

SBIR Phase II Final Report

**Commercial Implementation of
Biointensive IPM in Pepper Production
Systems**

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Summary

Florida's most destructive pepper pests are probably the pepper weevil (*Anthonomus eugenii* Cano) and various species of flower-feeding thrips. The only control treatments are toxic chemicals in the carbamate and pyrethroid groups. The carbamates and pyrethroids are in question because of FQPA, and their ability to exacerbate thrips problems. This means that when carbamates and especially pyrethroids are used on a frequent basis, beneficial insect populations are greatly reduced, which leads to resurgence of plant-feeding, damaging thrips. The overall objective of this project was to develop a proprietary biologically based insect management program for pepper weevils and thrips so that insecticide usage can be minimized. The project had two major foci: 1) evaluating various companion cover crops and weedy field margin habitats for their ability to carry natural enemies of phytophagous thrips; and 2) developing a biointensive management program for the pepper weevil based on an improved monitoring system for the weevil and a better understanding of the weevil's off-season survival.

Concerns about the performance and cost of the standard pepper weevil pheromone-based monitoring system have prompted recent developments in new pheromone formulations with increased longevity and attraction. We tested two new pepper weevil pheromone formulations at commercial pepper farms in the 1998 spring crop in southern Florida. Various trap designs were also evaluated in a preliminary trial. One dual lure system (TRE8420 + 8462) showed superior longevity and sensitivity compared to the standard lure and unbaited control. The new lure system retains activity up to five weeks in the field and provides an economical means for monitoring and controlling pepper weevils.

We used yellow sticky panel traps with Trece's newly formulated pepper weevil pheromone to monitor pepper weevils at different pepper farms across south Florida during the crop season and subsequent fallow. Traps detected weevils at least seven days before pepper fruit infestation was found in the field during routine scouting operations. Weevil trap catch was related not only to pepper fruit infestation but also, and in one site exclusively, to black nightshade growing on field borders and ditch banks. Black nightshade can act as an alternative host to pepper weevil. During the crop season, trap catch increased with increasing distance from the nearest weevil source. Traps attracted weevils from farther away in the absence of pepper than when pepper was present. Trap catch peaked during crop destruction activities. During the fallow, trap catch dropped but still exceeded that of the prior crop season. Trap catch was determined by the trap's relative attractiveness compared to nearby pepper and nightshade and correlated with disturbance events in the crop environment (i.e., field tillage and leveling, plastic laying, etc). Our study demonstrates that the new pepper weevil lure formulation has good field longevity and will therefore be more economical in monitoring pepper weevils than the previously marketed weevil lure. We now need to develop more efficient trap designs and determine the best placement strategies for the traps for cost efficacy and to avoid losses from pepper weevils. We also need to establish treatment thresholds based on the relationship of trap captures with weevil populations and fruit damage.

We examined the use of a biointensive control (PROKIL Cryolite 96) to assess its efficacy in controlling pepper weevil infestation on bell peppers. Treatments consisted of one-acre plots where half of a plot was treated and the other half left as a control. The use of PROKIL gave 2.5-4 times better control of pepper weevil than using no chemical control. However, its use still resulted in 9-30% fruit infestation. This level of control is often what is obtained by using much more toxic chemicals such as Vydate, which greatly reduce or eliminate beneficial insects. In this

study we also found a greater abundance of coccinellids (ladybeetles) at one site (Shiloh) than at other sites, which was directly related to the use of a biointensive pesticide program on that farm.

Berries from black nightshade were collected from various habitats across south Florida from March–September 1999, to determine the importance of this host plant in the weevil's lifecycle. Nightshade plants were found at pepper farms in disturbed habitats along field borders and cypress hammocks, and to a lesser extent, within sugarcane windbreaks. Infested berries were found during the spring crop, the summer fallow season, and into the subsequent fall crop. In one intensively sampled site in Palm Beach County, infestation averaged 2.21% during June and July but dropped to 0.42% in August, as plant vigor and abundance declined. Nightshade was also prevalent in tomato farms during the spring crop, and weevil infested berries were collected from these sites as well. More parasitic wasps were recovered from weevil infested nightshade fruit than from weevil infested pepper fruit. However, very low (<2.5%) or no parasitoids were recovered from nightshade or pepper fruit, respectively.

Flower-infesting thrips are a major concern in Florida pepper production due to fruit damage and virus disease dissemination. Natural enemies, such as *Orius insidiosus* (Say), can keep thrips populations below the economic threshold. Attracting and augmenting beneficial insect populations in and around pepper fields may maintain yields and reduce pesticide costs. We evaluated the potential of selected cover crops and weedy hosts to serve as refugia for beneficial insects. *Bidens alba* (Beggar ticks) supported a low-to-moderate, stable population of the thrips predator *Orius insidiosus* and a plethora of other beneficials as it bloomed year-round. Sunflower planted as a windbreak attracted high numbers of *Orius*, but only a single planting was evaluated. *Wedelia trilobata*, blooming from March to December, proved important in carrying *Orius* during the summer months and into the fall season. White Dutch Clover planted in drive middles and White Sweet Clover on field margins supported moderate-to-high *Orius* populations, but only toward the end of the spring season, and therefore cannot contribute to early-season thrips control. It should be noted that all of these companion plantings also supported populations of thrips, (mostly *Frankliniella bispinosa*) that are not considered important pests in pepper. These thrips are necessary to support *Orius* populations.

Glades Crop Care, Inc. has taken the results of this study and applied them to their consulting and scouting program. Based on these results and our years of experience in vegetable consulting we are strongly advocating to our growers the benefits of using the more efficacious pheromone traps to detect pepper weevil populations before they move into the field. Our research has shown that *Orius* can reduce damaging thrips populations that had previously been controlled poorly with several highly toxic pesticide applications, which destroyed most of the natural enemies in these systems. This has resulted in most of our scouted acres having fewer thrips problems and less use of highly toxic insecticides for their control. The other major pest of peppers, the pepper weevil, is now managed with a combination of insecticides that integrate the use of the much less toxic and predator-friendly PROKIL insecticide. These newly developed tactics have also been incorporated into Glades Crop Care's proprietary THRIPS software package.

We see several additional opportunities resulting from our study that will continue to augment the biointensive pest management system we have developed. One such opportunity is to examine how the weevil traps, nightshade, and biointensive insecticide programs can be integrated across a large pepper production area. More work also is needed in elucidating the movement of *Orius* in the field to understand its temporal and spatial dynamics in controlling thrips and other pests. Understanding the answers to these questions will move us that much closer to a complete, commercially viable, biointensive pest management program.

Work Area #1

Refuge and Cover Crop Plantings for Beneficial Insect Habitats

Project 1

Determine the Suitability of Field Border Plantings and of Cover Crop Plantings within the Crop as Nursery Areas for Beneficial Insects

Introduction: Thrips are a major concern in Florida pepper production due to fruit damage and viral disease transmission. Natural enemies, such as *Orius insidiosus*, should be able to keep thrips populations below the economic threshold. A method of attracting and augmenting this beneficial insect in and around pepper fields is needed to maintain yields and reduce pesticide use and costs. We evaluated the potential of using selected cover crops and weedy hosts as refugia for *Orius* and other beneficial insects.

Methodology: Blooms of pepper (*Capsicum annuum* L.), beggar ticks (*Bidens alba* (L.) DC), creeping oxeye (*Wedelia trilobata* (L.) Hitchc.), sunflower (*Helianthus annuum* L.) white Dutch clover (*Trifolium repens* L.) and white sweet clover (*Melilotus alba* Ders.) (hereafter referred to as pepper, *Bidens*, *Wedelia*, WDC and WSC, respectively) were collected weekly from March 1998 to May 1999 from 14 sites across six counties in south Florida (Table 1). Various other plant species, including pigeonpea, and black medic were also sampled occasionally. In addition, plantings of sunflower and Mexican sunflower (*Tithonia rotundifolia* (Mill.) S.F.Blake) were monitored from October–December 1999. Habitat types sampled are specified in Table 1. Selected pepper fields and adjacent habitats at the Shiloh and Green Cay sites were sampled twice a week to track thrips and *Orius* populations more accurately. Each collection consisted of a bulk sample of 35 blooms, picked randomly from an area of at least 1,000 ft². The number of blooms per square foot was estimated at each collection. Blooms were stored in a ziplock bag with 70% isopropyl alcohol. Arthropods were separated from the blooms by shaking the contents repeatedly with water, pouring it through a coarse sieve and then through a fine mesh sieve. The samples were examined with a 40X stereomicroscope and categorized into 60 taxa, including 12 thrips species, seven predator categories (*Orius*, predatory thrips and mites, spiders, lacewings, syrphids, and ladybeetles) and parasitic wasps.

Results: The results are summarized in Table 1, showing key parameters of the population dynamics of thrips and their major predator, *Orius insidiosus*. Other predators found in the blooms were too variable or scarce for analysis. *Frankliniella bispinosa* (Morgan) was the dominant thrips species, although in the three Asteraceae (*Bidens*, *Wedelia*, sunflower), *Microcephalothrips abdominalis* Crawford also occurred in significant proportions, particularly during the summer months.

Thrips and *Orius* population fluctuations varied by plant species (Fig. 1). Only *Bidens* bloomed year-round and carried thrips and *Orius* throughout the year, with peak numbers occurring in April-May and October. *Wedelia* bloomed from March to November; thrips and *Orius* peaked in May-June and September-October. WDC and WSC bloomed only during the spring season from March to May; peak thrips and *Orius* numbers developed in March-April. Among other leguminous plants sampled at least five times, *Cajanus cajan* L., *Crotalaria juncea* L., and *Medicago lupulina* L., mean *Orius* populations did not exceed 0.01 adults and/or nymphs per

bloom. The carrying capacity of a plant species; i.e., the maximum number of thrips or *Orius* per square foot, was obtained by multiplying the peak blooming density by the peak thrips or *Orius* density (Table 1). WDC had the highest carrying capacity for thrips, sunflower the lowest. WDC had the highest carrying capacity for *Orius* as well; *Wedelia* had the lowest. The thrips:*Orius* ratio was much lower for sunflower (1.3) than for other plant species (42.1 to 82.7). This means that sunflower produces many fewer thrips in relation to *Orius* (only about one thrips for every *Orius*, as opposed to 42 to 83 thrips for every *Orius* in the other crops). This is clearly a desirable characteristic, as thrips dispersing from a cover crop can invade an adjacent pepper crop. Sunflower therefore, is a very good candidate for use as predator refugia in pepper systems.

In addition to *Orius*, a wide variety of predatory arthropods and parasitoids were found in *Bidens* blooms throughout the year. These included various aphid predators such as larvae of syrphids, aphid midges, ladybeetles, lacewings, predatory mites (*Proprioseiopsis* nr *mexicanus* (Garmon) and *Typhlodromalus peregrinus* (Muma), and spiders. *Bidens* bloom stalks were commonly infested by *Aphis craccivora* Koch.

Wedelia, growing on field borders between sugarcane plants, on ditchbanks, and as an ornamental cover crop, bloomed from March to November, with a peak density of 2-3 blooms/ft² from June to September. *Orius* populations peaked in June and dropped off rapidly during the fall, which is not a desirable characteristic of refugia planting for control of flower thrips in peppers as the predator would be needed most in the fall. A predatory tubuliferan thrips, *Haplothrips gowdeyi* (Franklin), was relatively common on *Wedelia* throughout its blooming period. A wide variety of mites were also collected, including *Pseudoparasitus* sp. (Laelapidae), *Brevipalpus* nr. *selas* Pritchard and Baker (Tenuipalpidae), *Asca* nr. *duosetosa* Fox (Ascidae), *T. peregrinus*, and unidentified Oribatidae.

Sunflower, planted in November 1998 as windbreaks in a tomato farm in Hendry County (red Star), bloomed from late January to mid March 1999. Peak bloom density was only two blooms/ft² but blooms were much larger in size (5 - 8" diameter) than any other crop sampled, thus providing large quantities of pollen per unit surface area. The number of *Orius* per bloom greatly exceeded that of any other crop sampled: from 2.8 to 16 per bloom. The thrips species *M. abdominalis* and *F. bispinosa* were equally dominant.

A sunflower planting on field borders at the Green Cay farm was monitored from October-December 1999. The variety used was Autumn Beauty (Johnny Seeds) planted in August 1999 in a single row on recently cleared pepper field borders at a spacing of 12 inches. Autumn Beauty is a multi-headed mixture of varieties with pale-yellow, deep-yellow, and purple bloom colors. Blooming started in early October and lasted through early December. The hearts of the blooms measured about two inches, considerably smaller than the variety used at Red Star. Plants were in full bloom when pepper in adjacent fields started blooming. *Orius* numbers averaged one per bloom at the onset of flowering and reached 3.7 per bloom in mid December (Fig. 1a). Thrips (mostly *F. bispinosa* and *M. abdominalis*) peaked in late November. A nearby roadside planting of Mexican sunflower showed a similar pattern of *Orius*/thrips dynamics. Sunflower on pepper field rows appeared to lead to higher *Orius* numbers in blooms of pepper in adjacent fields, although differences were not statistically significant. On December 16, 1999, *Orius* in pepper plants in six fields with sunflower averaged 0.07 per bloom; without sunflower (same pepper variety and planting date), 0.02 per bloom. Thrips averaged 4.5 and 4.9 per bloom, respectively. While the population level of *Orius* seems low our field experience has shown that this is a reasonable density for control of thrips.

Timing of the blooming period of the companion crop relative to the pepper crop is critical. *Orius* is attracted to pollen and thrips. Ideally, the companion crop should start blooming well ahead of the pepper crop to give the *Orius* population a jump-start. Sunflower bloomed in February, which would be compatible with a spring pepper crop. It may be possible to plant sunflower on a monthly basis and thus extend the blooming period. *Bidens* bloomed year-round and was the only plant that occurred as a common weed throughout South Florida. Its presence around pepper fields depended upon weed management. Where it was allowed to flourish undisturbed, relatively high populations of *Orius* and other beneficials (predatory mites, syrphids, ladybeetles, lacewings, predatory thrips, and various parasitoids) developed, which could be of potential benefit to natural biological control in the pepper crop. *Wedelia* bloomed from March to December, but supported *Orius* only during the summer months after the spring pepper season had ended. It, therefore, has limited potential, but it combines well with sugarcane in windbreaks, where it covers the ground between sugarcane plants. Both *Wedelia* and *Bidens* are easy to control by tillage in field walkways and do not present a direct threat to pepper growth. WDC in drive middles can carry high levels of *Orius*, but peak numbers occur only toward the end of the spring crop. Therefore, its potential contribution to thrips control on peppers early in the season is limited. Sunflowers seem to be the best choice as a refugia for predators. As border plants they would not interfere with field operations and they supply a very good ratio of thrips to *Orius* (Bottenberg et al., 1999).

Project 2

Ratios of Pepper Crop to Cover Crop or Border Plantings

Introduction: The previous section has demonstrated that cover crops and weedy habitats have different capacities to support beneficial insects. This capacity determines the area needed to supply sufficient numbers of beneficials to a given pepper field.

Methodology: The area of cover crop required to achieve thrips control in pepper was calculated as follows. First, the predator-prey ratio needed to control thrips was derived by examining graphs of thrips and *Orius* population fluctuations in pepper fields where a predator-prey response was clearly visible with an increase and decline of thrips followed by an increase and decline of *Orius*. This occurred in three fields, in blocks 30 and 45 during the 1999 spring crop at Shiloh, and block 3W during the 1998 fall crop at Green Cay. The point at which thrips numbers started to drop and *Orius* numbers started to rise was used to calculate the predator-prey ratio required to initiate thrips population decline. The ratios for the fields were 0.0113, 0.0031 and 0.0069 respectively, giving an average of 0.007. A number of assumptions were made. It was assumed that the cover crop would be at its highest bloom density and peak thrips and *Orius* populations. These numbers were used to derive insect populations per square foot. The pepper crop was assumed to have five blooms per square foot and five thrips per bloom without any *Orius*. It was further assumed that the entire insect population from the cover crop would be forced to move into the adjacent pepper crop due to mowing. Because of the large variability in the percentage of predators that could be killed due to mowing (if most were nymphs at mowing almost all would die, if most were adults fewer would die, etc.) different rates of mortality (5, 25, 50, 75 and 95%) were used with different surface areas of cover crop (expressed as percentage of a pepper crop) to determine *Orius* and thrips populations and corresponding predator-prey ratios. The cover crop area with which a predator-prey ratio of 0.007 would develop in the adjacent pepper crop was determined graphically.

Results: The results are shown in Fig. 2. Depending on the density of thrips in the cover crop, a mowing event would probably lead to an initial increase in thrips population in the pepper blooms

because of the sudden movement of thrips from the cover crop into the pepper. However, this peak would decline rapidly in a matter of days as the *Orius* predators, which also moved along, devour the thrips. Sunflower and WDC required the least area. Even at 90% mortality the area demand was less than 10% of the pepper area. This is normally taken up by a cover crop planted in a driveway running through the center of a 2,000-ft long, 5-acre block or by the vegetation on the margins of a similar field. An area requirement larger than 10% is deemed unacceptable. *Wedelia* was the least effective cover crop in this simulation. Even at the lowest mortality rate, the area required was 19%. It exceeded 100% at a mortality rate of 80%. *Bidens* area requirement was up to 10% of the pepper crop when insect mortality was 75% or less. With WSC, the 10% area requirement was met up to an insect mortality rate of 50%. The mortality rate due to mowing is difficult to predict, but it can be assumed that all immatures will die and also a certain proportion of the winged adult thrips or *Orius*. Therefore, a mortality rate of 75% due to mowing is probably realistic. Besides mowing there is the possibility to simply disturb the refugia habitat by using chains pulled on a tractor, which would move predators and prey out of these systems without destroying them.

Project 3

Determine if Cover Crop Plantings Will be Additional Sources of Pest Problems

Cover crops were sampled for pests as previously described in Section # 1, Project 1. Thrips were found to be the major pest species in these cover crops. Other pests such as caterpillars, mites, other sucking insects were at very low levels (Figs. 3 & 4). The major thrips species were *Frankliniella bispinosa* and *Microcephalothrips abdominalis*. Neither of these thrips is considered very important pests in pepper (Frantz and Mellinger 1990 and 1997). Their numbers would have to become much greater in order to cause any yield reduction in pepper. Because these thrips are not resistant to any pesticides like other thrips species that are major pests (i.e., *F. occidentalis* and *Thrips palmi*) they can be easily controlled if their numbers become too great. At this time in south Florida inoculum levels of viral diseases transmitted by thrips are low and transmission is a minimal concern. Therefore, the companion plantings used to increase *Orius* populations will not lead to additional economic damage from pests, but should decrease thrips damage in pepper systems.

For more details consult Work Areas #1 and #2, project 1.

Work Area #2

Crop and Non-Crop Insect Survey

Project 1

Determine the Seasonal Distribution and Relative Abundance of Insect Pests and Associated Beneficial Insects

Introduction: The goal of this project was to confirm and further elucidate the seasonal cycles of armyworms, aphids, thrips, and *Orius* in fall and spring pepper crops.

Methodology:

- **Armyworm and Aphids:** Glades Crop Care's scouting records for the pepper farms Green Cay 1998 fall crop and Shiloh 1999 spring crop (farms are ≥ 60 miles apart) were entered in a spreadsheet format to analyze temporal and spatial dynamics of armyworm and aphid occurrence. Both farms are managed by the same grower. *B.t.* products were used when armyworm infestation in any single block exceeded 2% of plants with live worms. During routine scouting trips, every third block was inspected for pests and diseases by an experienced field scout. At each check, an area of approximately 100 x 100 feet was traversed from one side of the field to the other and about 100 - 200 plants visually inspected. Scouting trips were made twice a week, each block being checked every 10 days. Armyworm was assessed as the percentage of plants with live worms. Up to four species of armyworm were distinguished: beet, southern, sunia, and fall armyworm. Data were averaged by groups of 12 consecutive blocks that were planted within a span of 10 days. A complete spray record was available for the Green Cay site. In each field visited, aphid abundance was rated using a scale of 0 to 4 (Table 2). These ratings were then averaged across blocks within each group of twelve blocks.
- **Ladybeetles:** Yellow sticky traps were used to monitor the abundance and diversity of ladybeetles. Once a week during the month of April 1999, all ladybeetles were removed and counted by species from each of the yellow sticky traps at Shiloh, Pero, Silver Strand, Thomas #1, #2, and #3, and Brown82. It was assumed that these traps, placed around pepper fields, would provide a general reflection of the ladybeetle population in the pepper crop and surrounding vegetation. Sample specimens were identified by Dr. W. C. Welbourn, DPI, Gainesville, Florida.
- **Thrips and Orius:** Blooms of pepper were collected twice a week in selected fields in the Green Cay 1998 fall crop and the Shiloh 1999 spring crop, and thrips and *Orius* were counted, as described previously in Work Area #1.

Results:

- **Armyworm:** The results are shown in Figs. 3 and 4. Southern armyworm, mostly young instars, made up more than 90% of the species complex; the sum of all species is shown. Overall percentage armyworm infestation was higher during the Green Cay fall crop (1.9%) than during the Shiloh spring crop (0.9%). Armyworm infestation at Green Cay reached or exceeded the 2% threshold during 21 out of a total of 38 scouting trips (55%); at Shiloh this happened only eight times out of a total of 49 scouting trips (16%). A localized outbreak of

the yellow-striped armyworm *Spodoptera ornithogalli* (Gn.) of advanced instars on the west side of the Green Cay farm (bl. 20-32W), possibly due to treatment failure, exceeded the 2% mark on five consecutive trips from November 23 to December 14, 1998. Excluding this outbreak, there would have been two times that the 5% threshold was reached or exceeded at the Green Cay site, on August 31 (bl. 1-12W) and October 22, 1998, (all blocks). The Green Cay spray record showed that a total of 6 *B.t.* products were used: Match, Javelin, Dipel, XenTari, Cutlass and Crymax. A total of 20 applications was made between August 27, 1998, and January 18, 1999, or 0.9 applications per week. On seven occasions, tank mixes of two different *B.t.* products were used. Neemix (which is an organic insecticide that disrupts immature insects' growth patterns) was used twice; Spintor and Agrimek each were used three times. *B.t.* applications normally resulted in a rapid decline in infestation and maintained population levels below the 2% level for 4-6 days, except during the yellow-striped armyworm outbreak, possibly because the larger instars were less susceptible. During the Shiloh spring crop, armyworm infestation was lowest in the earlier planted blocks on the west side (0.66% seasonal mean), intermediate in the center blocks (0.77% seasonal mean), and highest in the later planted blocks on the east side (1.16% seasonal mean). A 5% peak was reached on February 1 in the center blocks and a 7% peak on April 12 in the East blocks. These trends are probably related to warmer temperatures as the spring season progressed. The spray record showed that 19 *B.t.* applications were made at Shiloh between 11/21/98 and 4/23/99 (22 weeks), or 0.9 applications per week. The *B.t.* products were Dipel, Javelin, XenTari and Crymax. Spintor was used a total of four times. While this many *B.t.* applications might seem excessive, it is our experience that this level of use is needed and should not lead to any resistance problems.

- **Aphids:** Aphids, primarily *Myzus persicae*, were generally less common during the Green Cay fall crop (Fig. 5) than during the Shiloh spring crop (Fig. 6). Aphid-transmitted virus diseases were seen only sporadically. Aphids at Green Cay became more common from mid December to mid January as the season progressed, but never exceeded the "moderate" rating. Provado was not applied for aphid control. At Shiloh, aphids were not a problem except in the latest planted blocks on the east side of the farm (blocks 47-58), where an outbreak developed in March 1999. This outbreak reached high levels in some blocks, resulting in a mean rating slightly over "moderate" on March 21. Provado was applied a total of four times. The first application on 12/31/98 lowered the aphid rating from 'low' to 'very low'. The second one on 2/10/99 reduced the rating from 'very low' to 'none' in the western and central parts of the farm but the eastern part remained unaffected. It is possible that no Provado was applied on the eastern end. It was here that the outbreak in the following month developed. Two applications of Provado (March 19 and 29) effectively controlled this outbreak.
- **Ladybeetles:** Ladybeetles were most abundant at the Shiloh location (Fig. 7). Mean weekly catch at this location varied from 4.3 to 6.2 ladybeetles per trap. At the other sites the highest catch was only 2.9 (at Brown82). The Pero site generally had the lowest ladybeetle catch. A total of six species were identified (Fig. 7). The most abundant species was *Cycloneda sanguinea*, which made up 52% of the total catch. Other common species were *Coelophora inaequalis* (19.5%) and *Harmonia axyridis* (11.8%). Three unidentified species were grouped into the unknown category (11.6%). Minor species (<2.5%) were *Olla v. nigrum*, *Psyllobora parvinotata*, and *Coleomegilla maculata*. The greater abundance of ladybeetles at the Shiloh site can be related to the benign pesticide regime, which allows some build-up of aphids on the pepper crop. Also, the lack of herbicide usage has created a rich and diverse flora along sugarcane windbreaks, roadsides and ditch banks, which provide pollen and aphids to ladybeetles.

- **Thrips and Orius:** Pepper blooming started in October and continued up to May; in 1998 thrips and *Orius* peaked in April, but in 1999 thrips peaked in March and *Orius* in March and May, respectively. Thrips and *Orius* populations were lower at Green Cay in the fall crop than in the spring crop (Fig. 8c). At Shiloh, the later planted fields had higher thrips numbers in the blooms than earlier planted fields (Fig. 9). The relationship of the number of thrips per bloom with planting date in days from November 6, 1998, was highly significant (Thrips = $0.06 + 0.14 * \text{Days}$, $F=103.8$, $p<0.01$, $df=3$, $R^2=0.97$). Data from three fall pepper fields at Green Cay (planted 8/18 to 10/28/98) show that *Orius* and thrips colonized pepper blooms at the same time, 39 ± 8 and 40 ± 5 days after planting, respectively (Fig. 8c). However, in the spring crop (five blocks at Shiloh farm planted from 11/7/98 to 2/3/99), *Orius* colonization was delayed (71 ± 12 days after planting) while the onset of thrips colonization remained similar (36 ± 6 days after planting) (Fig. 9). *Orius* showed a numerical predator-prey relationship with thrips in six pepper fields. *Orius* peak populations were significantly related to thrips peak populations in a positive, linear fashion ($Orius = -0.065 + 0.035 * \text{Thrips}$, $F=44.2$, $p<0.01$, $df=4$, $R^2=0.92$). *Orius* populations peaked from 14 to 32 days after thrips populations peaked; at this time thrips numbers were greatly reduced. Reduction in thrips population ranged from 90-100% in the fall crop and from 36-78% in the spring crop. This difference could be do to the higher activity and population peak of *Orius* in the fall. Thrips and *Orius* populations were compared between different sites where pepper blooms were collected during the spring 1999 crop (Table 3). Precision of the test may have been compromised by the low number of samples at sites other than Shiloh.

Thrips and *Orius* were generally highest at the Shiloh site but differences were significant only for thrips during the month of May. The Pero site had the lowest counts. Intensity of pesticide usage seems to be the main factor explaining these differences, but as accurate usage data are lacking, this relationship can not be validated. More research is needed to understand the temporal dynamics of thrips/*Orius* populations and the importance of bio-intensive management on worm and thrips control and predator dynamics.

Project 2

Investigation of the Biological Characteristics of *Orius insidiosus*

Introduction: The most important natural enemy found in our SBIR Phase I survey of pepper fields was the anthocorid *Orius insidiosus* (Say). *O. insidiosus* is a polyphagous predator of small insects (Abels, et al., 1978, Barber, 1936, Barry, et al., 1974), mites (Iglinsky and Rainwater, 1950, Holdsworth, 1972), and their immatures and eggs (Eveleens, 1974). This facultative phytophagous predator also feeds on plants (Armer, et al., 1998; Cohen, 1990). By feeding on plant material, this predator is capable of remaining in areas where prey (pests) are momentarily scarce (Coll, 1997; Cohen, 1996). Although *O. insidiosus* feeds on a variety of prey, it is especially good at controlling thrips (Veireand Degheele, 1992; Coll and Ridgeway, 1995).

Two thrips species *O. insidiosus* controls effectively are the western flower thrips, *Frankliniella occidentalis* (Perg.) and melon thrips, *Thrips palmi* Karny. Both pests can transmit virus diseases and cause feeding injury in vegetables. Conventional chemical control is usually not effective because of the thrips high reproductive rate (Kawai, 1995) and their low sensitivity to insecticides. Because *O. insidiosus* is such a potentially important biological control agent in Florida vegetable fields, its biological characteristics need to be better understood.

Importance as a Predator: *O. insidiosus* has been found to be an important predator on mites (Holdsworth, 1972; Brown and Shanks, 1976), aphids (Holdsworth, 1970; Goodarz and Davis, 1958; Knowlton, et al., 1938), *Helicoverpa* and *Heliothis* spp. (Harrison, 1960; Garmen and Jewett, 1914), Codling moth, *Cydia pomonella* (L) (Lingren, et al., 1968), several species of thrips (Coll and Ridgeway, 1995; Robinson, et al., 1972), whitefly (Isenhour, et al., 1981), cabbage looper, *Trichoplusia ni* (L) (Barry, et al., 1974), several tortricids (Atkins, et al., 1957), and many other insect and mite pests (Eveleens, 1974; Eveleens, et al., 1974; Burke, 1959; Estrada, 1973; Orphanides, et al., 1971; Stoltz and Stern, 1978; Naranjo and Gibson, 1996). *O. insidiosus* is found on many crops, such as cotton, soybean, field and sweet corn, crucifers, alfalfa, solanaceous crops, tobacco, sorghum, ornamentals, sugar beets, and various other vegetables, field crops, and weeds (Webster, 1885; Lingren, et al., 1968; Lopez, 1974; Ewing and Ivy, 1943; Forbes and Hart, 1900; Tugwell, et al., 1973; Fuchs and Harding, 1976; Frantz and Mellinger, 1990; Armer, et al., 1998). The importance of *O. insidiosus* as a biocontrol agent in these different systems and for these pests has typically become clear as a result of pest population explosions following applications of broad-spectrum insecticides (van den Bosch, et al., 1956; Stern, 1963; Guerra, 1974; Ehler and Miller, 1978, Frantz and Mellinger 1997). This led to an understanding of the economic importance of *O. insidiosus* in agricultural systems. While many studies have determined that *O. insidiosus* is important in keeping pest populations low, few have tried to integrate this natural enemy into any pest management program (Altieri and Whitcomb, 1979). The greatest use of *O. insidiosus* has been for the control of thrips in greenhouse production vegetables (Veise and Degheele, 1972; Kawai, 1995). More research is needed to understand how to integrate this valuable biocontrol agent into field cropping systems. Glades Crop Care has found through our many years of field experience that it is very probable that most of the secondary pest problems we see are due to the elimination of biological control agents and/or development of resistance by the pest. Both of these factors can be reduced or eliminated with judicious use of pesticides and a more biointensive management approach. *Orius* is an important biocontrol agent in our pepper fields.

Biology:

- **Distribution:** *O. insidiosus* is found most commonly in the eastern United States but can occur southward from Utah and Southern California into Mexico, Central and South America, and the West Indies (Herring, 1966). It occurs in a wide variety of crop and non-crop plant species. It can be introduced into any system that can support both plant and prey (Weber, 1953). All stages of *O. insidiosus* usually can be found concentrated in the flower itself, where its main prey, thrips, is located. Populations of *O. insidiosus* are usually correlated with thrips populations (Elkassabany et al., 1996; Frantz and Mellinger, 1990).
- **Systematics:** Western Hemisphere species of *Orius* are difficult to identify since most of the characters (i.e., body structures, setae position, etc.) used in Europe are no longer adequate; i.e., coloration was used almost exclusively (Herring, 1966). The single most useful character for distinguishing species is the left genital clasper of the male, which has been shown to be very constant. Females of many *Orius* spp. are still difficult to separate.
- **Feeding:** Both adults and nymphs of *O. insidiosus* feed on plants and insects. This omnivorous predator is capable of completing its development with either a plant (pollen and plant fluid) or prey food source (McCaffrey and Horsburgh, 1982). When *O. insidiosus* does feed on plants, it feeds within the xylem or mesophyll, supplying the insect mostly with water and a few nutrients. It does not feed in the phloem, as do other Hemipteran insects (aphids, whiteflies and plant bugs) that cause plant damage (Armer, et al., 1998).

- **Development:** *O. insidiosus* overwinters as an adult on various vegetation in and around fields. Females are in reproductive diapause during overwintering periods. Eggs are oviposited into the plant stem or leaf tissue. Eggs take approximately 1 to 3 days to eclose at 17° and 35° C, respectively, (Isenhour and Yeargan, 1981). There are 5 instars. Total developmental time from egg to adult is 8.3 to 34 days at temperatures of 35° and 17° C respectively, (McCaffrey and Horsburgh, 1986). A minimum temperature of 10° C is needed for egg and nymphal development. The degree days needed for development from egg to adult are approximately 278 ± 9 (McCaffrey and Horsburgh, 1986; Isenhour and Yeargan, 1981).
- **Plant/Predator Interactions:** Because *O. insidiosus* is capable of drawing nutrients from plants and uses them as an oviposition site, their interaction is important. Certain plants are rejected for oviposition even though female *O. insidiosus* feed on and in these plants; e.g., corn (Coll, 1997). Although all stages of *O. insidiosus* can be found on many crops, only a few are conducive to oviposition and offspring development. Coll (1997) found that *O. insidiosus* adult and nymphal survival were greatest on lima bean versus corn, tomato or pepper foliage. Therefore, consideration must be given to the type of plant used in studies with *O. insidiosus*, and whether plants are used for concentrating or building its populations.
- ***O. insidiosus*/Natural Enemy Interactions:** *O. insidiosus*, as a predator, feeds not only on pests, but also on other natural enemies. The phytoseiid mite, *Neoseiulus fallacis* (Gorman) and the stigmatid mite, *Zetzellia mali* (Ewing) are potential prey for *O. insidiosus* (Kramer, 1961). Predaceous thrips, which are often found associated with *Orius* spp., are also at risk; however, *Leptothrips mali* (Fitch) has a defensive mechanism which reduces predation (Parrella, et al., 1981). *O. insidiosus* has been observed to attack aphid predators, such as *Aphidoletes aphidomyza* (Rondani), *Chrysopa* spp. larvae and *Stethorus punctum* (LeConte). *O. insidiosus* can also interfere with parasitoids and has been found to consume larvae that were previously parasitized (Lingren et al., 1968). Other natural enemies have been found to prey on *O. insidiosus*. These include several spider species, *Philodromus* spp., *Misumenops* spp., and *Xysticus* spp., as well as *Chrysopa* spp., and even other *O. insidiosus* (McCaffrey and Horsburgh, 1986). All of these interactions demonstrate the difficulties of working with biological control agents, and need to be considered when a pest management program is being designed.
- **Success as a Biocontrol Agent:** In theory, whether a biocontrol agent is successful (i.e., suppresses pest population) will depend upon its searching behavior and its aggregation and reproductive ability (Everson, 1980). *O. insidiosus* has been determined to be a good disperser and colonizing species (Ehler, 1977). With its preadapted abilities of polyphagy and plant feeding, *O. insidiosus* can readily exploit prey populations in temporal cropping systems (Ehler, 1977). *O. insidiosus* has the ability to colonize favorable habitats, such as flowers, rapidly as it moves between and within the crop and other vegetation. With its rapid developmental rate of egg to adult in 10 – 14 days under temperatures encountered during the growing season, *O. insidiosus* is able to respond reproductively to most pests. Studies have shown that *O. insidiosus* responds numerically to thrips populations found in the crop (Isenhour, 1977; Coll and Ridgway, 1995). This response can be so great that thrips are less of a problem in fields where chemical applications are kept to a minimum (Frantz and Mellinger, 1990).

Systems where chemical applications have been made frequently suffer from outbreaks of secondary and even primary pests (Brown and Shanks, 1976; Burke, 1959; Eveleens, 1974;

Eveleens, et al., 1974). This is the difficulty in designing pest management programs in crops that have at least one key pest and several other secondary pests, which are usually kept under control by predators like *O. insidiosus*. The key pests, such as pepper weevil in pepper, must be kept under control or the crop could be a complete loss (Riley and King, 1994). To accomplish this level of control, several applications of insecticides must be made. When these applications are made, secondary pests (i.e., thrips) are often released because of predator loss. The loss of predators within a field may be compensated for by having refugia along field borders where predator populations could build and respond to an increase in pest numbers. *O. insidiosus* fits the profile of the type of predator that can respond numerically and functionally to change in pest density. The difficulty lies in how to manage the system as a whole for best overall horticultural and pest management system performance. Glades Crop Care, Inc., in designing a commercially acceptable biointensive pest management system for peppers, has taken a major step in this direction.

Project 3

Define Desirable Population Levels of Beneficial Insects

As seen in Work Area #1, Project #2 at a 90% mortality rate the land area demand is less than 10% of the pepper crop land area. The part of the field occupied by the companion planting is an area that is usually not cropped anyway. Areas along ditch banks are not used nor is the driveway in the middle of the block. The companion plants give another benefit besides increasing natural enemies, in that they greatly decrease weeds that normally grow in the non cropped areas. Therefore, an area requirement larger than 10% is unacceptable to the grower and unnecessary for natural enemy build-up. Based on our data and 20 years of experience scouting vegetables, it should be possible to increase natural enemies for biological control in the field using these companion plants and low toxicity pesticides. Moving these natural enemies from the refugia planting into the field when they are most needed becomes the next important step in a biointensive management program. One way to do this besides mowing is by using chains dragged behind a tractor to disturb the habitat, which should move predators and prey out of these systems without destroying them. Another possibility is to use supplemental food sources to 'lure' the natural enemies out of the refugia and into the crop. See Work Area #1, Project #2 for more details.

Work Area #3

Biointensive Management of the Pepper Weevil

Project 1

Survey of Biological Control Agents for Pepper Weevils

Introduction: Biological control is one of the pillars of integrated pest management. By minimizing pesticide usage, the impact of natural enemies on pest populations is maximized. However, parasitization and predation rates of pepper weevils are believed to be low, and the combined impact of beneficial insects is probably limited (Riley and King, 1994). The goal of this project was to assess the species abundance of parasitoids of pepper weevil to ascertain if they could be a useful tool in the control of this pest.

Methodology:

- **Nightshade Survey:** Nightshade berries were collected in paper bags from nightshade growing in several areas of pepper and tomato farms in the spring, summer fallow, and fall, 1999, crops. Full-sized green berries or berries about to change color were sampled. Ten to 15 berries were collected from each plant.
- **Pepper Fruit Survey:** Small (less than 2.5 cm. in dia.) pepper fruit were collected in paper bags in May, 2000, from two pepper farms with a moderate to high infestation of pepper weevil. A total of 400 pepper fruit was collected from the two farms. Fruit was randomly selected from 5 different areas on each farm.
- For both surveys, fruit was kept in the laboratory in paper bags and checked for the emergence of parasitoids 2–3 times per week. This occurred for 6 weeks after nightshade berry collection and 4 weeks after pepper fruit collection.

Results:

- **Parasitoids Reared from Nightshade Berries:** A total of 45 parasitoids were collected from the paper bags in which a total of 480 pepper weevils were reared from 31,986 nightshade berries. Identifications were made by G. E. Evans and L. A. Stange of DPI, Gainesville, Florida. The majority of the parasitoids probably originated from a berry borer (*Symmetrischema striatella* (Murtfeldt), Lepidoptera: Gelichiidae), determined by J. B. Heppner, DPI, Gainesville FL), which commonly infests nightshade berries. These parasitoids were: *Apanteles* sp. (Braconidae) (69%), an unknown Scelionid egg parasitoid (6%), and *Orgilus* sp. (Braconidae), an endoparasitoid (4%). Three other species may or may not have originated from pepper weevil hosts as their life history is not fully understood: *Euderus masoni* Yoshimoto (Eulophidae) (13%), an unknown Pteromalid (but not a *Catolaccus* sp., the most important pepper weevil parasitoid) (4%), and one unidentified species (4%). Even if the above three species were parasitoids of the pepper weevil, the overall rate of parasitism would only be 2.5%. Therefore, mortality from parasitism in south Florida is probably very low.

- ***Parasitoids Reared From Pepper Fruit:*** Although over 500 pepper weevil adults emerged from the collected fruit, no parasitic wasps were found to have emerged from the 400 pepper fruit collected.

Discussion: The reports for biological control on pepper weevil have been scarce and discouraging (Genung and Ozaki, 1972; Pratt, 1907; Wilson, 1986). Predators have had virtually no impact on controlling pepper weevil populations because larvae are protected inside the pepper fruit (Wilson, 1986). Parasitoids, though, offer a better opportunity for biological control. The parasitoid, *Catolaccus hunterii* Crawford, could have potential as a biocontrol for pepper weevil. This parasitoid actually needs to have the host (pest) live inside plant tissues before it recognizes it as a host. In one study, *C. hunterii* was found to inflict a 26% parasitism rate on pepper weevil in bell pepper (Riley and Schuster, 1992). While there are other parasitoids that have been found for pepper weevil, none are very effective at lowering pepper weevil populations (Meraz, 1905), and none definitively were recovered in our survey.

Conclusion: Even though we found, at best, only 2.5% parasitism of pepper weevil in the nightshade fruit, this should not totally eliminate the idea of using biocontrol agents for pepper weevil management. *Catolaccus hunterii* was found to have promise early in the season for pepper weevil control when pesticide applications were reduced (Riley and Schuster, 1992). However, this is difficult to accomplish as growers try to keep pepper weevil from establishing itself in the field. Once established, control procedures are not very effective (Riley and King, 1994). Therefore, it was not surprising that no parasitoids were recovered from any of the pepper fruit collected late in the season. Frequent pesticide applications had been made at both farms to try and control the pepper weevil infestation. Chemical controls need to be integrated with biological controls so that the biocontrol agent can flourish, but some chemical control of the pepper weevil is still needed. This is an essential part of a bio-intensive program that will depend on the availability of biopesticides that will control pepper weevil, but not destroy natural enemies. There are 1 or 2 possible bioinsecticides that might fit into this program. How well they do fit will have to be tested.

Project 2

Efficacy of Biologically Compatible Insecticides: Evaluation of PROKIL Cryolite 96 in controlling Pepper Weevil

Introduction: To assess the efficacy of PROKIL in controlling pepper weevil infestation on bell peppers.

Methodology: Non-replicated plots of 5 acres were used in the study. One half of each plot was treated while the untreated half represented the control. Planting date was January 15, 1999. PROKIL was applied on April 21, 1999, using a tractor-driven boom sprayer at an application rate of 50 gallons/acre. Two passes were made in the treated plots to ensure complete coverage. Only one application was made. Treatments: PROKIL at 8 lb/A, PROKIL at 12 lb/A, and Untreated Control. One week after application, a total of 50 fruit (1-2" in size) was randomly collected from five sub-plots in each treated and untreated plot. Subplots were single, 100' long beds between five pre-determined pairs of shovel ditches on either side of the central driveway. From each bed, 10 fruit were randomly collected and examined for oviposition dimples and presence of weevils (eggs, larvae, pupae) in the fruit. Thirteen days after application (6 days after

the first assessment), a second sampling was done from block 1 only (block 2 had been mowed the day before). A total of 70 fruit was collected from the control and treated half of the block from a total of five subplots. Subplots were comprised of seven beds between pre-determined pairs of shovel ditches; from each bed, two fruit were randomly collected, resulting in a total of 14 fruit per sub-plot or 70 per treatment. Differences between percentage fruit infestation and number of dimples per fruit between treated and untreated plots were tested using the nonparametric Wilcoxon test provided by the NPAR1WAY procedure of SAS version 6.12. Because the low-rate and high-rate PROKIL treatments were applied in different blocks, a statistical comparison of these treatments was not possible.

Results: The results are shown in Table 4. Differences in fruit infestation and dimples/fruit were significant between treated and untreated plots in both blocks.

Conclusions: The use of PROKIL gave 2.5-4 times better control of pepper weevil than using no chemical control. However, its use still resulted in 9-30% fruit infestation. This level of control is often what is obtained by using much more toxic chemicals such as oxamyl (Vydate), which greatly reduce or eliminate beneficial insects. Therefore, PROKIL has potential for use in a bio-intensive management program in conjunction with other chemical controls for pepper weevil management.

Project 3

Mass Production and Augmentative Release of Pepper Weevil Parasitoids

Because of the extremely low parasitism rate for pepper weevil in nightshade and pepper, and the fact that *Catolaccus hunterii* was not recovered in any of our surveys, this project was not continued.

Project 4a

Use of Pepper Weevil Aggregation Pheromone: Field Performance of a New Pepper Weevil Pheromone Formulation

Introduction: Pepper weevils cause damage to peppers, *Capsicum* spp., by larval feeding in fruit leading to fruit drop or contamination of fruit with frass and weevils (Riley and King, 1994). Oviposition and feeding punctures on fruits and blooms by adults also reduce fruit quality, while high populations of weevils can defoliate plants and prevent fruiting. Weevils are difficult to control once an infestation has become established in the field. Early detection of adults is essential so that a properly timed insecticide application can be made to prevent further population increase.

A variety of sampling methods have been developed. Visual inspection of plants provides the most consistent results, but is too time-consuming for use in commercial production settings (Riley et al., 1992). Likewise, yellow sticky traps can be used, but the intensity required makes this method too expensive as well (Riley and Schuster, 1994). Aggregation pheromones in combination with yellow sticky traps offer new perspectives in pepper weevil monitoring (Eller et

al., 1994). The standard formulation developed by USDA and modified by Trece has been on the market since 1995, but high production costs and limited field longevity have limited its adoption as a monitoring system. Recent developments in new pheromone formulations and production methods at Trece have yielded several new candidates. The purpose of this study was to test these new formulations in the field for sensitivity and longevity of attraction and to correlate trap catch with weevil fruit damage. We also evaluated various trap designs compared to the yellow sticky trap.

Methodology: Three lure systems were tested: standard lure, TRE 8420+8461 and TRE 8420+8462, and compared with an unbaited control treatment. Lures were prepared at Trece, Inc. (Salinas, Ca) and stored in a freezer before use. The standard lure treatment had two laminated 3-layer polymeric squares, each with a plastic hook, which was slipped through a hole in the upper edge of a 12" x 6" yellow sticky panel trap (Olson Products, Medina, Ohio). The other lure systems consisted of a polymer-based septum and a closed tube based on a different polymer which were inserted into receptacles on the traps. The traps were attached to a 0.25" thick, 48" long wooden dowel by inserting the dowel in holes provided in the top and bottom of the trap panel. The trap panel was positioned on the dowel in a concave shape with the lower edge at the level of the crop canopy. The trial was carried out at a commercial pepper farm 5 miles west of Jupiter, Palm Beach Co., Florida. The farm consisted of 58 blocks of 2-5 acres each (230 acres total) and was planted between November 14, 1997, and February 2, 1998. Blocks were 300-2,000 ft long and 50-ft wide, oriented north-south and separated by irrigation ditches with a sugarcane windbreak row on either side of the ditch. Two trials were conducted over a period of five weeks each. The first trial ran from April 6-May 11 on the west side of the farm, the second from April 27 to June 1 on the East Side of the farm. Treatments were arranged in a randomized complete block design. Traps were placed along field edges about two ft away from the sugarcane windbreak with at least 100 ft between traps. The sugarcane foliage around the trap was trimmed to eliminate interference with the trap. Traps were checked daily, except on weekends, and all weevils were counted and removed. Traps were rotated within replicates every time they were checked to reduce the effect of potentially uneven weevil distribution and trapping conditions. Panels were changed once a week. Traps were left in the field up to one week after the crop was mowed.

To correlate trap catch with weevil infestation in the field, 100 pepper fruit were randomly collected across the block and checked for weevil damage. Six blocks were assessed in this manner in the first trial week, five blocks in the second week, two blocks in the third week and five blocks in the fourth week.

Weevil trap catches were totaled by week and analyzed with the general linear models procedure of the statistical analysis system version 6.12 (SAS Institute, Cary, NC) to separate treatment effects. Data from the two trials were combined and analyzed as a split-plot design with the replication by treatment interaction as the error term. Trap catches were log-transformed to satisfy additivity and homogeneity requirements when necessary. When significant treatment effects occurred, means were separated using Fisher's protected least-significant difference test ($p=0.05$). Regression analysis was done to determine the relationship between trap catch with the TRE8420+8462 lure and percentage of fruit damage.

Pheromone Trapping During 1998 Summer Fallow: Yellow sticky traps baited with TRE 8420+8462 lure were used to monitor pepper weevils during the summer fallow period after crop destruct. On June 9, one month after the crop was harvested and ploughed under, nine yellow sticky traps baited with TRE 8420+8462 lure were placed at various locations throughout the 230 A commercial pepper farm; one trap was placed about 2,000 ft N of the farm along an irrigation

canal. Trapping continued for 5 weeks until July 7. This was repeated on August 25 when five traps were set out in the west half of the farm. Trapping continued until September 24. Traps were checked every one to three days, and weevils were counted and removed.

Results and Discussion:

- **Lure Trials:** The combination of TRE 8420 and 8462 generally resulted in the highest weevil catch (Table 5). TRE 8420+8462 was significantly better than the unbaited control at all lure ages, better than the standard lure at lure ages of two, three and five weeks, and better than TRE 8420+8461 with four and five week old lure. Percentage-wise, the TRE 8420+8462 caught 1.8 to 4.6 times as many weevils than the second most attractive lure. Loss of traps during mowing operations decreased the number of available replications toward the end of the trial. There was a positive linear relationship between trap catch of traps with TRE 8420+8462 (x) and % fruit damage (y). The equation ($y = 1.67 + 6.63 x$, $F=35$, $p<0.001$, $R^2=0.69$) suggests that a weekly catch of only one weevil per trap already corresponded to 8.3% fruit damage while with a zero catch there was still a low level of fruit damage (1.67%). In comparison, unbaited control traps did not catch weevils until 22% fruit damage.

Crop activities had a major impact on weevil trap catch in this study. Crop destruct mowing between April 8 and May 8 forced large numbers of adult weevils from pepper plants, which resulted in trap catches of up to 222 per trap per day. Similar observations have been made for the cotton boll weevil (Eller et al., 1994).

- **Pheromone Trapping During the Summer Fallow:** During the early summer fallow, from June 9 to July 7, a total of 20 weevils was trapped over a period of 28 days, or an average of 2 weevils per trap. Black nightshade (*Solanum nigrum* L.) was found in the cane windbreaks during a survey from June 16-26 at an average density of 0.87 plants per 100 ft. Of the 179 plants inspected, 6 adult weevils were found (0.03 per plant). Therefore, weevils caught on the traps in June could have come from the black nightshade. During the late summer fallow from August 25 to September 24, a total of three weevils were trapped. Nightshade plant population had greatly declined in August to 0.16 plants per 100 ft; no weevils were found on 57 plants. The pheromone traps demonstrated that they are sensitive and can attract weevils at extremely low and dispersed population levels. In three out of four commercial pepper farms, weevils have been collected from the pheromone traps before field infestation has been detected. The first weevil was collected at Boynton Beach on September 21 near a field planted on August 18, the second weevil on October 5 near a field planted on September 4, and the third weevil on October 22 near a field planted on September 7. By the end of October, field infestation had not yet been observed at these farms. Although the origin of the weevils remains unknown, the high sensitivity of the lure was again clearly demonstrated.
- **Conclusions and Future Studies:** Our tests have shown that the new pepper weevil lure formulation has good field longevity and will therefore be more economical in monitoring pepper weevils than the previously marketed weevil lure. We now need to develop more efficient, user-friendly trap designs and determine the best placement strategies for the traps to avoid losses from future weevil generations.

Project 4b

Monitoring Pepper Weevils with the Improved Lure System

Introduction - Biologically-based management of pepper weevil (*Anthonomus eugenii* Cano), one of Florida's most destructive pepper pests, is crucial because only toxic chemicals in the carbamate and pyrethroid groups are available as control treatments. When these compounds are used on a frequent basis, beneficial insect populations are annihilated, which may lead to resurgence of phytophagous thrips. There is a need to monitor weevils in the field so that pesticides are applied only when required. Scouting for weevils in the field is difficult and time-consuming and incipient outbreaks are often overlooked. Pheromones can be a useful tool in the monitoring and control of pepper weevils. Pheromones can also be useful in studying the life cycle of the pepper weevil in a broader context, particularly off-season survival on alternate hosts and the factors that contribute to weevil outbreaks.

Concerns about the quality and cost of the existing standard pepper weevil pheromone has prompted recent developments by Trece, Inc., of new pheromone formulations with increased longevity and attraction. The objectives were 1) to select an improved pepper weevil lure in collaboration with Trece, Inc., 2) to develop a protocol for monitoring pepper weevils in the field using the selected lure system. Developing the protocol included determining the length of time between the first trap catch and detection of weevil infestation of the field, the minimum number of traps required to provide accurate information about impending weevil outbreaks, the optimal placement of traps in relation to the crop field, and the relationship of trap catch with field infestation.

Methods: We tested two new formulations in commercial pepper farms in the 1998 spring and fall crops in southern Florida in collaboration with Trece, Inc. One formulation showed superior longevity and sensitivity compared to the standard lure and unbaited control. The new lure system has shown activity for up to five weeks in the field, and can provide an economical means for monitoring and controlling pepper weevils (Bottenberg and Lindgren, 1999). We continued developing a trap management protocol with the new pheromone formulation during the fall '98 and spring '99 crop in a total of 13 sites across south Florida. The standard (12" x 6") yellow sticky trap was used; trap panels were changed weekly while the lure was changed every four weeks. Trapping was normally started around bud stage but in some cases before or at planting. Off-season life cycle studies focused on the pepper weevil's most preferred alternate host, black nightshade. The abundance of this plant was monitored in a selected number of sites and berries were collected regularly to determine weevil infestation. Berries were stored in paper bags at room temperature and the emergence of adult weevils was recorded twice weekly for up to six weeks after collection. The survey was started in March and terminated in September 1999 when most nightshade stands began to decline severely.

Results:

- **Advance Warning Period:** We have found that after crop bloom the traps provide, in general, an advance warning of 7-10 days before infested fruit is detected in the field. Where traps are used from the onset of planting, the advance warning can be as long as two months. The first weevils trapped were most likely incoming migrants from other fields. Later on in the season, weevils trapped probably originated from within the site. A good example is site #11 (Table 6) where weevils were trapped up until bloom around mid-February. None were trapped for 5 weeks, after which increasing numbers were trapped from March 25 as field

infestation spread. Similar scenarios were developing at sites #9 and #10 where weevils were trapped as the fields were being planted, but infestation had not yet been detected.

- ***Trap Density and Placement:*** The minimum density of traps required depends on the traps' degree of attraction, the size and lay-out of the farm, and the amount of time available for monitoring. Our experience has demonstrated that traps placed away from pepper plants are more attractive to weevils than traps placed near the crop, particularly when blooming has started. Pepper plants with blooms and fruit produce olfactory compounds that attract weevils, and therefore compete with the pheromone traps. Pheromone traps are most attractive to weevils in the absence of a pepper crop, which explains the relatively high trap catches in sites where pepper has not yet been planted, but where weevils are already present. In other words, the traps attract weevils from farther away in the absence of pepper than when pepper is present. When pepper is blooming and setting fruit, the sphere of attraction of the traps is less than in a pre-bloom pepper crop. We estimate this minimum distance is in the range of 20-30 ft during the crop's reproductive phase; the upper limit is not known, but could be in the range of thousands of feet. We have found that traps placed at the rate of one per 10 acres give satisfactory results throughout the season. This number may be decreased before or at the onset of planting and increased as the crop matures. The most practical and efficient placement of traps is along roads around the perimeter of the farm, usually on the slightly elevated ditch bank between the road and the adjacent irrigation canal. Here they are well exposed to dispersing weevils, are easily accessible by scouts, and do not interfere with farm operations.

Continuous weevil trapping trials in nine sites across south Florida showed that weevil trap catch was related not only to pepper fruit infestation but also to black nightshade growing on field borders and ditch banks. Trap catch peaked during crop destruction activities (Fig. 10). During the fallow, trap catch dropped but still exceeded that of the prior crop season. Trap catch was governed by a number of factors, including presence of pepper and/or nightshade, size of weevil population in surrounding habitat, and habitat destruction events, such as mowing or plowing. When there was no disturbance event, trap catch remained low, even if there was a large weevil population nearby, because of the greater attractiveness of pepper or nightshade.

- ***Relationship of Trap Catch with Field Infestation:*** When expressing infestation as % fruit infested with weevil larvae or pupae, we have found that a trap catch of less than 0.1 weevil per trap per week during fruit production translates into a very low field infestation level (<1% of fruit) which is only marginally detectable during routine scouting operations; 0.1-1 weevil per trap per week means a moderate level of field infestation (1-10% of fruit), while >1 weevil per trap per week indicates a high level of field infestation (>10% of fruit) (Table 7). When nightshade is common, trap catch does not reflect pepper infestation, but the occurrence of weevils in the nightshade. Therefore, the predictive value of the traps is somewhat limited. However, as a tool to determine if weevils are present in an area, it can prove to be very useful, particularly at the onset of the season.

Project 5 Pepper Weevil Trap Designs

Trial 1: A preliminary trial to determine the efficacy of different trap designs was conducted at an abandoned pepper field in Homestead, Dade Co., Florida. Three designs were tested: 1) the standard 6"x12" yellow sticky panel trap (Olson Products, Medina, Ohio) mounted on a 0.25" thick 48" tall wooden dowel; 2) the USDA Cotton Boll Weevil trap (Dickerson, 1986) mounted on a 5/16" thick 48" tall wooden dowel, and 3) the Boll Weevil Attract and Control Tube or bait stick (Plato Industries, Houston, Texas) (McKibben et al., 1990; Villavosa et al., 1998). Tangletrap® glue (Tanglefoot Company, Grand Rapids, MI) was used to coat the outside of the bait sticks or the inside of the capture cylinder of the boll weevil trap. Insecticides were not used in these devices. Trece pepper weevil pheromone TRE 8420+8462 was inserted into the upper portion of the yellow sticky panel or bait stick, or placed in the capture cylinder of the boll weevil trap. The trial field measured approximately 10 acres, and had 24 beds with a single row of sugarcane every six beds. The traps were arranged in a randomized complete block design with five replications. Traps were placed in open gaps in the cane rows at least 100 ft apart. Traps were checked once a week for two consecutive weeks (September 4-18, 1998) and rotated within replications. Weevils were counted and removed.

Trial 2: An improved version of the boll weevil trap was tested during the spring 1999 crop at Shiloh. The trap had a closer fitting capture reservoir with a smaller-sized mesh screen so that pepper weevils, which are smaller than boll weevils, would not be able to escape from the trap. Traps were also painted yellow on the outside to make them more attractive. Lure was placed in the capture reservoir. To aid the dissemination of the attractant, 30 1-mm diameter holes were drilled in the side of the reservoir. A total of four improved boll weevil traps were tested from January through April 1999. Traps were placed about 100 ft from standard yellow sticky traps along roadsides.

Results:

- **Trial 1:** The results are shown in Table 8. The yellow sticky traps caught more weevils (2 ± 1.4 per trap) than the bait stick (0.4 ± 0.5) and boll weevil traps (0.2 ± 0.4). Total catch (13 weevils) was low, probably because the trial was conducted at the end of the summer when weevil populations in the field were greatly diminished.
- **Trial 2:** No weevils were trapped in the boll weevil traps during the entire period, while the yellow sticky traps captured weevils regularly (see section on pepper weevil monitoring). Likewise, three improved boll weevil traps at the Brown82 site did not trap any weevils during the same period, while numerous weevils were trapped with the yellow sticky traps.
- **Conclusion:** the yellow sticky trap remains the most effective trap design.

Project 6

Role of Nightshade in Pepper Weevil Lifecycle

Introduction: The lifecycle of the pepper weevil *Anthonomus eugenii* Cano, one of Florida's major pests of pepper, is still not fully understood. How this pest bridges the off-season is crucial to the weevil's survival. In Florida, pepper is planted in the fall and/or spring and harvested from November to May, leaving the hot summer months as the off-season. When only one crop is planted the off-season is even longer. Previous studies have shown that weevils survive the summer on black nightshade (*Solanum americanum* Mill. and *S. nigrum* L.) and untended pepper plants. The role of black nightshade was considered incidental rather than essential in the weevil's lifecycle: nightshade becomes infested only after recent outbreaks on pepper (Patrock and Schuster, 1987). However, recent pheromone monitoring trials by Glades Crop Care, Inc., suggest that pepper weevils can occur in areas with nightshade but without pepper, such as tomato farms far from pepper production areas. These observations led to the development of this survey with the goal of monitoring the infestation of black nightshade berries in different pepper and non-pepper habitats.

Methodology: Nightshade berries were collected in paper bags from black nightshade plants growing in tree nurseries, citrus groves, and along field borders, sugarcane windbreaks, and cypress hammocks in pepper and tomato farms during the spring, summer, and fall 1999 crops. Adult weevils were not counted, as the large size of the plants often prevented an accurate assessment of the number of adults present. Sites were located in Palm Beach, Martin, St. Lucie, Hendry, and Collier counties. Only full-sized, green berries or berries that were about to change to the dark-violet color of mature berries were collected. Mature berries were not collected because they rapidly turn moldy, and were also less likely to be infested with weevils. Up to five clusters (each containing 2-10 berries) of berries would be collected from a single plant. Size, vigor, maturity, and presence of pests and diseases on plants were also noted. In some sites the number of plants along each pepper field surveyed was also counted. The berries were kept in the laboratory in paper bags and checked two to three times per week up to six weeks after collection. The survey was started in March and terminated in September 1999 when most nightshade stands began to decline severely.

Results:

- **Weevil Infestation:** Weevils were reared from nightshade berries in every habitat surveyed (Table 9) during the spring, summer, and early fall season; no weevils were recovered after mid-August 1999. At the Red Star tomato farm in Hendry County, where a vigorous nightshade population developed within sunflower windbreaks and along ditch banks and field borders, one pepper weevil was recovered from 1,412 berries (0.07%). The nearest pepper farm is about five miles from the Red Star location. At the Brown82 site, a single nightshade plant was uprooted from a pepper field with a moderate level of weevil infestation. About half the berries were removed, yielding a total of 850 berries from which 26 weevils developed (3.80%). At the Green Cay site, nightshade plants were found only in a tree nursery adjacent to a fallow pepper field in July. Despite the fact that the last fall pepper crop had been disked under in February, three weevils were reared from a total of 693 berries. No weevils were reared from berries collected during October-December. The 230 acre Shiloh site near Jupiter, Palm Beach Co., had a highly vigorous nightshade stand with numerous berries along field borders, windbreaks, and hammocks during June and July after the spring pepper crop had been disked under. Out of 23 collections of 300 to 1,347 berries each, only two collections did not produce weevils. The rest had infestation levels ranging from 0.21 to 8.49%. The overall infestation based on a total of 16,837 berries was 2.12%.

The Thomas site, consisting of three adjacent farms ranging from 60 to 200 acres in size, was characterized by a dense stand of nightshade plants on field borders (without a sugarcane windbreak) along pepper fields during the 1999 spring crop (planted January-March 1999). One of the Thomas farms had been planted with tomato for six consecutive years before the spring pepper crop was planted. This farm was about two miles from the other two farms where peppers and tomatoes were rotated every year. Out of 14 spring season collections of 100 to 1,178 berries each, four did not contain weevils; the rest had infestation rates ranging from 0.09 to 1.95%. Mean infestation rates for March, April, May and July were 0.18, 0.36, 0.32 and 1.63%, respectively, suggesting an increase in infestation over time. However, the July collection was made from a limited number of field borders while in previous months the entire site was covered. Overall infestation based on 8,593 berries was 0.45%. The spring pepper crop developed a low level of weevil infestation only toward the end of the season because the insecticide regime on this farm was intense. Pepper weevil pheromone traps captured weevils throughout the season from the time of planting into the following fall tomato crop. No weevils were recovered from berries collected from October-November, 1999. At this time there was a tomato crop in the fields that were previously planted with pepper.

- **Nightshade Vigor and Abundance:** Nightshade was found growing vigorously during the summer season along field borders and cane windbreaks. Cane windbreaks were located on both sides of irrigation ditches between fields. Like other farms in south Florida, the Shiloh site has a number of cypress hammocks ranging in size from a fraction of an acre to several acres. Field borders along hammocks typically do not have sugar cane windbreaks. Sugarcane windbreaks were mown in May but the sugarcane rapidly grew back to its usual height of 7-8 ft by mid August. In September-October, a second mowing was done on one side of each ditch to allow a backhoe to deepen the ditch. A sudangrass cover crop was grown in the fallow fields during the summer, reaching a height of 6-8 ft by the end of July. The first mowing of the cover crop was in mid-August. More nightshade plants (no./ft) were found on field borders along hammocks (July: 0.169; August 0.04) than along sugarcane windbreaks (July: 0.02; August 0.01). Differences were significant by Fisher's Exact T-test (T-values of 5.35 and 2.37 for July and August, respectively.). Mature plants reached heights of 4-5 ft with canopies 4 ft wide, and carried numerous berry clusters totaling up to 2,000 berries per plant. Vigor and abundance of plants declined during late summer and early fall as other weeds such as grasses, *Bidens* sp., and *Ludwegia* sp. became more dominant and competed with nightshade.
- **Pests:** Spider mites *Tetranychus evansi* Baker & Pritchard (determined by W. C. Welbourn, DPI, Gainesville, FL) tobacco hornworm, southern armyworm, leafrollers, stinkbugs, leaf-footed bugs and diseases (an unidentified downy mildew) took a heavy toll on nightshade vigor (Tables 10 and 11). An unidentified pyralid caterpillar was also found feeding within the berries, causing an emergence hole similar to that caused by pepper weevils. Feeding by Hemipterans caused dark circular blemishes on the fruit. Tomato mottle virus (determined by G. W. Simone, Plant Disease Clinic, Gainesville, FL) was also found at the Thomas site, and possibly the Shiloh site, but did not appear to affect plant vigor. Mature plants were often heavily defoliated by caterpillar pests; however, new growth with leaves and blooms sprouted from growing tips. In windbreaks, the number of nightshade plants declined by an average of 56% from July to August, along the hammocks, by 77%. In one field (which was not included in the above analysis), a new stand of germinating plants developed in a strip between the sudangrass cover crop and the sugarcane windbreak. These plants developed berries by mid-August. Mowing of the cover crop and field borders and subsequent tilling and disking of the field destroyed most remaining nightshade during September. In October,

a total of only 5 nightshade plants were counted on 16,950 ft of field border (or 0.3 plants per 1,000 ft), vs. 1,397 plants on 27,990 ft border in July and 422 plants on 22,340 ft border in August. Assessments made in June and August of 1998 showed a similar rate of decline in nightshade abundance and vigor as in 1999, except that there appeared to be fewer plants present (Fig. 11). In June 1998, 179 plants were counted on 20,637 ft of border (Table 10). In August 1998, 57 plants on 35,268 ft of border were counted (Table 11). By November, numerous nightshade plants were germinating along field borders, producing blooms and berries by mid December. A collection of nightshade berries made on December 7, 1999, did not yield any weevils. An assessment made on December 22, 1998, on the west border of block 1, showed a great abundance of young nightshade plants with blooms and developing berries. Mature berries started to appear in January. Thus, the lifecycle of nightshade appears to be as follows: 1) Land preparation in October prior to laying beds brings up nightshade seed to the soil surface. 2) Seeds germinate, and by December numerous seedlings are growing along windbreaks and hammock borders. As the season continues, many seedlings perish due to competition for space, water, and nutrients with other weed species. 3) Mature berries start to appear by January, but the plants continue to grow until July. By that time, plants can be 4 ft high and canopies can measure 4-5 ft across, bearing up to 2,000 berries. 4) From July on, plants deteriorate rapidly due to mowing, diseases, and insects. 5) By October, most plants have died off.

Black nightshade plays a more important role in the lifecycle of the pepper weevil than previously assumed. Pepper weevils can survive and reproduce on nightshade berries without having access to pepper; however, weevil populations go through a general decline in the late fall even if pepper and/or nightshade is present.

Conclusions: In the first comprehensive study on the pepper weevil lifecycle in California, Elmore (1934) already noted that weevils had been observed breeding in nightshade berries throughout the growing season and that serious infestations in pepper could be traced directly to nightshade. However, a survey near Bradenton, Florida, failed to confirm these findings and concluded that peppers are the main host of the pepper weevil (Goff and Wilson, 1937). Later studies by Patrock and Schuster (1987; 1992) demonstrated that pepper weevil can indeed breed on various species of nightshade, including black nightshade, but that weevils can be found reproducing on black nightshade only on farms that had recent infestations of the weevils on pepper. Our findings, particularly from the tomato farms, strongly suggest that weevil populations can maintain themselves on nightshade for many generations without having access to pepper. Therefore a new strategy for weevil control may be as follows: 1) Use the weed as a trap crop after final harvest and then destroy it. 2) Destroy any nightshade on or near the farm 3-4 weeks before planting the pepper crop. These strategies would need to be tested in growers' fields.

Work Area #4

Biointensive Management of Broadmites

Broadmite ratings were tabulated from existing scouting reports from Green Cay 1998 fall season and Shiloh 1999 spring season and analyzed as described previously for armyworm and aphid assessments. Broadmites were rated as none (0), low (1), moderate (2), and high (3). A low rating means a few scattered plants (< 5%) with broadmites. Moderate means widespread infestation, but damage and broadmite population is limited. High means widespread infestation and severe damage.

Ratings never exceeded “moderate” in any single field. Broadmites were more common during the Green Cay fall season than during the Shiloh spring season (Figs. 8a and b). At Green Cay, broadmites were detected during 27 out of 41 scouting trips (66%), at Shiloh during 9 out of 48 trips (19%). Agrimek was used three times at Green Cay, while dicofol was used three times at Shiloh.

Work Area #5

Manipulation of Other Beneficial Populations

This work has been primarily incorporated into work under #1 and #2, e.g. predaceous mites and parasitic wasps. A separate project is discussed below:

Project 1

Augmentative Release Trials with *Coleomegilla maculata* on Peppers and Selected Weedy Hosts

Introduction: To evaluate if *C. maculata* ladybeetles (CM) can be established in pepper crops and/or weedy border habitats.

Methodology: Two trials were conducted, one at a pepper farm (Shiloh) near Jupiter, Palm Beach Co., and another at Glades Crop Care’s research farm (Kitchen Creek) near Hobe Sound, Martin Co. (Table 12). CM larvae and adults were supplied by Predation, Inc. (now Entomos, Inc.) through overnight express mail and released the same day (trial 1 and 2) or two days after arrival at Glades Crop Care’s Jupiter office. Insects were packed in Styrofoam cups with shredded paper, pollen, and a moisture source, and generally arrived in excellent condition. Larvae and adults were released onto host flowers infested with thrips (mostly Florida flower thrips *Frankliniella bispinosa*) either individually with a small brush, by placing clumps of shredded paper with larvae on the plant canopy, or in the case of adults, by shaking a cup gently above plants. *Wedelia* and *Bidens* sp. (Asteraceae) are good hosts of the Florida flower thrips and other thrips species that rarely cause economic damage in pepper. In trial 3, releases were also

made on *Bidens* plants with aphid colonies, probably *Aphis coreopsides*, which cannot feed on pepper. Behavior of a number of released insects was followed until they disappeared from sight. The release sites were visited twice a week over the next 3 weeks, and the crop or weedy vegetation was closely inspected for ladybeetles.

Results:

- **Trial 1:** Larvae rapidly explored pepper blooms and crawled in between anthers when thrips were present, but rapidly left the bloom if no prey was available. Small instar larvae were able to explore the blooms more efficiently than large instars. Adults were not observed entering blooms, but generally moved around on the foliage and stems and subsequently flew off. In two out of five larvae observed, CM larvae immediately fed on thrips. One fed on thrips inside the bloom, the other outside, underneath the calyx. It was generally very difficult to track the larvae, which is why only five larvae could be accurately monitored. On April 24, 9 days after release, an adult CM was collected from pepper blooms. On May 7, 22 days after release, one adult CM was trapped on a yellow sticky trap in block 53, ca. 900 ft. east of the release site. As no CM had ever been trapped or collected previously, it is assumed that this adult originated from the release site.
- **Trial 2:** Releases were made as described above. CM larvae and adults did not go into *Wedelia* blooms, probably because they are too tightly packed and have little space for the relatively large larvae. (On the other hand, *Orius* sp., a much smaller insect predator, is not uncommon in *Wedelia* blooms). No recovery of CM was made after the release at the Kitchen Creek site.
- **Trial 3:** When placed on *Bidens* blooms, some larvae moved in between the anthers, but the majority spent little time on or inside the bloom and crawled down the stems. It was difficult to follow the movement of larvae within the plant foliage because most larvae moved down along the stems without moving up to the blooms. The adults that were released all flew off within minutes. No recoveries of CM have been made so far at this site.

Conclusions: CM may be able to feed on thrips inhabiting pepper blooms, but not on blooms of Asteraceae. More release trials on pepper, especially earlier in the season, are needed to confirm these preliminary observations.

Work Area #6 ***Beauveria bassiana* Strain Screening**

Although Glades Crop Care, Inc. had strong evidence that *Beauveria bassiana* could be very beneficial in the control of thrips in peppers (Frantz and Mellinger, 1998) Mycotech has declined to collaborate with us in this regard.

Work Area #7

Lowering Pest Management Costs With Biointensive IPM

Examining the costs and benefits of a biointensive IPM program is an extremely difficult task. Whole books have been written on the subject (Benbrook et al., 1996). Government and universities are not sure as to the most pertinent criteria to use in deciding what constitutes reduced risk or biointensive IPM practices or how best to measure them.

Glades Crop Care, Inc. has modified the IPM measurement approach suggested by Benbrook in the 1996 book 'Pest Management at the Crossroads', and applied it to a set of both pepper and tomato growers. We have found the methodology data-intensive but valuable as a way to engage our more innovative growers in an assessment of the strengths and weaknesses of their management systems. Growers participating in this project raised many questions about possible economic tradeoffs associated with different pepper management options. Indeed, it is clear to us that economics must play an integral role in the field-testing and evaluation of both discrete new technologies, as well as area-wide management systems.

A key dimension of the study entails estimating the impact on non-target beneficials and secondary pests resulting from each pesticide or practice incorporated into a system in transition toward biointensive IPM. While an application of Vydate or pyrethroids may appear somewhat more cost effective in dealing with a thrips flare-up, we are certain that the season-long consequences of the use of broad-spectrum carbamates, OPs, and synthetic pyrethroids are of economic significance when comparing the costs of alternative programs. Growers sense this too, but hunches carry little weight when a \$40,000 per acre crop is on the line. In future work, we want to build into our field experiments additional data gathering and monitoring that will allow us to quantify these secondary impacts. Once we have a sense of how the systems respond biologically, we will have the basis to more fully project the economic consequences of alternative system configurations. We are certain that many questions of interest to growers will arise in the course of this exercise and that some surprises will result.

We are aware of another major economic issue, which we hope to have a chance to work on in future years. Biointensive IPM depends upon a sophisticated infrastructure of "soft" tools, information, trained people, and management options. The necessary infrastructure is just emerging in many essential areas, and in general, economies of scale have yet to be realized. Our sense is that there are great opportunities for area-wide cooperation and coordination, which will both improve efficacy and lower costs, in effect lessening the cost of the infrastructure that must be put in place. We hope to develop tools and methods to study and quantify these opportunities, in the hope of identifying high-return investments for growers, the pesticide industry, the food industry, and government research programs and universities.

Work Area #8 Pesticide Efficacy Testing

Project 1 Shifts in Pesticide Usage

Methodology: Pesticide usage records from 1996 through 1998 were obtained from seven pepper farms across South Florida ranging in size from 35 to 900 acres or a total of 2403 acres. The total amount of active ingredient applied per acre was calculated for each farm and insecticide used. These amounts were added up for all farms and divided by the total acreage to obtain the mean amounts of active ingredient applied per acre. The average of the 1996-97 spring and fall seasons represented the baseline of insecticide usage. The amounts of active ingredient applied in the 1997-98 spring and fall season were expressed as a percentage of the 1996-97 baseline data.

Results: The results are shown in Table 13. A total of 30 active ingredients were recorded, of which 24 were used in 1996-97, 17 in spring 1997-98, and 25 in fall 1997-98. Five products (carbaryl, PROKIL, diazinon, NPV virus, and oxydemeton-methyl) that were used in 1996-97 were not used in 1997-98. There were six new products in 1997-98 (crop oil, dimethoate, esfenvalerate, garlic/sugar/capsaicin and spinosad). Seven products (acephate, azinphos-methyl, chlorpyrifos, endosulfan, permethrin, pyrethrins, and rotenone) were used in the 1997-98 fall but not in the spring crop. Products that saw an increase in both spring and fall season usage were cyfluthrin, cyromazine, dicofol, imidacloprid, and neem seed extract. Products that were not used in the spring crop but whose use increased in the fall crop were acephate, azinphos-methyl, and rotenone. Endosulfan's usage was up with only 4% in the fall crop and can be regarded as almost unchanged; it was not used in the spring crop. The use of azadaractin, *B.t.*, methomyl and sulfur was down in both seasons. Chlorpyrifos, permethrin, pyrethrins, and Rotenone were down in the fall, and not used at all in the spring crop. Oxamyl was down in the fall, but up in the spring crop. It is important to note that there were more cases where the environmentally damaging organophosphates and carbamates were either not used or reduced, compared to the few cases where their use was increased. The increase in oxamyl was directed at pepper weevils.

Work Area #9 Thrips Management and Taxonomy Software

THRIPS is a computerized knowledge base for the identification and management of vegetable thrips (Frantz et al., 1997). It is a 7 MB program that runs on Windows. Nine major species of thrips in the United States and *O. insidiosus*, are comprehensively covered by accurate field identification, management tactics, and diseases vectored. The product has been well received thus far, and we are planning ways to improve the marketing of the product.

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References Cited

- Ables, J. R., S. L. Jones, and D. W. McCommas, Jr. 1978. Response of selected predator species of different densities of *Aphis gossypii* and *Heliothis virescens* eggs. *Environ. Entomol.* 7:402-404.
- Altieri, M. A., and W. H. Whitcomb. 1979. Manipulation of insect populations throughout seasonal disturbance of weed communities. *Prot. Ecol.* 1:185-202.
- Armer, C. A., R. N. Wiedenmann, and D. R. Bush. 1998. Plant feeding site selection on soybean by the facultatively phytophagous predator *Orius insidiosus*. *Entomol. Exp. Appl.* 86:109-118.
- Atkins, E. L., Jr., M. H. Frost, Jr., L. D. Anderson, and A. S. Deal. 1957. The "omnivorous leaf roller" *Platynota stultana* Wlsh. on cotton in California: nomenclature, life history, and bionomics (Lepidoptera, Tortricidae). *Calif. Tech. Bull. No. 50:251-259.*
- Barber, G. W. 1936. *Orius insidiosus* (Say), an important natural enemy of the corn earworm. *USDA Tech. Bull. No. 504, 24 pp.*
- Barry, R. M., J. H. Hatchett, and R. D. Jackson. 1974. Cage studies with predators of the cabbage looper, *Trichoplusia ni*, and corn earworm, *Heliothis zea*, in soybeans. *Environ. Entomol.* 9:71-78.
- Benbrook, C. M. with E. Groth, J. M. Halloran, M. K. Hansen, and S. Marquardt. 1996. "Pest Management at the Crossroads." Consumers Union of United States, Inc., Yonkers, NY. 272 pp.
- Bottenberg, H., G. Frantz and H. C. Mellinger. 1999. Refuge and cover crop plantings for beneficial insect habitats. *Proc. Fla. State Hort. Soc.* 112:339-341.
- Bottenberg, H., Lingren, B. 1998. Field performance of a new pepper weevil pheromone formulation. *Proc. Fla. State Hort. Soc.* 111:48-50.
- Brown, G. C., and C. H. Shanks, Jr. 1976. Mortality of twospotted spider mite predators caused by the systemic insecticide, carbofuran. *Environ. Entomol.* 5:1155-9.
- Brunt, A. A., Crabtree, K., Dallwitz, M. J., Gibbs, A. J., Watson, L. and Zurcher, E. J. (eds.). 1996. `Plant Viruses Online: Descriptions and Lists from the VIDE Database. Version: 16th January, 1997.
<http://biology.anu.edu.au/Groups/MES/vide/>
- Burke, H. R. 1959. Toxicity of several insecticides to two species of beneficial insects on cotton. *J. Econ. Entomol.* 52:616-618.
- Chellemi, D. O., Funderburk, J. E. and Hall, D. W. 1994. Seasonal abundance of flower-inhabiting *Frankliniella* species (Thysanoptera: Thripidae) on wild plant species. *Florida Entomologist.* 80:257-261.

- Childers, C. C. and Beshear, R. J. 1992. Thrips (Thysanoptera) species associated with developing citrus flowers in Florida and a key to adult Terebrantia females. *J. Entomol. Sci.* 27:392-412.
- Cohen, A. C. 1990. Feeding adaptations of some predaceous Hemiptera. *Ann. Entomol. Soc. Am.* 83:1215-1223.
- Cohen, A. C. 1996. Plant feeding by predatory Heteroptera: evolutionary and adaptational aspects of trophic switching. In: O. Alomar & R. N. Wiedenmann (eds.) *Zoophytophagous Heteroptera: Implications for Life History and Integrated Pest Management*. Thomas Say Publications in Entomology. Lanham, MD, pp. 1-17.
- Coll, M., and R. L. Ridgway. 1995. Functional and numerical responses of *Orius insidiosus* (Heteroptera: Anthocoridae) to its prey in different vegetable crops. *Ann. Entomol. Soc. Am.* 88:732-738.
- Coll, M. 1997. Feeding and living on plants in predatory Heteroptera. In: M. Coll & J. R. Ruberson, (eds), *Predatory Heteroptera in Agroecosystems: Their Ecology and Use in Biological Control*. Thomas Say Publication in Entomology. Lanham, MD, pp140-153.
- Dickerson, W. A. 1986. Modified boll weevil trap. U.S. Patent 4,611,425.
- Eger Jr., J. E., Stavisky, J. and Funderburk, J. E. 1998. Comparative toxicity of Spinosad to *Frankliniella* spp. (Thysanoptera: Thripidae), with notes on a bioassay technique. *Florida Entomologist* 81:547-551.
- Ehler, L. E. 1977. Natural enemies of cabbage looper on cotton in the San Joaquin Valley. *Hilgardia*. 45:703-106.
- Ehler, L. E. and J. C. Miller. 1978. Biological control in temporary agroecosystems. *Entomophaga*. 23:207-12.
- Elkassabany, N., Ruberson, J. R., and Kring, T. J. 1996. Seasonal distribution and overwintering of *Orius insidiosus* (Say) in Arkansas. *J. Entomol. Sci.* 31:76-88.
- Eller, F. J., R. J. Bartelt, B. S. Shasha, D. J. Shuster, D. G. Riley, P. A. Stansly, T. F. Mueller, K. D. Shuler, B. Johnson, J. H. Davis, and C. A. Sutherland. 1994. Aggregation pheromone for the pepper weevil, *Anthonomus eugenii* Cano (Coleoptera: Curculionidae): identification and field activity. *J. Chem. Ecol.* 20:1537-1555.
- Estrada, J. S. 1973. Fluctuations in the populations of beneficial insects and evaluation of chemical control of cotton pests in the Lagoon District during the cycle of 1970. *Folia Entomol. Mex.* 25:58-67.
- Eveleens, K. G. 1974. The induction of secondary pests in the cotton growing industry of California, USA by chemical insect control. *Entomol. Ber.* 34:4-9.
- Eveleens, K. G., R. van den Bosch, and L. E. Ehler. 1974. Secondary outbreak induction of beet armyworm by experimental insecticide applications in cotton in California. *Environ. Entomol.* 2:497-503.

- Everson, M. L. 1980. The making of a good biocontrol agent. USDA Bull. 846. 36 pp.
- Ewing, K. P., and E. E. Ivy. 1943. Some factors influencing bollworm populations and damage. J. Econ. Entomol. 36:602-605.
- Forbes, S. A., and C. A. Hart. 1900. The economic entomology of the sugar beet. Ill. Agr. Exp. Stn. Bull. 60:397-532.
- Frantz, G., and H. C. Mellinger. 1990. Flower thrips (Thysanoptera: Thripidae) collected from vegetables, ornamentals and associated weeds in south Florida. Proc. Fla. State Hort. Soc. 103:134-137.
- Frantz, G., and H. C. Mellinger. 1997. Aspects of biologically based pest management in commercial pepper production. Proc. Fla. State Hort. Soc. 110:295-297.
- Frantz, G., and H. C. Mellinger. 1998. Potential use of *Beauveria bassiana* for biological control of thrips in peppers. Proc. Fla. State Hort. Soc. 111:79-81.
- Frantz, G., H. C. Mellinger and T. Fasulo. 1998. THRIPS, a computerized knowledgebase for the identification of thrips infesting vegetables in the United States. Proc. Fla. State Hort. Soc. 110:298-299.
- Fuchs, T. W., and J. A. Harding. 1976. Seasonal abundance of arthropod predators in various habitats in the lower Rio Grande Valley of Texas. Environ. Entomol. 5:288-290.
- Garman, H., and H. H. Jewett. 1914. The life history and habits of the corn earworm. Ky. Agric. Exp. Stn. Bull. 187:511-519.
- Genung, W. G., and H. Y. Ozaki. 1992. Natural enemies of the pepper weevil, *Anthonomus eugenii*, Cano. Univ. Fla. AREC, Belle Glade, Mimeo Rpt EV-1972-2, Belle Glade. 15 pp.
- Goodarzy, K., and D. W. Davis. 1958. Natural enemies of the spotted alfalfa aphid in Utah. J. Econ. Entomol. 51:612-6.
- Guerra, S. L. 1974. Developments of populations of beneficial and harmful insects and effects of chemical control in the lagoon region. Avances de investigacion: combate integrado de plagas del algodono en la Comarca Laguera y region de Ce.
- Harrison, F. P. 1960. Corn earworm oviposition and the effect of DDT on the egg predator complex in corn silk. J. Econ. Entomol. 53:1088-94.
- Herring, J. L. 1966. The genus *Orius* of the Western Hemisphere (Hemiptera: Anthocoridae). Ann. Entomol. Soc. Am. 59:1093-109.
- Holdsworth, R. P., Jr. 1970. Aphids and aphid enemies: Effect of integrated control in an Ohio apple orchard. J. Econ. Entomol. 63:530-535.
- Holdsworth, R. P. 1972. European red mite predators and their management. Proc. Ohio State Hort. Soc. 125:86-88.

- Iglinsky, W., and C. F. Rainwater. 1950. Observations and life history notes on *Orius insidiosus* (Say), an important natural enemy of the red spider mite, *Spoganychus* spp., on cotton in Texas. *Southwestern Entomol.* 43:567-568.
- Isenhour, D. J. 1977. "Seasonal fluctuations of *Orius insidiosus* (Say) and Thysanoptera in adjacent soybeans and corn in Missouri". M.S. thesis, Univ. of Missouri, Columbia, MO. 76 pp.
- Isenhour, D. J., and K. V. Yeargan. 1981. Effect of temperature on the development of *Orius insidiosus* with notes on laboratory rearing. *Ann. Entomol. Soc. Am.* 74:114-116.
- Kawai, A. 1995. Control of *Thrips palmi* Karny (Thysanoptera: Thripidae) by *Orius* spp. (Heteroptera: Anthocoridae) on greenhouse eggplant. *Appl. Entomol. Zool.* 30:1-7.
- Knowlton, G. F., C. F. Smith, and F. C. Harmston. 1938. Pea aphid investigations. *Proc. Utah Acad. Sci.* 15:71-80.
- Kramer, P. 1961. Untersuchungen über den einfluss einiger arthropoden auf raubmilben (Acari). *Z. Angew. Zool.* 48:257-311.
- Lingren, P. D., R. L. Ridgway, and S. L. Jones. 1968. Consumption by several common arthropod predators of eggs and larvae of two *Heliothis* species that attack cotton. *Ann. Entomol. Soc. Am.* 61:613-618.
- Lopez, E. G. 1974. "Selected predators of aphids in grain sorghum and their movement to cotton". M.S. thesis, Texas A & M Univ., College Station, TX. 60 pp.
- McCaffrey, J. P., and R. J. Horsburgh. 1982. Interspecific interactions between *Orius insidiosus* and *Leptothrips mali*. *Environ. Entomol.* 11:1104-1107.
- McCaffrey, J. P., and R. L. Horsburgh. 1986. Biology of *Orius insidiosus* (Heteroptera: Anthocoridae) a predator in Virginia apple orchards. *Environ. Entomol.* 15:984-988.
- McKibben, G. H., J. W. Smith and W. L. McGovern. 1990. Design of an attract-and-kill device for the boll weevil (Coleoptera: Curculionidae). *J. Entomol. Sci.* 25:581-586.
- Naranjo, S. E. and R. L. Gibson. 1996. Phytophagy in predaceous Heteroptera: effects on life history and populations dynamics. In: O. Alomar and R. N. Wiedenmann (eds.), *Zoophytophagous Heteroptera: Implications for Life History and Integrated Pest Management*. Thomas Say Publications in Entomology. Lanham, MD. pp. 57-93.
- Orphanides, G. M., D. Gonzalez, and B. R. Bartlett. 1971. Identification and evaluation of pink bollworm predators in southern California. *Entomophaga.* 64:421-424.
- Parrella, M. P., J. P. McCaffrey, and R. L. Horsburgh. 1981. Compatibility of *Leptothrips mali* with *Stethorus punctum* and *Orius insidiosus*: predators of *Panonychus ulmi*. *Environ. Entomol.* 9:694-696.
- Pratt, F. C. 1907. Control of the pepper weevil with chemicals and predators in pepper. *USDA Bull. No.* 63:55-58.

- Riley, D. G., and D.J. Schuster. 1992. The occurrence of *Catolaccus hunterii*, a parasitoid of *Anthonomus eugenii* in insecticide treated bell pepper. *Southwestern Entomol.* 17:71-72.
- Riley, D. G., and D. J. Schuster. 1994. Pepper weevil adult response to colored sticky traps in pepper fields. *Southwestern Entomol.* 19:93-107.
- Riley, D. G., D. J. Schuster and C. S. Barfield. 1992. Sampling and dispersion of pepper weevil (Coleoptera: Curculionidae) adults. *Environ. Entomol.* 21:1013-1021.
- Riley, D. G. and E. G. King. 1994. Biology and management of the pepper weevil *Anthonomus eugenii* Cano (Coleoptera: Curculionidae): a review. *Entomol. (Trends in Agric. Sci.)* 2:109-121.
- Stern, V. M. 1963. The effects of various insecticides on *Trichogramma semifumatum* and certain predators in southern California. *J. Econ. Entomol.* 56:348-350.
- Stoltz, R. L., and V. M. Stern. 1978. The longevity and fecundity of *Orius tristicolor* when introduced to increasing numbers of the prey *Frankliniella occidentalis*. *Environ. Entomol.* 7:197-198.
- van den Bosch, R., H. T. Reynolds, and E. J. Dietrick. 1956. Toxicity of widely used insecticides to beneficial insects in California cotton and alfalfa fields. *J. Econ. Entomol.* 49:359-63.
- Veire, M. van de, and D. Degheele. 1992. Biological control of the western flower thrips, *Frankliniella occidentalis* (Perg.) (Thysanoptera: Thripidae) in glasshouse sweet peppers by *Orius* spp. *Biocontrol Sci. Tech.* 2:281-283.
- Villavaso, E. J., W. L. McGovern, and T. L. Wagner. 1987. Efficacy of bait sticks versus pheromone traps for removing boll weevils (Coleoptera: Curculionidae) from released populations. *J. Econ. Entomol.* 91:637-640.
- Wilson, R. J. 1986. "Biology of the Pepper Weevil, *Anthonomus eugenii* Cano in Florida Pepper Fields". MS Thesis, University of Florida, Gainesville, FL. 94 pp.