated for banded cucumber beetle, *Diabrotica balteata* LeConte (McLaughlin et al. 1991, Ventura et al. 2001), so similar pheromones may exist for striped cucumber beetles which could also be extracted and used as an attractant. Several other kairomone formulations have been found to be effective in attracting striped cucumber beetles (Jackson et al. 2005) which could likewise be tested as a trap crop enhancement.

The stimulo-deterrent method could also be used to increase the relative attractiveness of the trap crop by testing various methods of decreasing the attractiveness of the main cucumber crop, and a future study could focus on comparing various methods and techniques to that end. In this study it was difficult to determine the effects that the addition of a PyGanic spray had in the second year of the study, so future research could include such insecticide use as a treatment to better gauge its actual effectiveness in lowering striped cucumber beetle densities when applied to the trap crop. This treatment could be compared with other methods for

reducing striped cucumber beetle densities on the trap crop such as the use of a bug vacuum.

Since row covers provide early season exclusion of striped cucumber beetles, future experiments could test placing row covers over the trap crop as well as the protected crop. This should deny striped cucumber beetles suitable habitat and oviposition sites in the field early in the season. This tactic could potentially prevent striped cucumber beetles from infesting the trap crop only to multiply and spill over into the protected crop as soon as the row covers are removed. By barring the cucumber beetles access to all potential host plants in the field, many of them would be forced to relocate and lay their eggs elsewhere, potentially reducing the number of beetles in the field later in the season after row cover removal. Meanwhile this tactic might save the trap crop for later use, keeping it fresh for when row covers are removed.

Finally, it would be good to correlate observations in this study and any similar field studies that may follow with an analogous laboratory study to better zero in on specific treatment effects in a more controlled environment.

## APPENDIX 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.: 2008-11

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

EVALUATING ORGANIC-COMPLIANT MANAGEMENT STRATEGIES FOR  
STRIPED CUCUMBER BEETLE IN CUCUMBERS

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

Entomology Museum, Michigan State University (MSU)

Other Museums:

Investigator's Name(s) (typed)

Matthew E. Kaiser

Date November 20, 2008

\*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 1 of 1 Pages

| Species or other taxon               | Label data for specimens collected or used and deposited | Number of:                                                                                          | Museum where deposited |
|--------------------------------------|----------------------------------------------------------|-----------------------------------------------------------------------------------------------------|------------------------|
| <i>Acelymnna vittatum</i>            | Matt Kaiser 9/5/06 MSU Ent Farm E Lansing MI             | Adults ?<br>Adults ?<br>Pupae<br>Nymphs<br>Larvae<br>Eggs                                           | Other<br>0 MSU         |
| (Use additional sheets if necessary) |                                                          |                                                                                                     |                        |
| Investigator's Name(s) (typed)       |                                                          | Voucher No. 2008-11                                                                                 |                        |
| Matthew E. Kaiser                    |                                                          | Received the above listed specimens for deposit in the Michigan State University Entomology Museum. |                        |
| Date                                 | 24-Nov-08                                                | November 24, 2008                                                                                   |                        |
|                                      |                                                          | Date                                                                                                |                        |

## APPENDIX 2: ANOVA AND LS MEANS SEPERATION TABLES

Table A2.1: 2006 Number of beetles per plant ANOVA of plant diversity treatments

| Source    | DF  | Mean Square | Expected Mean Square                                                                                                       | Error Term                            | Error DF | F     | P       |
|-----------|-----|-------------|----------------------------------------------------------------------------------------------------------------------------|---------------------------------------|----------|-------|---------|
| Trt       | 2   | 6.46        | $\text{Var}(\text{Residual}) + 60 \text{ Var}(\text{smp}(\text{trt})) + \text{Q}(\text{trt}, \text{trt} * \text{date})$    | $\text{MS}(\text{smp}(\text{trt}))$   | 9        | 7.93  | 0.0103  |
| Date      | 14  | 21.58       | $\text{Var}(\text{Residual}) + 12 \text{ Var}(\text{date} * \text{rep}) + \text{Q}(\text{date}, \text{trt} * \text{date})$ | $\text{MS}(\text{date} * \text{rep})$ | 42       | 42.74 | <0.0001 |
| Trt*Date  | 28  | 0.93        | $\text{Var}(\text{Residual}) + \text{Q}(\text{trt} * \text{date})$                                                         | $\text{MS}(\text{Residual})$          | 621      | 2.38  | 0.0001  |
| Rep       | 3   | 1.48        | $\text{Var}(\text{Residual}) + 12 \text{ Var}(\text{date} * \text{rep}) + 180 \text{ Var}(\text{rep})$                     | $\text{MS}(\text{date} * \text{rep})$ | 42       | 2.93  | 0.0444  |
| Date*Rep  | 42  | 0.50        | $\text{Var}(\text{Residual}) + 12 \text{ Var}(\text{date} * \text{rep})$                                                   | $\text{MS}(\text{Residual})$          | 621      | 1.29  | 0.1111  |
| Smpl(Trt) | 9   | 0.81        | $\text{Var}(\text{Residual}) + 60 \text{ Var}(\text{smp}(\text{trt}))$                                                     | $\text{MS}(\text{Residual})$          | 621      | 2.07  | 0.0298  |
| Residual  | 621 | 0.39        | $\text{Var}(\text{Residual})$                                                                                              |                                       |          |       |         |

**Table A2.2: 2006 Percent defoliation per plant ANOVA of plant diversity treatments**

| Source    | DF  | Mean Square | Expected Mean Square                                                                         | Error Term             | Error DF | F    | P       |
|-----------|-----|-------------|----------------------------------------------------------------------------------------------|------------------------|----------|------|---------|
| Trt       | 2   | 0.108       | $\text{Var(Residual)} + 52 \text{ Var(smpl(trt))} + Q(\text{trt}, \text{trt} * \text{date})$ | $\text{MS(smpl(trt))}$ | 9        | 7.44 | 0.0124  |
| Date      | 12  | 0.111       | $\text{Var(Residual)} + 12 \text{ Var(date*rep)} + Q(\text{date}, \text{trt} * \text{date})$ | $\text{MS(date*rep)}$  | 36       | 7.70 | <0.0001 |
| Trt*Date  | 24  | 0.016       | $\text{Var(Residual)} + Q(\text{trt} * \text{date})$                                         | $\text{MS(Residual)}$  | 537      | 1.54 | 0.0487  |
| Rep       | 3   | 0.063       | $\text{Var(Residual)} + 12 \text{ Var(date*rep)} + 156 \text{ Var(rep)}$                     | $\text{MS(date*rep)}$  | 36       | 4.39 | 0.0099  |
| Date*Rep  | 36  | 0.014       | $\text{Var(Residual)} + 12 \text{ Var(date*rep)}$                                            | $\text{MS(Residual)}$  | 537      | 1.35 | 0.0864  |
| Smpl(Trt) | 9   | 0.014       | $\text{Var(Residual)} + 52 \text{ Var(smpl(trt))}$                                           | $\text{MS(Residual)}$  | 537      | 1.36 | 0.2014  |
| Residual  | 537 | 0.011       | $\text{Var(Residual)}$                                                                       |                        |          |      |         |

**Table A2.3: 2006 Number of striped cucumber beetles per plant LS means separation of plant diversity treatments<sup>1</sup>**

| Date    | Means Separation of Treatments <sup>2</sup> |                      |                          |
|---------|---------------------------------------------|----------------------|--------------------------|
|         | Cucumber                                    | Cucumber w Trap Crop | Cuc & Tomato w Trap Crop |
| 6-20-06 | 0.00±0.00a                                  | 0.33±0.09b           | 0.16±0.08ab              |
| 6-23-06 | 0.41±0.13a                                  | 0.47±0.14a           | 1.13±0.27b               |
| 6-27-06 | 1.16±0.27a                                  | 0.80±0.18a           | 1.06±0.25a               |
| 6-30-06 | 4.59±0.81b                                  | 1.58±0.30a           | 2.63±0.55a               |
| 7-03-06 | 5.63±1.39b                                  | 1.95±0.35a           | 3.94±0.72b               |
| 7-06-06 | 7.66±1.09b                                  | 3.16±0.41a           | 6.81±1.10b               |
| 7-10-06 | 9.19±1.38b                                  | 3.13±0.51a           | 8.63±1.26b               |
| 7-13-06 | 7.63±1.50a                                  | 4.63±0.67a           | 3.69±0.63a               |
| 7-17-06 | 4.66±1.19a                                  | 4.03±0.77a           | 4.09±0.71a               |
| 7-21-06 | 3.63±0.73a                                  | 3.53±0.39a           | 3.31±0.65a               |
| 7-24-06 | 4.19±0.79a                                  | 3.87±0.47a           | 4.22±0.55a               |
| 7-27-06 | 4.75±0.56a                                  | 4.30±0.43a           | 5.09±0.65a               |
| 7-31-06 | 6.09±0.99a                                  | 4.19±0.38a           | 4.13±0.54a               |

<sup>1</sup> Means were compared using *t*-tests of least-squares means.

<sup>2</sup> Letters differing across rows signify significant differences at P = 0.05.

**Table A2.4: 2006 Percent defoliation per plant LS means separation of plant diversity treatments<sup>1</sup>**

| Date    | Means Separation of Treatments <sup>2</sup> |                      |                          |
|---------|---------------------------------------------|----------------------|--------------------------|
|         | Cucumber                                    | Cucumber w Trap Crop | Cuc & Tomato w Trap Crop |
| 6-27-06 | 4.69±1.05a                                  | 11.02±2.08a          | 8.59±1.76a               |
| 6-30-06 | 10.78±1.39a                                 | 9.45±1.43a           | 8.43±1.11a               |
| 7-03-06 | 21.56±3.00a                                 | 13.75±1.83a          | 17.96±1.94a              |
| 7-06-06 | 30.00±2.34b                                 | 18.44±1.87a          | 27.50±1.72b              |
| 7-10-06 | 26.88±2.93a                                 | 17.89±1.16a          | 20.63±1.74a              |
| 7-13-06 | 25.78±3.29a                                 | 16.77±1.50a          | 21.88±2.59a              |
| 7-17-06 | 19.53±2.29a                                 | 16.80±1.44a          | 17.66±1.94a              |
| 7-21-06 | 14.06±1.64a                                 | 15.70±1.39a          | 14.84±1.46a              |
| 7-24-06 | 14.53±1.70a                                 | 15.16±1.24a          | 19.67±3.08a              |
| 7-27-06 | 17.34±3.22a                                 | 12.76±1.21a          | 12.67±1.51a              |
| 7-31-06 | 14.53±2.36a                                 | 14.45±1.99a          | 17.34±2.87a              |

<sup>1</sup> Means were compared using *t*-tests of least-squares means.

<sup>2</sup> Letters differing across rows signify significant differences at P = 0.05.

**Table A2.5: 2007 Number of striped cucumber beetles per plant ANOVA of plant diversity treatments**

| Source    | DF  | Mean Square | Expected Mean Square                                                                                                | Error Term                            | Error DF | F     | P       |
|-----------|-----|-------------|---------------------------------------------------------------------------------------------------------------------|---------------------------------------|----------|-------|---------|
| Trt       | 2   | 17.31       | $\text{Var}(\text{Residual}) + 56 \text{ Var}(\text{smp}(\text{trt})) + Q(\text{trt}, \text{trt}^* \text{date})$    | $\text{MS}(\text{smp}(\text{trt}))$   | 9        | 35.68 | <0.0001 |
| Date      | 13  | 43.54       | $\text{Var}(\text{Residual}) + 12 \text{ Var}(\text{date}^* \text{rep}) + Q(\text{date}, \text{trt}^* \text{date})$ | $\text{MS}(\text{date}^* \text{rep})$ | 39       | 37.78 | <0.0001 |
| Trt*Date  | 26  | 4.27        | $\text{Var}(\text{Residual}) + Q(\text{trt}^* \text{date})$                                                         | $\text{MS}(\text{Residual})$          | 579      | 14.85 | <0.0001 |
| Rep       | 3   | 7.37        | $\text{Var}(\text{Residual}) + 12 \text{ Var}(\text{date}^* \text{rep}) + 168 \text{ Var}(\text{rep})$              | $\text{MS}(\text{date}^* \text{rep})$ | 39       | 6.39  | 0.0013  |
| Date*Rep  | 39  | 1.15        | $\text{Var}(\text{Residual}) + 12 \text{ Var}(\text{date}^* \text{rep})$                                            | $\text{MS}(\text{Residual})$          | 579      | 4.01  | <0.0001 |
| Smp1(Trt) | 9   | 0.49        | $\text{Var}(\text{Residual}) + 56 \text{ Var}(\text{smp}(\text{trt}))$                                              | $\text{MS}(\text{Residual})$          | 579      | 1.69  | 0.0886  |
| Residual  | 579 | 0.29        | $\text{Var}(\text{Residual})$                                                                                       |                                       |          |       |         |

**Table A2.6: 2007 Percent defoliation per plant ANOVA of plant diversity treatments**

| Source    | DF  | Mean Square | Expected Mean Square                                                                                                | Error Term                            | Error DF | F     | P       |
|-----------|-----|-------------|---------------------------------------------------------------------------------------------------------------------|---------------------------------------|----------|-------|---------|
| Trt       | 2   | 0.086       | $\text{Var}(\text{Residual}) + 40 \text{ Var}(\text{smp}(\text{trt})) + Q(\text{trt}, \text{trt} * \text{date})$    | $\text{MS}(\text{smp}(\text{trt}))$   | 9        | 45.77 | <0.0001 |
| Date      | 9   | 0.133       | $\text{Var}(\text{Residual}) + 12 \text{ Var}(\text{date} * \text{rep}) + Q(\text{date}, \text{trt} * \text{date})$ | $\text{MS}(\text{date} * \text{rep})$ | 27       | 40.00 | <0.0001 |
| Trt*Date  | 18  | 0.033       | $\text{Var}(\text{Residual}) + Q(\text{trt} * \text{date})$                                                         | $\text{MS}(\text{Residual})$          | 411      | 15.78 | <0.0001 |
| Rep       | 3   | 0.011       | $\text{Var}(\text{Residual}) + 12 \text{ Var}(\text{date} * \text{rep}) + 120 \text{ Var}(\text{rep})$              | $\text{MS}(\text{date} * \text{rep})$ | 27       | 3.24  | 0.0377  |
| Date*Rep  | 27  | 0.003       | $\text{Var}(\text{Residual}) + 12 \text{ Var}(\text{date} * \text{rep})$                                            | $\text{MS}(\text{Residual})$          | 411      | 1.60  | 0.0310  |
| Smpl(Trt) | 9   | 0.002       | $\text{Var}(\text{Residual}) + 40 \text{ Var}(\text{smp}(\text{trt}))$                                              | $\text{MS}(\text{Residual})$          | 411      | 0.91  | 0.5149  |
| Residual  | 411 | 0.002       | $\text{Var}(\text{Residual})$                                                                                       |                                       |          |       |         |

**Table A2.7: 2007 Number of striped cucumber beetles per plant LS means separation of plant diversity treatments<sup>1</sup>**

| Date    | Means Separation of Treatments <sup>2</sup> |                      |                          |
|---------|---------------------------------------------|----------------------|--------------------------|
|         | Cucumber                                    | Cucumber w Trap Crop | Cuc & Tomato w Trap Crop |
| 6-27-07 | 0.09±0.05a                                  | 0.20±0.07ab          | 0.41±0.12b               |
| 7-01-07 | 1.59±0.32a                                  | 1.73±0.29a           | 1.75±0.40a               |
| 7-04-07 | 1.34±0.31a                                  | 2.28±0.33b           | 2.06±0.40b               |
| 7-08-07 | 4.59±0.65b                                  | 3.02±0.28a           | 3.59±0.37ab              |
| 7-11-07 | 3.72±0.59b                                  | 1.64±0.24a           | 2.59±0.48ab              |
| 7-18-07 | 2.34±0.32a                                  | 1.84±0.24a           | 1.91±0.33a               |
| 7-22-07 | 5.06±0.72a                                  | 4.38±0.52a           | 3.13±0.49a               |
| 7-25-07 | 0.91±0.23a                                  | 0.95±0.18ab          | 1.91±0.45b               |
| 7-29-07 | 4.06±0.46a                                  | 6.39±0.71b           | 7.41±1.16b               |
| 8-01-07 | 2.06±0.44a                                  | 14.72±1.54c          | 9.81±1.49b               |
| 8-05-07 | 8.59±1.62a                                  | 24.64±2.27b          | 27.13±2.90b              |
| 8-08-07 | 2.19±0.33a                                  | 4.52±0.51b           | 5.44±0.76b               |
| 8-12-07 | 7.19±1.06a                                  | 17.41±1.88b          | 19.00±2.35b              |
| 8-15-07 | 5.63±0.64a                                  | 7.48±1.29a           | 5.88±0.82a               |

<sup>1</sup> Means were compared using *t*-tests of least-squares means.

<sup>2</sup> Letters differing across rows signify significant differences at  $P = 0.05$ .

**Table A2.8: 2007 Percent defoliation per plant LS means separation of plant diversity treatments<sup>1</sup>**

| Date    | Means Separation of Treatments <sup>2</sup> |                      |                          |
|---------|---------------------------------------------|----------------------|--------------------------|
|         | Cucumber                                    | Cucumber w Trap Crop | Cuc & Tomato w Trap Crop |
| 7-01-07 | 4.69±0.38b                                  | 2.81±0.35a           | 3.75±0.50ab              |
| 7-04-07 | 8.13±0.58b                                  | 6.33±0.36a           | 7.97±0.81b               |
| 7-08-07 | 10.63±0.95a                                 | 9.14±0.54a           | 10.63±0.74a              |
| 7-11-07 | 0.31±0.22a                                  | 0.23±0.13a           | 0.16±0.16a               |
| 7-22-07 | 6.72±0.53a                                  | 5.94±0.47a           | 6.13±0.45a               |
| 7-29-07 | 7.03±0.67a                                  | 8.05±1.08a           | 6.41±0.51a               |
| 8-05-07 | 6.72±0.58a                                  | 13.91±1.04b          | 13.28±1.41b              |
| 8-08-07 | 5.00±2.50a                                  | 17.27±2.31b          | 15.31±3.07b              |
| 8-12-07 | 7.34±0.55a                                  | 14.14±0.97b          | 15.31±2.03b              |
| 8-15-07 | 8.44±1.11a                                  | 32.03±2.88c          | 15.63±2.19b              |

<sup>1</sup> Means were compared using *t*-tests of least-squares means.

<sup>2</sup> Letters differing across rows signify significant differences at P = 0.05.

**Table A2.9: 2007 Percent scarring per fruit LS means separation of plant diversity treatments<sup>1</sup>**

| Date    | Means Separation of Treatments <sup>2</sup> |                      |                          |
|---------|---------------------------------------------|----------------------|--------------------------|
|         | Cucumber                                    | Cucumber w Trap Crop | Cuc & Tomato w Trap Crop |
| 7-29-07 | 18.50±3.15a                                 | 16.47±1.76a          | 24.03±3.02a              |
| 8-05-07 | 11.91±1.00a                                 | 32.02±2.24b          | 29.38±2.90b              |
| 8-12-07 | 13.16±0.94a                                 | 34.19±2.07b          | 30.00±2.78b              |

<sup>1</sup> Means were compared using *t*-tests of least-squares means.

<sup>2</sup> Letters differing across rows signify significant differences at *P* = 0.05.

**Table A2.10: 2006 Number of striped cucumber beetles per plant ANOVA of attractant treatments**

| Source    | DF  | Mean Square | Expected Mean Square                                                                                                                | Error Term   | Error DF | F     | P       |
|-----------|-----|-------------|-------------------------------------------------------------------------------------------------------------------------------------|--------------|----------|-------|---------|
| Trt       | 3   | 35.79       | $\text{Var(Residual)} + 24 \text{ Var(smpl(trt))} + Q(\text{trt, date*trt}) + Q(\text{trt, date*trt}) + 0.215 \text{ MS(Residual)}$ |              | 33.87    | 30.03 | <0.0001 |
| Date      | 13  | 32.17       | $\text{Var(Residual)} + 8 \text{ Var(date*rep)} + Q(\text{date, date*trt}) \text{ MS(date*rep)}$                                    |              | 52       | 10.00 | <0.0001 |
| Date*Trt  | 13  | 4.04        | $\text{Var(Residual)} + Q(\text{date*trt})$                                                                                         | MS(Residual) | 470      | 2.02  | 0.0175  |
| Rep       | 4   | 2.52        | $\text{Var(Residual)} + 8 \text{ Var(date*rep)} + 112 \text{ Var(rep)}$                                                             | MS(date*rep) | 52       | 0.78  | 0.5410  |
| Date*Rep  | 52  | 3.22        | $\text{Var(Residual)} + 8 \text{ Var(date*rep)}$                                                                                    | MS(Residual) | 470      | 1.61  | 0.0061  |
| Smpl(Trt) | 14  | 0.97        | $\text{Var(Residual)} + 30.571 \text{ Var(smpl(trt))}$                                                                              | MS(Residual) | 470      | 0.49  | 0.9404  |
| Residual  | 470 | 2.00        | Var(Residual)                                                                                                                       |              |          |       |         |

**Table A2.11: 2006 Percent defoliation per plant ANOVA of attractant treatments**

| Source    | DF  | Mean Square | Expected Mean Square                                                                                      | Error Term                                                           | Error DF | F     | P       |
|-----------|-----|-------------|-----------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------|----------|-------|---------|
| Trt       | 1   | 0.028       | $\text{Var(Residual)} + 30 \text{ Var(smpl(trt))} + Q(\text{trt}, \text{date}^* \text{trt})$              | $0.9 \text{ MS(smpl(trt))} + 0.1 \text{ MS(Residual)}$               | 13       | 10.34 | 0.0068  |
| Date      | 7   | 0.059       | $\text{Var(Residual)} + 6.8571 \text{ Var(date}^* \text{rep)} + Q(\text{date}, \text{date}^* \text{trt})$ | $0.9882 \text{ MS(date}^* \text{rep)} + 0.0118 \text{ MS(Residual)}$ | 28       | 2.40  | 0.0465  |
| Date*Trt  | 7   | 0.015       | $\text{Var(Residual)} + Q(\text{date}^* \text{trt})$                                                      | $\text{MS(Residual)}$                                                | 226      | 1.71  | 0.1081  |
| Rep       | 4   | 0.028       | $\text{Var(Residual)} + 6.4 \text{ Var(date}^* \text{rep)} + 51.2 \text{ Var(rep)}$                       | $0.9224 \text{ MS(date}^* \text{rep)} + 0.0776 \text{ MS(Residual)}$ | 30       | 1.21  | 0.3275  |
| Date*Rep  | 28  | 0.025       | $\text{Var(Residual)} + 6.9388 \text{ Var(date}^* \text{rep)}$                                            | $\text{MS(Residual)}$                                                | 226      | 2.85  | <0.0001 |
| Smpl(Trt) | 6   | 0.002       | $\text{Var(Residual)} + 33.333 \text{ Var(smpl(trt))}$                                                    | $\text{MS(Residual)}$                                                | 226      | 0.23  | 0.9.654 |
| Residual  | 226 | 0.008       | $\text{Var(Residual)}$                                                                                    |                                                                      |          |       |         |

| Table A2.12: 2006 Number of beetles per plant ANOVA of Butternut Squash rows at 1.5m and 9m from the trap crop |     |             |                                                     |               |          |       |         |  |  |
|----------------------------------------------------------------------------------------------------------------|-----|-------------|-----------------------------------------------------|---------------|----------|-------|---------|--|--|
| Source                                                                                                         | DF  | Mean Square | Expected Mean Square                                | Error Term    | Error DF | F     | P       |  |  |
| Trt                                                                                                            | 1   | 6.221       | Var(Residual) + 70 Var(smpl(trt)) + Q(trt,date*trt) | MS(smpl(trt)) | 6        | 18.99 | 0.0048  |  |  |
| Date                                                                                                           | 13  | 19.836      | Var(Residual) + 8 Var(date*rep) + Q(date,date*trt)  | MS(date*rep)  | 52       | 36.52 | <0.0001 |  |  |
| Date*Trt                                                                                                       | 13  | 1.126       | Var(Residual) + Q(date*trt)                         | MS(Residual)  | 470      | 1.87  | 0.0312  |  |  |
| Rep                                                                                                            | 4   | 2.090       | Var(Residual) + 8 Var(date*rep) + 112 Var(rep)      | MS(date*rep)  | 52       | 3.85  | 0.0082  |  |  |
| Date*Rep                                                                                                       | 52  | 0.543       | Var(Residual) + 8 Var(date*rep)                     | MS(Residual)  | 470      | 0.90  | 0.6677  |  |  |
| Smpl(Trt)                                                                                                      | 6   | 0.328       | Var(Residual) + 70 Var(smpl(trt))                   | MS(Residual)  | 470      | 0.54  | 0.7745  |  |  |
| Residual                                                                                                       | 470 | 0.602       | Var(Residual)                                       |               |          |       |         |  |  |

**Table A2.13: 2006 Percent defoliation per plant ANOVA of Butternut Squash rows at 1.5m and 9m from the trap crop**

| Source    | DF  | Mean <sup>2</sup> | Expected Mean Square                                                                                                           | Error Term                                                                         | Error DF | F    | P       |
|-----------|-----|-------------------|--------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------|----------|------|---------|
| Trt       | 1   | 0.000006          | $\text{Var}(\text{Residual}) + 30 \text{ Var}(\text{smp}(\text{trt})) + \text{Q}(\text{trt}, \text{date} * \text{trt})$        | $0.9 \text{ MS}(\text{smp}(\text{trt})) + 0.1 \text{ MS}(\text{Residual})$         | 6.5343   | 0.00 | 0.9772  |
| Date      | 7   | 0.019901          | $\text{Var}(\text{Residual}) + 6.8571 \text{ Var}(\text{date} * \text{rep}) + \text{Q}(\text{date}, \text{date} * \text{trt})$ | $0.9882 \text{ MS}(\text{date} * \text{trt}) + 0.0118 \text{ MS}(\text{Residual})$ | 28.593   | 6.68 | <0.0001 |
| Date*Trt  | 7   | 0.009693          | $\text{Var}(\text{Residual}) + \text{Q}(\text{date} * \text{trt})$                                                             | $\text{MS}(\text{Residual})$                                                       | 226      | 3.67 | 0.0009  |
| Rep       | 4   | 0.000815          | $\text{Var}(\text{Residual}) + 6.4 \text{ Var}(\text{date} * \text{rep}) + 51.2 \text{ Var}(\text{rep})$                       | $0.9224 \text{ MS}(\text{date} * \text{rep}) + 0.0776 \text{ MS}(\text{Residual})$ | 32.31    | 0.28 | 0.8915  |
| Date*Rep  | 28  | 0.002981          | $\text{Var}(\text{Residual}) + 6.9388 \text{ Var}(\text{date} * \text{rep})$                                                   | $\text{MS}(\text{Residual})$                                                       | 226      | 1.13 | 0.3063  |
| Smp1(Trt) | 6   | 0.006731          | $\text{Var}(\text{Residual}) + 33.333 \text{ Var}(\text{smp}(\text{trt}))$                                                     | $\text{MS}(\text{Residual})$                                                       | 226      | 2.55 | 0.0208  |
| Residual  | 226 | 0.002641          | $\text{Var}(\text{Residual})$                                                                                                  |                                                                                    |          |      |         |

**Table A2.14: 2006 Number of striped cucumber beetles per plant LS means separation of attractant treatments<sup>1</sup>**

| Date    | Means Separation of Treatments <sup>2</sup> |                      |                     |
|---------|---------------------------------------------|----------------------|---------------------|
|         | Hubbard Squash                              | Squash + Attractants | Grass + Attractants |
| 6-12-06 | 5.50±0.92a                                  | 6.55±1.22a           | .                   |
| 6-15-06 | 14.15±1.50a                                 | 16.65±1.68a          | .                   |
| 6-19-06 | 35.05±4.08a                                 | 45.25±5.72a          | .                   |
| 6-22-06 | 25.85±5.39a                                 | 29.95±4.07a          | .                   |
| 6-26-06 | 13.20±2.09a                                 | 14.40±2.30a          | .                   |
| 6-29-06 | 14.35±2.71a                                 | 20.55±4.05a          | .                   |
| 7-03-06 | 14.20±3.11a                                 | 33.60±5.14b          | .                   |
| 7-07-06 | 15.85±2.27a                                 | 30.45±3.74b          | .                   |
| 7-11-06 | 15.20±1.88b                                 | 27.80±3.02c          | 0.20±0.20a          |
| 7-14-06 | 18.30±2.25a                                 | 21.35±2.40a          | .                   |
| 7-18-06 | 13.40±1.84a                                 | 10.50±1.08a          | .                   |
| 7-27-06 | 25.20±2.41a                                 | 29.75±3.04a          | .                   |
| 8-01-06 | 21.55±3.37a                                 | 22.50±1.86a          | .                   |
| 8-10-06 | 20.15±3.27a                                 | 29.70±4.60a          | .                   |

<sup>1</sup> Means were compared using *t*-tests of least squares means.

<sup>2</sup> Letters differing across rows signify significant differences at P = 0.05.

**Table A2.15: 2006 Percent defoliation per plant L.S means separation of attractant treatments<sup>1</sup>**

| Date    | Means Separation of Treatments <sup>2</sup> |                      |
|---------|---------------------------------------------|----------------------|
|         | Hubbard Squash                              | Squash + Attractants |
| 6-29-06 | 16.75±2.84a                                 | 13.00±1.11a          |
| 7-03-06 | 8.75±1.02a                                  | 10.00±1.26a          |
| 7-11-06 | 10.00±1.97a                                 | 10.00±2.58a          |
| 7-14-06 | 9.00±0.93a                                  | 8.50±1.03a           |
| 7-18-06 | 9.00±1.63a                                  | 7.50±1.12a           |
| 7-27-06 | 5.50±0.72a                                  | 6.25±0.62a           |
| 8-01-06 | 11.25±1.85a                                 | 8.50±1.63a           |
| 8-10-06 | 21.50±5.43b                                 | 12.50±2.25a          |

<sup>1</sup> Means were compared using *t*-tests of least-squares means.

<sup>2</sup> Letters differing across rows signify significant differences at *P* = 0.05.

**Table A2.16: 2006 Striped cucumber beetles per plant LS means separation of Butternut Squash rows<sup>1</sup>**

| Date    | Means Separation of Treatments <sup>2</sup> |              |
|---------|---------------------------------------------|--------------|
|         | 1.5m Butternut                              | 9m Butternut |
| 6-12-06 | 0.80±0.37a                                  | 1.55±0.39a   |
| 6-15-06 | 2.25±0.46a                                  | 4.30±0.58b   |
| 6-19-06 | 8.10±1.32a                                  | 5.90±0.90a   |
| 6-22-06 | 4.15±1.03a                                  | 4.40±0.54a   |
| 6-26-06 | 2.35±0.48a                                  | 4.50±0.62b   |
| 6-29-06 | 2.65±0.50a                                  | 3.65±0.71a   |
| 7-03-06 | 3.35±0.80a                                  | 4.75±1.20a   |
| 7-07-06 | 2.60±0.84a                                  | 2.65±0.48a   |
| 7-11-06 | 1.15±0.66a                                  | 2.80±0.60a   |
| 7-14-06 | 2.25±0.43a                                  | 3.45±0.94a   |
| 7-18-06 | 5.20±0.62a                                  | 4.50±0.72a   |
| 7-27-06 | 12.20±1.60a                                 | 14.65±1.54a  |
| 8-01-06 | 6.10±0.45a                                  | 9.05±0.89a   |
| 8-10-06 | 13.00±2.50a                                 | 8.90±1.10a   |

<sup>1</sup> Means were compared using *t*-tests of least-squares means.

<sup>2</sup> Letters differing across rows signify significant differences at P = 0.05.

**Table A2.17: 2006 Percent defoliation per plant LS means separation of Butternut Squash rows<sup>1</sup>**

| Date    | Means Separation of Treatments <sup>2</sup> |              |
|---------|---------------------------------------------|--------------|
|         | 1.5m Butternut                              | 9m Butternut |
| 6-29-06 | 10.75±1.16a                                 | 11.00±1.56a  |
| 7-03-06 | 11.75±1.51a                                 | 10.00±1.03a  |
| 7-11-06 | 8.50±1.67a                                  | 9.00±1.25a   |
| 7-14-06 | 6.00±0.46a                                  | 6.00±0.46a   |
| 7-18-06 | 7.50±1.12a                                  | 6.50±0.76a   |
| 7-27-06 | 5.00±0.63a                                  | 4.25±0.55a   |
| 8-01-06 | 4.75±0.44a                                  | 12.00±2.06a  |
| 8-10-06 | 8.75±1.88a                                  | 5.80±0.89a   |

<sup>1</sup> Means were compared using *t*-tests of least-squares means.

<sup>2</sup> Letters differing across rows signify significant differences at P = 0.05.

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