Andrew Cavanagh
University of Massachusetts Extension
250 Natural Resources Rd
Amherst, MA 01003
Phone: (413) 577-3976
Fax: (413) 545-5858
Email: acavanagh@psis.umass.edu

Economic Entomology

Horticultural Entomology

Using Trap Crops for Control of *Acalymma vittatum* (Coleoptera: Chrysomelidae) Reduces Insecticide Use in Butternut Squash

A. Cavanagh[1], R. Hazzard[1], L. S. Adler[2] , J. Boucher[3]

[1]Dept of Plant, Soil and Insect Science, 250 Natural Resources Rd, Amherst, University of Massachusetts, MA 01003

[2]Dept of Plant, Soil and Insect Science, 270 Stockbridge Road, University of Massachusetts, Amherst MA 01003

[3]Cooperative Extension System, 24 Hyde Avenue, University of Connecticut, Vernon CT 06066

Abstract

Striped cucumber beetle, *Acalymma vittatum* F.*,* is the primary insect pest of cucurbit crops in the Northeastern United States. Adult beetles colonize squash crops from field borders, causing feeding damage at the seedling stage and transmitting bacterial wilt *Erwinia tracheiphila* Hauben et al 1999. Conventional control methods rely on insecticide applications to the entire field, but surrounding main crops with a more attractive perimeter could reduce reliance on insecticides. *Acalymma vittatum* demonstrates a marked preference for Blue Hubbard squash (*Cucurbita maxima* Duchesne) over butternut squash (*C. moschata* Poir). Given this preference, Blue Hubbard squash has the potential to be an effective perimeter trap crop. We evaluated this system in commercial butternut fields in 2003 and 2004, comparing fields using perimeter trap cropping with Blue Hubbard to conventionally managed fields. In 2003 we used a foliar insecticide to control beetles in the trap crop borders, and in 2004 we compared systemic and foliar insecticide treatments for the trap crop borders. We found that using a trap crop system reduced or eliminated the need to spray the main crop area, reducing insecticide use by up to 94% compared to conventional control methods, with no increase in herbivory or beetle numbers. We surveyed the growers who participated in these experiments and found a high level of satisfaction with the effectiveness and simplicity of the system. These results suggest that this method of pest control is both effective and simple enough in its implementation to have high potential for adoption amongst growers.

Key words: *Acalymma vittatum,* butternut squash, *Cucurbita maxima*, integrated pest management, perimeter trap crops

Introduction

Vegetable crops are an important commodity in the United States, valued at $12.7 billion in 2002 (USDA 2002). Northeastern states have a high proportion of their vegetable crop industry invested in cucurbit crops, including squash, melons, cucumbers, and pumpkins; in Massachusetts, 40% of the vegetable-crop acreage is devoted to cucurbit crops (USDA 2002). The value of winter squash has been estimated at greater than $5 million for the state (Hollingsworth et al. 1998). Butternut squash (*C. moschata* Poir) is the primary winter squash crop in MA, representing 54% of all winter squash harvested in the Massachusetts (Clifton 2007). The main insect pest of butternut squash is the striped cucumber beetle‸~~(~~*Acalymma vittatum* F.~~)~~, which also serves as the vector for *Erwinia tracheiphila* Hauben et al. 1999, a bacterium which causes a lethal wilt disease in cucurbits. The current chemical control strategies for this pest face rising costs, environmental concerns, and the potential for developing pesticide resistance. Growers often implement integrated pest management (IPM) strategies to mitigate spraying, but this generally entails spraying based on economic thresholds rather than reducing the amount of the crop that is sprayed. Perimeter trap cropping represents an IPM strategy that can potentially reduce the proportion of the field that requires insecticides (reviewed in Shelton & Badenes-Perez 2006). Blue Hubbard‸~~(~~*Cucurbita maxima* Duchesne~~)~~, due to its attractiveness to striped cucumber beetles (Boucher & Durgy 2004, McGrath & Shishkoff 2000, Pair 1997), has strong potential as a trap crop in a perimeter trap cropping system (PTC hereafter). Our experiments tested a Blue Hubbard PTC system over two years in commercial butternut fields.

Striped cucumber beetles are ranked as the most important insect pest in cucurbit crops in the Northeastern US, and the Northeast Vegetable IPM Working Group has ranked the cucumber beetle and bacterial wilt complex as a region-wide problem that causes significant reduction in yield and results in high insecticide use (N.E. Vegetable IPM Working Group, 2003). In New England, cucumber beetles overwinter as adults in the woods and brush borders surrounding fields, colonize cucurbit fields from the edges inward in early to mid-June, and can completely destroy newly germinated plants (Metcalf & Metcalf 1993). Damage to leaves and early flowers takes place over a month-long period in New England, followed by a period of inactivity aboveground after adults have laid eggs in the soil and died. New adults emerge in mid to late summer and continue to feed, damaging leaves, flowers, and fruit, before leaving the fields for overwintering sites (Metcalf & Metcalf 1993). Relatively low amounts of herbivory (20% by the 3-leaf stage) can significantly reduce yield in winter squash (Hoffmann et al. 2000). In addition, the percentage of the beetle population infected with *Erwinia tracheiphila* may be as high as 78% (Fleischer et al. 1999). Cucurbits suffer the greatest yield loss from the bacterial wilt caused by *E. tracheiphila* when they are infected as young plants, making early season protection from beetles critical for bringing a crop to harvest (Yao et al. 1996, Brust 1997). Yield losses from bacterial wilt in winter squash and pumpkins have increased in the past decade (McGrath 2004), necessitating the development of control methods that reduce transmission of wilt during the most susceptible stages of plant development.

There are many issues associated with insecticide use, including time and financial costs, human health, environmental concerns, the potential for evolution of insect resistance, and damage to non-target organisms (Jeryaratnam 1990, Denholm & Rowland 1992, Cassarett et al 2001). Conventional pest management for many cucurbit crops requires two to eight applications of insecticides such as carbaryl, other carbamates, or synthetic pyrethroids (Brust & Rane 1995, Brust & Foster 1999). It is possible that full field insecticide applications of insecticides can reduce yield by deterring or harming pollinators (e.g., Brust & Foster 1995), on which cucurbit crops depend for pollination and fruit set (Kemp and Bosch 2001). Growers in the Northeast have recently adopted the use of systemic insecticides (e.g., imidacloprid) in the furrow at planting, which protects cucurbit crops from early feeding damage. This has the advantage of eliminating the need for precise timing with foliar applications, and potentially lowering overall pesticide use. However, the insecticide cost is higher than with foliar applications, and widespread adoption of systemic insecticides may lead to the evolution of insect resistance more quickly than foliar treatments. Imidacloprid has caused enough concern among beekeepers that it has been banned in France, though research has thus far not supported these concerns (Maus et al. 2007). Insecticide resistance in not widespread in *A. vittatum*, but has been reported in the closely related *Diabrotica virgifera virgifera* LeConte (Zhu 2001), and strategies that reduce the risk of pesticide resistance are an essential part of any IPM program. Therefore, developing methods for controlling cucumber beetles with limited reliance on insecticides could have the advantages of delaying insecticide resistance, reducing environmental impacts, and preserving pollinators and natural enemies.

Perimeter trap cropping uses insect preference for certain hosts to concentrate pest insects in the crop border, away from the main crop. The more attractive crop is planted around the outer edge of the entire main crop (Hokkanen 1991, Boucher et al. 2003, Boucher & Durgy 2004, Shelton & Badenes-Perez 2006). Similar strategies have been used successfully in collards, summer squash, peppers, and papaya (Aluja et al. 1997, Mitchell et al. 2000, Boucher et al. 2003, Boucher & Durgy 2004). Striped cucumber beetles overwinter in the woods surrounding fields, and move into a crop from the edges. This makes them a good candidate for control via PTC, as they will encounter the attractive border before they come into contact with the main crop. The beetles concentrate in the borders before dispersing into the field, allowing insecticides to be applied to a much smaller area. If the border is treated with a systemic insecticide at planting, the crop may be protected throughout the critical early growth period. Reducing the field area sprayed with insecticides may also provide a refuge for beetles that are susceptible to chemical controls, potentially delaying the evolution of resistance (Liu & Tabashnik 1997, Zhao et al. 2000, Tang et al. 2001).

Blue Hubbard squash is highly attractive to striped cucumber beetles in comparison with butternut squash (*C. moschata* Poir) and has low susceptibility to bacterial wilt (McGrath & Shishkoff 2000). It has been used as an effective perimeter trap crop in summer squash and cantaloupe, allowing for adequate beetle control with greatly reduced applications of insecticides (Pair 1997, Boucher & Durgy 2004). Blue Hubbard is similar to butternut squash in terms of its days to maturity, temperature and spacing requirements. These factors make it a promising perimeter trap crop for butternut squash.

The goal of this research was to test the effectiveness of a perimeter trap crop system in reducing the amount of insecticide needed to effectively control the primary pest of butternut. We performed trials for two years in commercial fields to determine whether a PTC system would allow growers to reduce insecticide use without increasing herbivory or beetle numbers in the main crop. We compared herbivory and insecticide use between fields with a PTC system or conventional full field insecticide applications.

Materials and Methods

Experimental Design. To assess the effectiveness of PTC systems in commercial agriculture, we assigned treatments to 13 commercial butternut squash fields in MA. Seven fields were planted and managed using a PTC system. The other six used conventional chemical control practices. Fields ranged in size from 0.20 to 10.05 hectares (mean+s.e.: 1.38 +0.09).

Borders comprised an estimated 3-14% of the total field. All squash was planted by machine in rows 1.5-2.1 m apart, with an in-row seed spacing of 35.5-45.7 cm. Separation between fields was variable, with a 200 m minimum distance between fields. No fields were immediately adjacent to other cucurbit crops. As we were working with existing agricultural fields and commercial crops, our ability to control for size, shape, and other field variables was limited; however, these variable conditions are exactly those under which this system will have to function to be useful to growers. Similar experiments were conducted in 2003 and in 2004. All growers planted their fields as they normally would, except for the inclusion of the border in the PTC fields. Cultivation and nutrient management were performed by the grower, as per the needs of the field and standard management practices. The threshold over which we recommended spraying in the main crop was an average of one beetle per plant up to the five leaf stage and two beetles per plant thereafter until flowering.

All PTC fields used a Blue Hubbard border as the trap crop. During 2003, this border was treated with a foliar application of carbaryl (Sevin XLR Plus, Bayer CropScience, Research Triangle Park, NC) at the first sign of beetles and at roughly 10 day intervals thereafter. The main crop in PTC systems was left untreated. Conventional fields received full field applications of insecticide according to the normal practices of the growers, which were dictated by beetle pressure. Fields were monitored at weekly intervals from 3 June to 14 July (peak beetle season that year). During each census, 25 plants were randomly selected and scouted in the field borders to determine beetle numbers and the level of herbivory in the borders of the field. Another 25 were randomly selected and scouted from a row half way between the border and the center of the field to determine beetle numbers and the level of herbivory in the main crop. Plants were scouted for number of live and dead beetles, presence of cotyledon damage, and overall defoliation of the plant. We rated cotyledon damage as the presence or absence of damage, and overall leaf defoliation on a 0-5 scale in 20% increments, with 0 for no damage. Cotyledon damage was recorded as a separate measure from leaf herbivory because it is possible that beetle preferences differs between cotyledons and true leaves due to chemical differences (as discussed in Tallammy & Krischik 1988). We also recorded insecticide use as the number of times borders and/or main crops were sprayed.

The experimental design in 2004 was very similar to that of 2003, except that we also examined the effects of treating the border with the systemic insecticide imidacloprid (Admire 2F, Bayer CropScience, Research Triangle Park, NC) using a furrow drench applied at planting to the Hubbard borders of the PTC fields and to the whole field in the conventional fields. This was done after consulting with several growers, as the use of a systemic seemed likely to alleviate difficulties in timing the initial spray correctly. The design was adapted to include two levels of insecticide: systemic (Admire) and foliar (Sevin), crossed in a 2x2 factorial design with system (PTC or conventional), for a total of four treatment combinations. We initially had three fields per treatment combination, for a total of 12 fields. One of our PTC systemic fields failed to emerge due to wet weather, leaving only two fields in that category. Fields were scouted for beetles and herbivory at weekly intervals between 4 June and 6 July following the 2003 protocol. The number of sprays required for adequate beetle control was recorded for each field. At the end of the season in 2004, growers were given a survey in which they were asked to quantify their satisfaction with different aspects of the system, including its effectiveness, usability, cost relative to conventional methods, and impact on yield relative to their past experiences with more traditional methods.

Statistical Analysis. We asked how PTC *vs*. conventional management affected herbivory and beetle numbers in the border and main crop, and what proportion of the field was treated with insecticide. All data were analyzed using PROC GLM in SAS V. 9.1 (SAS-Institute, 2004). We evaluated the impact of a PTC system on herbivory and beetle numbers in the main crop using MANOVA with system (PTC or conventional) and insecticide type (foliar or systemic, 2004 only) as the independent factors. We used the same model for beetle numbers and damage in field borders to determine whether borders of PTC fields had more beetles than borders of conventional fields. Beetle numbers, defoliation, and cotyledon damage were averaged over censuses to provide one measure per response for analysis. Analyzing data from the first four censuses alone, when beetle damage may have the highest impact on plant health, provided qualitatively the same results as averaging over the whole season (data not shown). Beetle numbers were square root transformed to meet assumptions of normality; other data were normal without transformation. Cotyledon damage was not recorded in one field with early cultivation, and so was analyzed separately in both years since MANOVA excludes replicate fields with any missing responses.

Insecticide use was analyzed as total proportion of field with insecticides applied. As fields were of uneven size and shape, proportion of field with insecticides applied was a more universal measurement than area treated, amount of insecticide used, or other absolute measures of insecticide use. Because fields were of uneven shape the border area was estimated as if the fields were rectangular with length to width proportions of 1:2. For example, a two hectare field of irregular proportions would be standardized as a rectangular two hectare field with a width of 100 m and a length of 200 m. Assuming that the PTC borders were 1.8 m wide, this would give us an estimated border area of 1092 m^2. Standardizing the fields in this way allowed us to quantify and compare pesticide use between fields of different size and shape. Exact measurement of the sometimes curved or jagged field edges was not practical. As all fields were roughly rectangular in shape, we believe that this method provides a reasonable estimation of border area. The total proportion of fields treated in each system were compared using ANOVA with system (PTC or conventional) as the independent variable in 2003, and system, insecticide type (foliar or systemic), and their interactions as the independent variables in 2004. In both years, the response was normalized with square root transformations. We used square root transformations instead of the arcsine(sqrt(x)) transformation usually used for proportional data because multiple sprays of the entire field resulted in proportions greater than one. Grower satisfaction surveys were summarized but not subject to statistical analysis.

Results

Herbivory and beetle numbers. In 2003, system (PTC or conventional) did not affect herbivory in the main crop (MANOVA: Wilks' $\lambda = 0.97$, $F_{2, 10} = 0.16$, $P = 0.85$). ANOVA indicated no significant effect of PTC on cotyledon damage ($F_{1, 10} = 0.52$, $P = 0.49$) in the main crop, which was analyzed separately in both years due to missing values for one field. PTC treatment had a significant effect on herbivory in the borders (MANOVA: Wilks' $\lambda = 0.52$, $F_{2, 10} = 4.59$, $P = 0.039$). Subsequent univariate analysis indicated that the Blue Hubbard borders of the PTC fields attracted significantly more beetles than the borders of the conventional fields (Fig. 1), but defoliation ratings and cotyledon damage were not different between PTC and conventional fields.

In 2004, neither system (PTC or conventional), insecticide treatment (foliar or systemic), nor their interaction significantly affected beetle numbers, defoliation (MANOVA: Wilks' $\lambda > 0.45$, $F_{2, 6} < 3.70$, $P > 0.09$ for all) or cotyledon damage in the main crop (ANOVA: $F_{1, 6} = 0.53$,

$P = 0.50$). There were eight times as many beetles in Blue Hubbard compared to conventional borders (mean + s.e.: PTC: 2.95 +1.50; Conventional: 0.36 + 0.21), although the effects of system, insecticide, and their interaction on herbivory and beetle numbers in the borders were not statistically significant (MANOVA: Wilks' $\lambda > 0.54$, $F_{2,6} < 0.29$, $P > 0.16$ for all; Fig. 1).

Insecticide use. In 2003, the proportion of PTC fields treated with insecticides was half that of the conventional fields, although this difference was not statistically significant ($F_{1,11} = 2.65$, $P = 0.13$; Fig. 2).

In 2004, using a PTC system reduced the proportion of the field requiring insecticides by an average of 94% ($F_{1,7} = 111.36$, $P < 0.0001$, Fig. 2). Insecticide type (foliar or systemic) had a marginally significant effect on the proportion of the field requiring treatment ($F_{1,7} = 5.23$, $P = 0.056$; mean ± s.e.: foliar: 0.88 ± 0.38; systemic 0.62 ± 0.24). The interaction of system (PTC or conventional) and insecticide (foliar or systemic) was not significant ($F_{1,11} = 1.01$, $P = 0.35$), indicating that PTC effectively reduced insecticide use regardless of the type of insecticide used.

Discussion

Fields with Blue Hubbard borders required 50% and 94% less insecticide use than conventional fields in 2003 and 2004 respectively, although this effect was only significant in 2004. Beetle pressure was similar in both years (mean beetles per plant in the main crop was 0.28 in 2003 and 0.31 in 2004). Although the PTC fields required less insecticide overall, the PTC system did not eliminate the need for insecticides in the main crop; in 2003 six out of seven PTC fields received one or more full-field sprays. One of the major obstacles to effective use of PTC in 2003 was the precise timing required to effectively apply insecticides to the Blue Hubbard border before it was breached by the beetles. Another obstacle was grower reluctance to refrain from spraying crops, even though in some cases they were not at risk. Issues with the critical timing of the foliar insecticides were addressed in the 2004 trials with the use of a systemic insecticide at planting and better communication with participating growers. These modifications led to greatly improved effectiveness; in 2004 the main crop of PTC fields did not exceed threshold beetle numbers and no PTC fields required full-field insecticide treatments. There was a marginally significant increase in the proportion of the field requiring spray in fields treated with a foliar insecticide regardless of system type. This difference is likely due to some of the conventional foliar treated fields requiring multiple applications, while the systemic fields required only one application of insecticide for full season control. It is important to note that in 2004 the beetle populations and herbivory in the main crop of all fields were not significantly different even though the main crops of the PTC fields were not treated with any insecticide, while the main crops of the conventional fields all required insecticide treatment. These results show that using a PTC system can reduce or eliminate the need for full field insecticide treatments on this crop, leading to higher profit margins for the grower, reduced exposure to potentially dangerous toxins, and potential preservation of pollinators and natural enemies.

Ten growers who were introduced to PTC in this research were surveyed at the end of the 2004 growing season. All considered the system to be good or excellent overall and were satisfied with the way the system worked for them. Eight of the ten growers using the system found that it saved them money; the remaining two felt there was no difference in savings because the bulk of their costs was due to the labor of mixing insecticides, rather than the amount and area sprayed. All of the growers spent the same or less time on beetle control using a PTC system compared with conventional methods, and all of the growers reduced their insecticide use by implementing the PTC system. The results of the grower survey, while anecdotal, support the empirical evidence in this study. To the agricultural community at large, the opinions and experiences of fellow growers often weigh more heavily than experimental data in their considerations of pest management options. Our objective for this study was to evaluate not only whether PTC reduced insecticide use, but also how PTC would be accepted by the growers. The positive results of this survey, and our experience in working with the growers who volunteered their fields, showed that PTC has strong potential for adoption.

While a reduction in insecticide use will likely be the most important benefit for the growers who adopt PTC systems, there may be other advantages as well. Using a cropping strategy that provides an unsprayed refuge for susceptible pest individuals can delay the onset of insecticide resistance in insect populations (Liu & Tabashnik 1997, Zhao et al. 2000). In addition, it has been shown that increasing the size of the refuge generally slows the development of resistance (Tang et al. 2001). Perimeter trap cropping provides for a large proportion of the field (up to 97% in this study) to act as a refuge for susceptible individuals, and may help preserve the useful life of several important agricultural chemicals. While directly evaluating the effectiveness of PTC in delaying insecticide resistance is beyond the scope of this study, it is clear that the system meets the basic criteria for an effective refuge strategy.

Some current implementations of IPM have been criticized for being too reliant on chemical controls and under-utilizing tactics which promote the inherent strengths of agricultural ecosystems (Lewis et al. 1997, Ehler & Bottrell 2000). Rather than relying entirely on scout-and-spray approaches, PTC modifies crop layout to take advantage of pest host colonization behavior. Our work shows that PTC significantly reduces insecticide use while potentially providing a refuge to preserve beneficial insects such as pollinators and natural enemies, and may also help delay insecticide resistance. In this sense, PTC as an IPM tactic represents a total system approach to pest management.

The basic principles of trap cropping are not new. Many traditional farming systems rely on trap cropping for control of insect pests, and there are examples in the US dating back to 1860 (Hokkanen 1991). With the advent of modern chemical controls, these methods of pest control have largely fallen out of use. Trap cropping has only recently been adopted in modern commercial agriculture (Hokkanen 1991, Pair 1997, Boucher et al. 2003, Boucher & Durgy 2004, Shelton & Badenes-Perez 2006). Traditional chemical control measures face increased pressure from rising costs, environmental concerns, and insecticide resistance, necessitating the development of alternative pest control measures. In his review of trap crop systems, Hokkanen (1991) suggested that at least 35-40 important pest species could likely be controlled with some form of trap cropping, and yet only a handful of trap crop systems are used regularly in commercial agriculture. In a similar more recent review, Shelton & Bedenes-Perez (2006) found that trap cropping was still underutilized in commercial agriculture, even in crops in which field trials have shown success with the system. Exploring the potential of new trap crop systems and developing methods that are acceptable to growers are important strategies for increasing the economic and environmental sustainability of farms.

Our experiments demonstrated that perimeter trap cropping can provide effective striped cucumber beetle control while greatly reducing insecticide use in commercial butternut squash fields. Most of the growers who participated in this experiment have adopted this system as their own, and were still using it as of this writing. The high level of satisfaction with the system expressed by growers who participated in the experiment indicates that PTC has excellent potential for adoption by growers wishing to reduce their insecticide costs and exposure.

Acknowledgements

We thank Neal Woodard, Amanda Brown, Tim Andematten, Wes Autio, and Sorrel Hatch, without whose help this work would not have been possible, and Dr. Rob Wick and two anonymous reviewers for comments on the manuscript. We thank cooperating growers John Boisvert, Wally Czjakowski, Edwin Matuszko, Al and Bill Mckinstry, Ray Rex, Ken Santos, Len Shuzdak, Jim Ward, and Tim Wheeler. Funding for this research was provided by grants from SARE (LNE03-177).

References

Aluja, M., Jimenez, A., Camino, M., Pinero, J., & Aldana, L. (1997). Habitat manipulation to reduce papaya fruit fly (diptera : Tephritidae) damage: Orchard design, use of trap crops and border trapping. J. Econ. Entomol., 90(6), 1567.

Baker, M. B., Alyokhin, A., Porter, A. H., Ferro, D. N., Dastur, S. R., & Galal, N. (2007). Persistence and inheritance of costs of resistance to imidacloprid in colorado potato beetle. J. Econ. Entomol., 100(6), 1871-1879.

Boucher, T. J., Ashley, R., Durgy, R., Sciabarrasi, M., & Calderwood, W. (2003). Managing the pepper maggot (diptera : Tephritidae) using perimeter trap cropping. J. Econ. Entomol., 96(2), 420-432.

Boucher, T. J., & Durgy, R. (2004). Demonstrating a perimeter trap crop approach to pest management on summer squash in New England. Journal of Extension, 42(5) http://www.joe.org/joe/2004october/rb2.shtml

Brust, G. E. (1997). Differential susceptibility of pumpkins to bacterial wilt related to plant growth stage and cultivar. Crop Prot., 16(5), 411-414.

Brust, G. E., & Foster, R. E. (1995). Semiochemical-based toxic baits for control of striped cucumber beetle (coleoptera, chrysomelidae) in cantaloupe. J. Econ. Entomol., 88(1), 112-116.

Brust, G. E., & Foster, R. E. (1999). New economic threshold for striped cucumber beetle (coleoptera : Chrysomelidae) in cantaloupe in the midwest. J. Econ. Entomol., 92(4), 936-940.

Brust, G. E., & Rane, K. K. (1995). Differential occurrence of bacterial wilt in muskmelon due to preferential striped cucumber beetle feeding. HortScience, 30(5), 1043-1045.

Clifton, N. (2007). New England winter squash crop profile New England Pest Management Network. http://pronewengland.org/INFO/PROpubs/PMSP/WinterSquashPMSP-2006-04-14.pdf.

Cassarett, L. J., Klaassen, D. C., & Doull, J. (2001). Chapter 22: Toxic effects of pesticides, pp 722-810. In Cassarett & Doull's Toxicology: The Basic Science of Poisons. McGraw-Hill Professional, New York, NY.

Denholm, I., & Rowland, M. W. (1992). Tactics for managing pesticide resistance in Arthropods: theory and practice. Annu. Rev. Entomol. 37:91-112.

Ehler, L. E., & Bottrell, D. G. (2000). The illusion of integrated pest management. Issues in Science and Technology, 16(3), 61.

Fleischer, S. J., de Mackiewicz, D., Gildow, F. E., & Lukezic, F. L. (1999). Serological estimates of the seasonal dynamics of Erwinia tracheiphila in Acalymma vittata (Coleoptera : Chrysomelidae). Environ. Entomol., 28(3), 470.

Hoffmann, M. P., Ayyappath, R., & Kirkwyland, J. J. (2000). Yield response of pumpkin and winter squash to simulated cucumber beetle (coleoptera : Chrysomelidae) feeding injury. J. Econ. Entomol., 93(1), 136-140.

Hokkanen, H. M. T. (1991). Trap cropping in pest-management. Annu. Rev. Entomol., 36, 119-138.

Hollingsworth, C., Mordhurst, C. A., Hazzard, R., & Howell, J. (1998). Pumpkin & winter squash project: 1998 grower survey and ICM project goals, p.14 in R. Hazzard, ed. Vegetable and Small Fruit Integrated Crop and Pest Management Program, 1998 Annual UMass Extension publication, Amherst MA.

Jeryaratnam, J. (1990). Acute pesticide poisoning: a major global health problem. World Health Stat. Q. 43(3) 139-144.

Kemp, W. P., and J. Bosch. 2001. Bees in your backyard. American Bee Journal 141: 183-185.

Lewis, W. J., van Lenteren, J. C., Phatak, S. C., & Tumlinson, J. H.,III. (1997). A total system approach to sustainable pest management. Proc. Natl. Acad. Sci., 94(23), 12243-12248.

Liu, Y. B., & Tabashnik, B. E. (1997). Experimental evidence that refuges delay insect adaptation to bacillus thuringiensis. Proc. R. Soc. of Lond. Biol., 264(1381), 605-610.

Maus, C., Cure, G., & Schmuck, R. (2007). Safety of imidacloprid seed dressings to honey bees: A comprehensive overview and compilation of the current state of knowledge. Bulletin of Insectology, 56(1), 51.

Metcalf, R.L. & Metcalf, A.M. (1993). Striped Cucumber Beetle, pp14.32-14.24. In Destructive and Useful Insects, 5th ed. McGraw-Hill, inc. New York, New York.

McGrath, M. T. (2004). Diseases of cucurbits and their management. In S. A. Naqvi (Ed.), Diseases of fruits and vegetable: Diagnosis and management (pp. 455). New York: Springer-Verlag New York, LLC.

McGrath, M. T., & Shishkoff, N. (2000). Comparison of cucurbit crop types and cultivars for their attractiveness to cucumber beetles and susceptibility to bacterial wilt. Biological and Cultural Tests 15:154 .

Mitchell, E. R., Guangye, H., & Johanowicz, D. (2000). Management of diamondback moth (lepidoptera : Plutellidae) in cabbage using collard as a trap crop. HortScience, 35(5), 875.

North East Vegetable IPM Working Group. 2003. IPM Priorities for Vegetables in the Northeast: http://northeastipm.org/work_vegepriority.cfm

Olson, E. R., Dively, G. P., & Nelson, J. O. (April 2000). Baseline susceptibility to imidacloprid and cross resistance patterns in colorado potato beetle (coleoptera: Chrysomelidae) populations. J. Econ. Entomol., 93, 447-458(12).

Pair, S. D. (1997). Evaluation of systemically treated squash trap plants and attracticidal baits for early-season control of striped and spotted cucumber beetles (coleoptera: Chrysomelidae) and squash bug (hemiptera: Coreidae) in cucurbit crops. J. Econ. Entomol., 90(5), 1307-1314.

SAS-Institute. (2004). Base SAS 9.1 procedures guide, vol 1-4. Cary, NC: SAS Publishing.

Shelton, A. M., & Badenes-Perez, F. R. (2006). Concepts and Applications of Trap Cropping in Pest Management. Annu. Rev. Entomol., 51(1), 285-308.

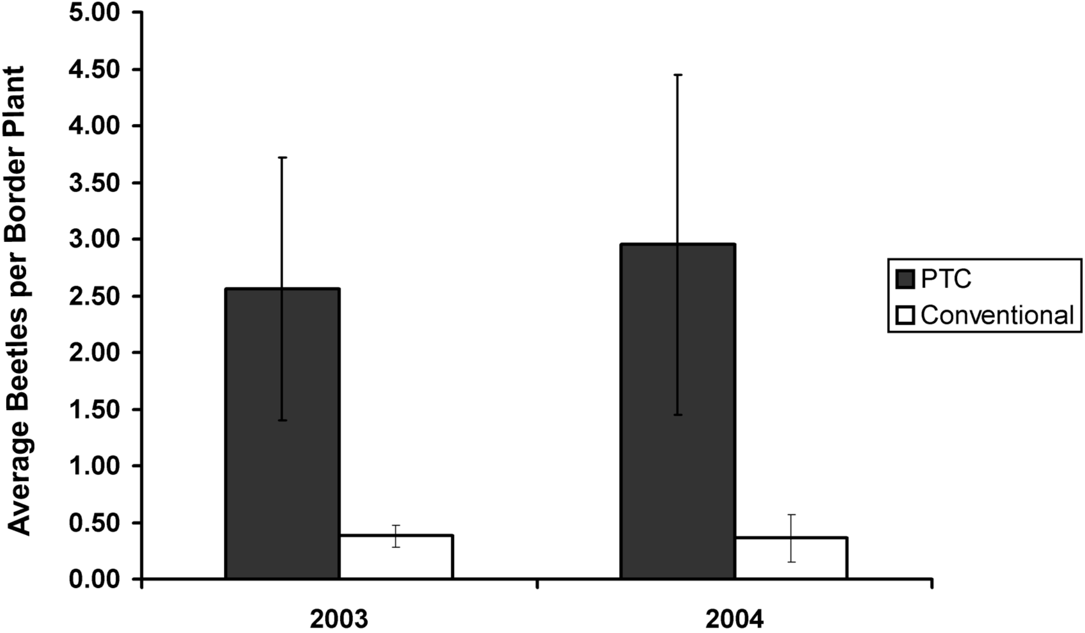
Tallamy, D.W., & Krischik, V.A. (1988). Variation and Function of Cucurbitacins in *Cucurbita*: an Examination of Current Hypothesis. Am. Nat, 133(6), 766-786.

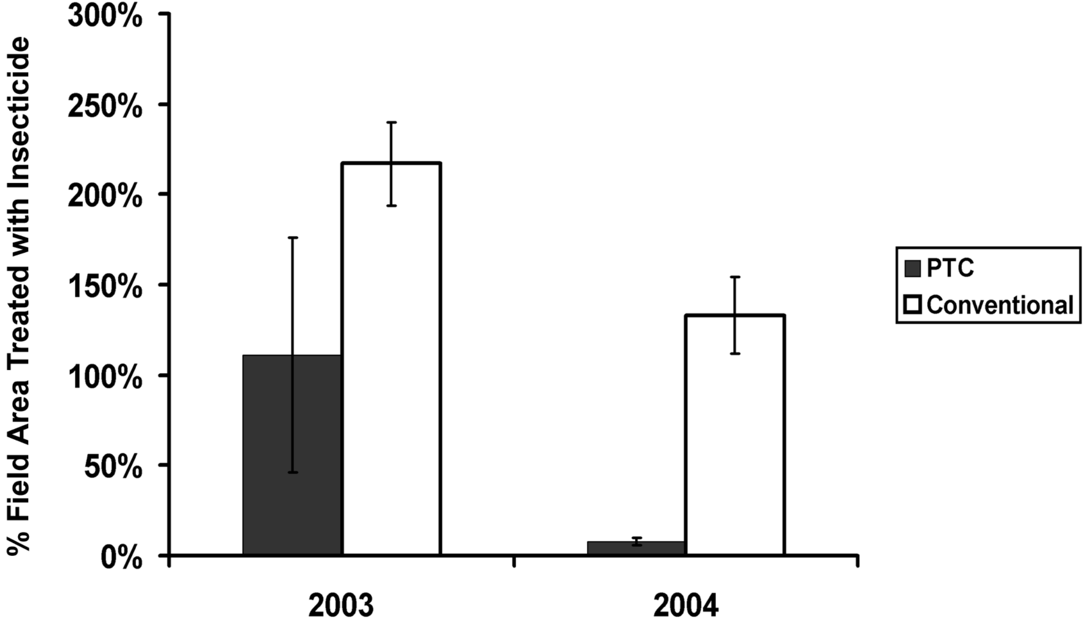
Tang, J. D., Collins, H. L., Metz, T. D., Earle, E. D., Zhao, J. Z., Roush, R. T., et al. (2001). Greenhouse tests on resistance management of Bt transgenic plants using refuge strategies. J. Econ. Entomol., 94(1), 240-247.

(USDA) U.S. Department of Agriculture. 2002. Census of Agriculture. USDA, Beltsville, MD.

Yao, C. B., Zehnder, G., Bauske, E., & Klopper, J. (1996). Relationship between cucumber beetle (coleoptera: Chrysomelidae) density and incidence of bacterial wilt of cucurbits. J. Econ. Entomol., 89(2), 510-514.

Zhao, J., Bishop, B. A., & Grafius, E. J. (October 2000). Inheritance and synergism of resistance to imidacloprid in the colorado potato beetle (coleoptera: Chrysomelidae). J. Econ. Entomol., 93, 1508-1514(7).


Average Beetles per Border Plant
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
2003
2004
PTC
Conventional


% Field Area Treated with Insecticide
300%
250%
200%
150%
100%
50%
0%
2003
2004
■ PTC
□ Conventional