Project Title: Sustainable systems for cucurbit crops on organic farms

Award number: 2009-51300-05581

Period of funding: September 1, 2009-August 31, 2012 (currently on one-year no-cost extension)

Primary Institution: Iowa State University

Project Director Name and email: Mark Gleason (mgleason@iastate.edu)

Project Director telephone: 515-294-0579

Website: Organic Cucurbit Growing Community (http://organiccucurbit.plp.iastate.edu/)

The purpose of the project: The project's goals were: 1) determine how spunbond row covers, compost fertilizers, and plant-growth-promoting bacteria can be integrated into practical and profitable organic production of muskmelon and butternut squash in Iowa, Kentucky, and Pennsylvania; 2) develop weather-based models to help predict key risk periods for cucumber beetles, squash bug, and squash vine borer; 3) find out how floral provisioning strips affect bee traffic and yield, and quality in adjacent squash and muskmelon fields; 4) determine how landscape diversity near farms affects bee visits to cucurbit crops; 5) calculate profitability of the integrated management strategies that were trialed in the project (goal 1); and 6) share the findings with organic vegetable growers in the Midwest, Mid-South, and Mid-Atlantic Regions.

Progress to date:

1) Integrating row covers, compost, and plant-growth-promoting rhizobacteria in muskmelon and butternut squash. Replicated field trials were conducted for 3 years on university farms in IA, KY, and PA. The trials compared the standard organic grower practice of removing row covers at anthesis (when female cucurbit flowers start to appear) with delaying their removal until 10 days later. For the delayed-removal treatments in IA, we compared opening the row cover ends at anthesis with placing bumble bee hives (Koppert, Inc.) under the covers. A treatment with no row cover protection was used as a control. KY trials included an "on-off-on" row cover treatment that removed row covers for approximately 2 weeks during fruit set, then replaced them for the rest of the season; PA initially also included a full-season row cover treatment on butternut squash with bumble bees underneath, and IA trialed an on-off-on strategy for squash in Years 2 and 3. Initially, the trials also incorporated two levels of locally sourced composted organic matter each year as fertilizer, representing assumed 10% and 30% N mineralization rates of the compost; commercial bagged fertilizer (Fertrell, Inc.) served as a control. In addition, the trials included a treatment that incorporated a plant-growth-promoting rhizobacteria product (Kodiak) in growing media during transplant preparation. OMRI approved insecticides (mainly Pyganic) and fungicides were applied as needed. Populations of the key insect pests (cucumber beetles, squash bug, and squash vine borer) were monitored, as well as the incidence of plants damaged or killed by these insects and by bacterial wilt (carried by cucumber beetles), along with marketable and cull yield.

RESULTS varied among states and years, but several trends emerged.

Muskmelon. In all 6 site-years where there were appreciable cucumber beetle populations, delaying row cover removal significantly suppressed incidence of bacterial wilt – by up to 38% - compared to the no-row-cover control and row cover removal at anthesis. Bumble bees under row covers for 10 days did not affect yield in Iowa, so this was discontinued after Year 1. The on-off-on row cover strategy suppressed bacterial wilt, but results varied widely. For example, the strategy worked well in Year 1 in KY, in a very dry season, except for an unanticipated pest problem: voles sheltering under the row covers ate holes in

melons before harvest. Year 2 had relatively low cucumber beetle pressure in KY. In PA, delaying row cover removal by 10 days consistently suppressed bacterial wilt in years with significant cucumber beetle populations, and improved marketable yield compared to either the standard-practice control (row covers removed at anthesis) or the non-covered control. There were no consistent differences in marketable yield associated with compost treatments. Similarly, adding Kodiak PGPR bio-inoculant during transplant preparation had no consistent impact on either the incidence of bacterial wilt or marketable yield. Frequency of insecticide and fungicide sprays was generally lower in row-covered than non-covered plots, and the on-off-on treatment required the fewest sprays.
Bottom line: Delaying row cover removal by 10 days, supplemented with Pyganic sprays based on scouting, has good potential to help Midwest and Mid-Atlantic growers control bacterial wilt with less need for insecticide use. Under heavy cucumber beetle pressure such as in KY, the on-off-on row cover strategy has promise but some problems (vole damage to fruit) need to be worked out. Compost use delivered commercial yields at lower application rates, which is consistent with our hypothesis of higher N-mineralization rates of compost under row covers. This finding has strong potential for reducing input costs associated with compost when working with row covers. Kodiak did not look promising as a bio-activator.
Butternut squash. We found no consistent yield advantage by extending the row-covered period for either 10 days after anthesis or the entire season compared to removing them at anthesis, but the latter treatment (the standard grower practice) often out-yielded the non-covered control. The on-off-on row cover treatment sometimes resulted in the lowest yield. Year 3 saw a near-complete wipeout of the KY squash crop, even under row covers, due to extremely high squash bug populations. Yields with compost treatments were often comparable to those with Fertrell and exceeded the no-fertilizer control. Kodiak had no consistent impact on yield. Under extremely high late-season squash bug and cucumber beetle pressure in IA in 2012, most unprotected squash plants died due to insect pest feeding before fruit had matured, leaving the full-season (on-off-on) row cover treatment as the only one with substantial marketable yield.
Bottom line**:** Row cover removal at anthesis was usually the best option for marketable yield on butternut squash. Delaying row cover removal for longer periods – either for 10 more days, or then replacing it until harvest – had variable results, sometimes reducing yield but in other site-years preserving yield when other management options failed under high squash bug pressure. Results for compost addition and Kodiak were similar to those for muskmelon.

2) Developing degree-day models for cucumber beetles, squash bug, and squash vine borer.
Early-season recruitment. Beginning in early spring of 2010, 2011, and 2012, prior to the time when growers plant their fields, we deployed a flat of 'Blue Hubbard' squash seedlings at each of 10 sites on university farms in IA, PA, and KY to monitor for early-season recruitment of cucumber beetles and squash bugs, using yellow sticky cards and visual inspection three times per week for at least 5 weeks. **Phenology strips** consisted of two adjacent 50-ft-long rows each of butternut squash and muskmelon that had no insecticide applications, from which 10 plants per crop were inspected twice per week until harvest for squash bug adults, eggs and nymphs as well as adult cucumber beetles using vacuum aspiration. This provided biofix data (time of colonization of a crop) and population dynamics data.**Pheromone traps.** Monitoring for squash vine borer was done using pheromone lures suspended from Hartstack traps. Two traps were per farm were checked twice per week for adult moths from late May until mid-August.

RESULTS.

Striped cucumber beetle. We focused on this species since it occurs in all 3 states and is the main vector for *Erwinia tracheiphila*, which causes bacterial wilt. Results from 6 site-years in KY and PA showed that overwintering adult beetles (a primary source of the bacterium early in the season) started their recruitment to cucurbits at 150 (range of 140-160) degree-days (base 55^{o} F) after January 1. This biofix – the first ever developed for the overwintering generation of striped cucumber beetle - is important because it can be used to alert growers to start protection measures against this major pest and estimate generational times at a farmscape or landscape level. Using 30-year climatology data, we can narrow the window to approximately 11 calendar days in PA, and 10 calendar days in IA and KY. We also successfully modeled recruitment rate to trap-flats as a classic Gompertz equation, and used that, plus the measured biofix (time-of-colonization in the phenology strip) to predict time of emergence of a 2^{nd} and subsequent generation in the phenology strip. Initial efforts to validate the current-season model with population dynamics data from the phenology strips met with variable results, mainly because it was difficult to distinguish which adults came from reproduction within the phenology strip versus continued immigration from the farmscape. Nevertheless, all replications among states and years showed very good agreement between predicted and observed emergence of new adults when we used biofixes to assume when egg-laying was initiated, and advanced the population from eggs to adults with temperature-dependent development rates.

Bottom line: The early-season recruitment model provides a powerful new tool to warn growers about the start of high-risk springtime periods for striped cucumber beetle, which can be used to optimize trap-cropping efforts, and when to couple trap-cropping with late planting as a management tool. The whole-season phenology model can determine the number of generations per year that will occur in a given year and location.

Squash bug. In KY and PA, squash bug adults began to appear on trap flats about 140 to 175 degree-days (base 60^{o} F), which was surprisingly early compared to the literature.

***Bottom line*:** Early-stage research set the foundation for future development of a degree-day model for squash bug.

Squash vine borer. Six site-years of monitoring in IA, KY and PA resulted in a threshold for capture of late-stage pupae of squash vine borer of 1,080 degree-days, base 50^{o} F, since January 1. However, the variation in the threshold degree-day level among site-years was substantial. We concluded that numerous additional site-years of data are needed before proposing a practical degree-day model for squash vine borer.

Bottom line: More field data are needed before a reliable degree-day model for squash vine borer can be developed.

3) Find out how floral provisioning strips affect bee visitation and yield in nearby squash and muskmelon fields.

In spring 2010, we transplanted 10 species of native flowers in a randomized pattern in double 120-m-long strips at a university farm in each state. In 2010, 2011, and 2012, 6-row subplots (10 m long) of muskmelon and butternut squash were planted parallel to and on either side of the floral provisioning strip. The control plot, located at least 500 m from the floral provisioning plot on the same farms, consisted of same-size subplots of muskmelon and butternut squash, but with a grass or bare-earth strip replacing the floral provisioning strip. The study was thus replicated by state rather than by farms within states, and repeated for 3 years. The cucurbit crops were protected with row covers until anthesis. We sampled populations of bees weekly on flowers in both the floral provisioning strips and the cucurbit crops; bees were identified to major taxa and counted during visual surveys, and also collected from the floral provisioning strips and cucurbit crops using Bug Vac aspirators. Bee samples from the Bug Vacs were identified to species in almost all cases, and to genus for *Lasioglossum*. Marketable and cull yields were recorded for each cucurbit row individually. In addition, seeds from a subsample of muskmelon and butternut squash per row were counted as a measure of pollination .

RESULTS.

The spatial pattern of harvestable yield with distance from the floral provisioning strip varied with site, year, and cucurbit crop. Similarly, the yields of cucurbit crops adjacent to the flower strip vs. the control (grass) strip also had a variable trend. The 2012 butternut squash harvest was completed in late September in IA, and 2012 data analysis is ongoing. Identification of the 2010 and 2011 bee collections has been completed, and bees from 2012 will be identified by December 31.

4) Determine how landscape diversity near farms affects bee visits to cucurbit crops.

Eight farms were selected in each state, representing a continuum of landscape diversity from simple to complex. During the summers of 2010 and 2011, each farm was visited twice. During each farm visit, bees in muskmelon and winter squash flowers found in 40 one-m^2 quadrats were observed and identified to morpho-species (broad groups of similar-looking species). Bees were then collected by two individuals for 15 minutes (30 minutes total collection) in the cucurbit field. The bees were killed using kill jars and placed in a freezer until they could be pinned and later identified to species. In addition, 15 bee bowls (plastic bowls filled with water, dish detergent, salt and propylene glycol) were set out in the cucurbit field for a week (five bowls each of yellow, blue and white color). The insects captured in the bowls were collected a week later, stored in 70% ethanol solution, and refrigerated until they could be pinned and later identified to species, mainly by Dave Biddinger at Penn State University.

Digital maps of the landscape surrounding each farm were downloaded from USGS National Land Cover Database 2006. A 3-mile-diameter perimeter was drawn around each farm (digitally on the computer using Geographic Information System (GIS) tools) and the land cover type/category was visually verified by researchers in the field following each summer of bee observation and collection. Qualitative and quantitative land cover summaries were performed using GIS tools in ArcMap. Statistical analysis of the landscape data in relation to bee diversity and abundance is ongoing.

5) Calculate profitability of the integrated management strategies that were trialed in the project.

We are using a partial budget analysis to assess costs and returns for the management options in the field trials integrating row covers, compost amendments, and Kodiak in muskmelon and butternut squash production. Results from IA, PA, and KY are being analyzed separately due to divergence of field experiments in Years 2 and 3 in response to regional differences in pest pressure and other factors. The analysis, which includes all three field years (2009-2011 in PA, and 2010-2012 in IA and KY), is ongoing.

6) Share the results with organic cucurbit growers.

Advisory Panel. The project has been advised by a 12-grower Advisory Panel, including 4 organic growers from each state. The Advisory Panel has participated in each of the project's 10 teleconferences over a 3-year period, and provided timely feedback for interpretation of results as well as vital reality checks on experimental design modifications.

The **project website** (http://organiccucurbit.plp.iastate.edu/) is becoming the centerpiece of the project's long-distance outreach. It includes information on all the project PIs and graduate students, digests of project results, numerous images of project activities as well as pest and insect damage on cucurbits, and field day reports and relevant extension bulletins, as well as scientific papers related directly to the project's purposes. Topics range from pest, disease and crop management to growing techniques. The site has interactive capability, allowing growers to comment on its content and be part of a community through the use of social media tools (Facebook, Twitter and YouTube). The site was beta-tested in 2011 by four Iowa organic cucurbit growers, who made several very useful suggestions to improve the site's usefulness to growers. The suggested improvements were incorporated and additional resources, graphics and pictures added.

The Penn State PIs and collaborators have developed an **interactive web-based decision tool** that allows growers to determine when they should begin watching for striped cucumber beetles in their fields. The site is based on a site-specific temperature grid for eastern North America that allows a grower to click on his/her farm location on a map to obtain the latest degree-day totals along with an indication of how close they are to the threshold for overwintering adult beetles to fly to cucurbit fields. This web-based tool is in a final design phase and will be available for testing by growers in spring 2013.

Extension and/or education activities completed or upcoming:
Field days. Eight field days in 2010 - two in Iowa (June 29 at Muscatine; July 29 at Gilbert), four with University of Kentucky PIs (two in Lexington, KY on June 16 and July 22, one at Carl Benson's farm in Forkland, KY on August 10, and one in Knoxville, TN, on August 19), and two in Pennsylvania (July 8 at Rock Springs, and July 16 at Limestoneville and Harleton). An additional 8 field days in 2011 were held as follows: one in Iowa (July 19 at Gilbert); four in KY (one in Lexington (September 6), one in Frankfort (September 27), one in Murray (March 16), and one in Princeton (August 19); and three in Pennsylvania (July 12 in Liverpool, July 18 in Loganton, and July 27 in Fleetwood). An additional three field days, one per state, featured the project's field trials in summer 2012.
Grower meetings. We have shared findings with growers through publication of research summaries in handouts to growers at indoor meetings of grower groups in 2010 including Practical Farmers of Iowa (January 9 in Marshalltown), Iowa Fruit and Vegetable Growers Association (January 29 in Des Moines), Pennsylvania Association for Sustainable Ag (PASA) (February 5-6 in State College), and the regional Pollinator Short Course (July 29 in University Park, PA), and the Kentucky Fruit and Vegetable Conference (Jan 4-5). Four additional meetings were held in Kentucky during the winter of 2011 and at a two-day Vegetable Growers Academy on January 31-February 1 and February 15-16, 2012.
On-farm demonstration trials. Nine organic growers (three each in Iowa, Pennsylvania, and Kentucky) gained hands-on experience with using row covers to protect melons and squash during on-farm trials coordinated by the project team in 2010. The number of the project's on-farm trials was reduced to six for the 2011 and 2012 growing seasons.

Websites, patents, inventions, or other community resources created:

Website. Organic Cucurbit Growing Community (http://organiccucurbit.plp.iastate.edu/)

The significance of our findings to organic agriculture:

- We showed that spunbond row covers have can allow for organic muskmelon and butternut squash production that otherwise would have been difficult to impossible by providing timely protection from key pests and diseases as well as environmental extremes.
- Our degree-day model for timing the early-season activity of striped cucumber beetle will help cucurbit growers to take timely counter-measures against this extremely damaging pest. An easy-to-use website will give all U.S. growers ready access to the model's advice.
- Results of our pollinator field studies will help cucurbit growers to decide whether adding flowering perennials to their farms and increasing habitat diversity can safeguard the bees that pollinate their crops and thereby protect their yield.
- The website will extend the project's impact after its completion. Growers will be able to keep using and adding to the existing resources through the social media tools that were created.

Other comments or recommendations for future work:

- Our study reinforced the impression that integrated organic management systems for cucurbit crops must be customized to regional conditions, including pest and disease pressure, climate, and soils. What works for Kentucky growers is unlikely to be the best answer for Pennsylvania or Iowa. Given the wide divergence of outcomes in our integrated-management field studies even among years on the same farm, it is also clear that row covers need further investigation over more years per site to understand the full range of their positive and negative impacts on marketable yield and profitability.
- The use of row covers needs to be streamlined and made more efficient if their benefits are to reach growers with more than an acre or two of crops to be covered. The primary needs are: 1) a labor-efficient and affordable way to deploy, remove, store, and re-deploy them; 2) a Life Cycle Analysis that indicates the energy costs associated with their use; and 3) a set of guidelines that

help growers to maximize the useful lifespan of row covers, in order to reduce waste and cost. The project team is currently engaged in two additional USDA-funded projects to meet these needs.

- Our development of a degree-day model to predict the timing of striped cucumber beetle activity during the critical early period of the cucurbit growing season needs to be validated by additional years of monitoring in several eastern U.S. states in addition to IA, PA, and KY, to insure that it in generalizable over as broad a geographic region as possible.