Interactions in Entomology: Aphids, Aphidophaga and Ants in Pecan Orchards[1]

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Abstract Three methods for conserving aphidophaga were tested in multiple factor controlled field experiments over two seasons in four pecan, (*Carya illinoensis* Wangenheim (K. Koch)) orchards. Two of the orchards were planted in the 1920's and had closed canopies; and the other two were planted in 1976 and 1985 and had open canopies. Intercrops of hairy indigo (*Indigofera hirsuta* L.) and hemp sesbania (*Sesbania exaltata* [Rafinesque-Schmaltz] Cory), sown as summer annuals in strips between tree rows, a chemical barrier sprayed on the tree trunk preventing foraging of the red imported fire ant (*Solenopsis invicta* Buren) in the tree crown, and a predator attractant were tested in these experiments. Significant interaction effects were found in blackmargined aphid (*Monellia caryella* (Fitch)), ladybeetle (Coccinellidae), and red imported fire ant abundance. On most sample dates there were no differences among treatments in abundance of pecan aphids or aphidophaga, whereas, on certain sample dates aphids were significantly reduced by the combination of enhancement techniques or one enhancement technique. Intercrop treatments did not affect red imported fire ant activity on most sampling dates. Hairy indigo intercrop was associated with season-long reductions in ant activity in the pecan tree at a young orchard in 1994 and not 1993. Seasonal changes in ant foraging were the same in the tree, the herbicided areas of the orchard and the areas with intercrops at one of the old and differed at one of the young orchards. Ladybeetle abundance was higher in the trees on certain sample dates where ants were excluded from the tree. In laboratory observations, cowpea aphid (*Aphis craccivora* Koch) was not an acceptable prey for multicolored Asian ladybeetle (*Harmonia axyridis* Pallas). Cowpea aphids were eaten by convergent ladybeetle (*Hippodamia convergens* Guerin-Mineville). Multicolored Asian ladybeetle were more effective than convergent ladybeetle in preventing aggressive red imported fire ants from forcing them off the plant.

Key Words *Carya illinoensis, Monellia caryella, Solenopsis invicta, Hippodamia convergens, Olla v-nigrum, Coccinella septempunctata, Harmonia axyridis,* intercrops, biological control.

Ants interact with other insects in agricultural systems (Way and Khoo 1992, Dutcher 1993, Perfecto and Castineiras 1998), interfering with biological control of homopterous insect pests in cherry (Gruppe 1990), cassava (Cudjoe et al. 1993), coffee (Reimer et al. 1993), cowpea (Adenuga and Adeboyeku 1983), guava (Verghese and Tandon 1987), peach (Kreiter and Iperti 1984) pecan (Tedders et al. 1990, Dutcher 1998), tuliptree (Dreistadt et al. 1986), and white fir (Tilles and Wood 1982), and preying on pest insects in cotton (Sterling 1978, Fernandez et al. 1994), pecan

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(Dutcher and Sheppard 1981), sweet potato and banana (Castineiras et al. 1991a, b), coconut (Loehr 1992), and oak (Ito and Higashi 1991). Often ants attend homopterous insects and prey on pests in the same cropping system. In these cases, aphids can enhance effectiveness of the ant as a primary predator by supplying honeydew, or the aphids can become more abundant with ant attendance and increase the incidence of aphid-borne plant disease. The bigheaded ant, *Pheidole megacephala* (F.), is conserved for control of weevils by growers of sweet potato, banana and certain vegetables (Perfecto and Castineiras 1998). The imported red fire ant, *Solenopsis invicta* Buren, attending cotton aphids killed adults and larvae of the convergent ladybeetle, *Hippodamia convergens* Guerin-Meneville (Vinson and Scarborough 1989). Ants had to be excluded from peach trees, by spraying glue on the trunk, to enable ladybeetles to prey on four aphid species in peach trees (Kreiter and Iperti 1986). Ladybeetle behavior during ant encounters may be an important factor in the success of a ladybeetle species in an ant-infested orchard system. Aside from leaving the site of an encounter by falling, flying off the plant, or walking away, the defensive behavior of ladybird beetles against ants includes thanotosis and reflex bleeding (Hodek and Honek 1996).

Blackmargined aphid, yellow pecan aphid, and black pecan aphid, [*Monellia caryella* (Fitch), *Monelliopsis pecanis* Bissell, *Melanocallis caryaefoliae* (Davis)] commonly infest pecan foliage (Edelson and Estes 1983). Aphid predators [primarily *Olla v-nigrum* (Mulsant), *Coccinella septempunctata* L., *Hippodamia convergens* Guerin-Meneville, *Cycloneda sanguinea* (L.), *Harmonia axyridis* Pallas, and *Chrysoperla rufilabris* (Burmeister), and *C. quadripunctata* (Burmeister)] play an important role in maintaining pecan aphid populations at low levels (Edelson and Estes 1987, Liao et al. 1985, Tedders 1986). Infestations of pecan aphids cause significant production losses in pecan each year (Dutcher 1985). The aphids are difficult to control with insecticides. Efficacy is not sufficient to stop aphid populations during their exponential growth phase. Most insecticides destroy populations of predators and parasites leading to a resurgence of aphids. Repeated use of carbaryl or pyrethroids results in insecticide-resistant aphid populations which are very difficult to control (Dutcher and Htay 1985). Indigenous natural enemies of the pecan aphid complex cause significant reductions in the aphid populations (Liao et al. 1985). In the absence of predators, blackmargined aphid populations are able to increase on pecan foliage at any time that the pecan is foliated (Liao et al. 1984). These predators do not regulate the aphids at a low enough abundance to prevent premature defoliation, low nut quality and reduced flower production that are often associated with poor aphid control (Dutcher 1985). Generalist predators can be cultured on alternate prey aphids in intercrops on the pecan orchard floor (Bugg and Dutcher 1989). However, red imported fire ant infestations, common to most southeastern pecan orchards, remove these predators from the intercrops (Bugg and Dutcher 1989) and trees (Tedders et al. 1990). Control of red imported fire ants can be achieved by treating the mounds directly, partitioning ant foraging with trunk sprays of chlorpyrifos or by culturing the alternate prey aphids on hemp sesbania that repels red imported fire ant (Kaakeh and Dutcher 1992). Biological control of pecan aphids might be improved by manipulating plant species in orchard ground cover to supply alternate prey for ladybeetles and lacewings (Tedders 1983, Bugg and Dutcher 1989, Bugg et al. 1991).

Hemp sesbania, *Sesbania exaltata* [Rafinesque-Schmaltz] Cory, and hairy indigo, *Indigofera hirsuta* L., are summer cover crops developed for pecan orchards to improve soil nitrogen, promote soil structure, suppress harmful weeds, and provide refuge for natural enemies of pecan aphids (Bugg and Dutcher 1989, 1993). Both crops sustain a high population density of cowpea aphid, *Aphis craccivora* Koch, and other alternate prey for generalist predators of the pecan aphid complex. Alternate prey developing on intercrops for the entire summer will often maintain certain aphidophagous insects at high numbers (Bugg and Dutcher 1989).

Red imported fire ant workers feed on honeydew produced by aphids, but attack and kill many aphidophagous species (Morrill 1977). Mowing of orchard ground cover causes a change in the ratio of red imported fire ant on the ground to that in pecan trees (Tedders et al. 1990). While red imported fire ants forage freely on hairy indigo, hemp sesbania plants showed 100% repellency to ants for 8 d in the greenhouse, whether these plants were infested or kept free of cowpea aphids. Also, hemp sesbania extract showed repellency and caused mortality of red imported fire ants (Kaakeh and Dutcher 1992). The purpose of the following study was to measure the effects of three ladybeetle conservation techniques on the seasonal abundance of blackmargined aphid, coccinellids and red imported fire ant in the pecan trees and to observe the behavioral interactions of ladybeetles, cowpea aphid and red imported fire ants in the laboratory.

Methods and Materials

Orchards. The studies were conducted in research orchards in Sumter, Burke and Tift counties in Georgia and Baldwin Co. in Alabama during 1993 and 1994. Each site had drip irrigation installed in weed-free (herbicided) tree rows and mowed sod between the tree rows (alleys). The 15-ha Sumter site was planted to the cultivars 'Stuart' and 'Schley' in 1924, and was subdivided into large 12 to 25 tree plots for experimentation. The trees were 20 m high, planted 26 trees/ha and the tree canopy was closed. The Burke site was planted to the cultivar 'Stuart' in the 1920's, and the density during the experiment was 22 trees/ha with a closed canopy. The Tift site with 23 ha, planted to the cultivar 'Desirable' in 1985, was bearing fruit and the trees were 7 m high planted at a density of 52 trees/ha and an open tree canopy. The Baldwin site was on the Gulf Coast Experiment Station of Auburn University. This 2.7-ha orchard was planted to the cultivar 'Cheyenne' in 1976 at a density of 45 trees/ha. The canopy was open. All locations were managed according to the recommendations of the Cooperative Extension Services in each state.

Treatments. At Sumter and Burke, the mixture of hairy indigo and sesbania (+ic) was compared to a control of mowed sod (–ic). At both orchards, within each treatment plot there were two subplot treatments for red imported fire ants: (1) exclusion of ants from the tree crown (+a); (2) no exclusion (–a). Ants were excluded by applying a trunk spray of chlorpyrifos at an application rate of about 1.0 kg actual insecticide per ha in mid-June of 1993 and again at budbreak (mid-April) of 1994. About 1 liter of final spray (0.08 liter Lorsban 4E (Dow Chemical Co.) per liter water) was applied as a band about 1 m wide completely around the trunk using 25 liter per ha. This treatment excluded ants in most trees for the entire season. Whenever ants were detected in the treated trees, the tree trunks of those trees were resprayed. At Tift and Baldwin, four warm-season cover crop treatments (hemp sesbania only, hairy indigo only, hemp sesbania and indigo mixture, and mowed sod of bermuda and bahia grasses) were randomly assigned to plots. The warm season cover crop treatments were the variable part of a standard relay cropping system of crimson clover (*Trifolium incarnatum* L.) to hairy vetch (*Vicia villosa* Roth) plus cereal rye (*Secale*

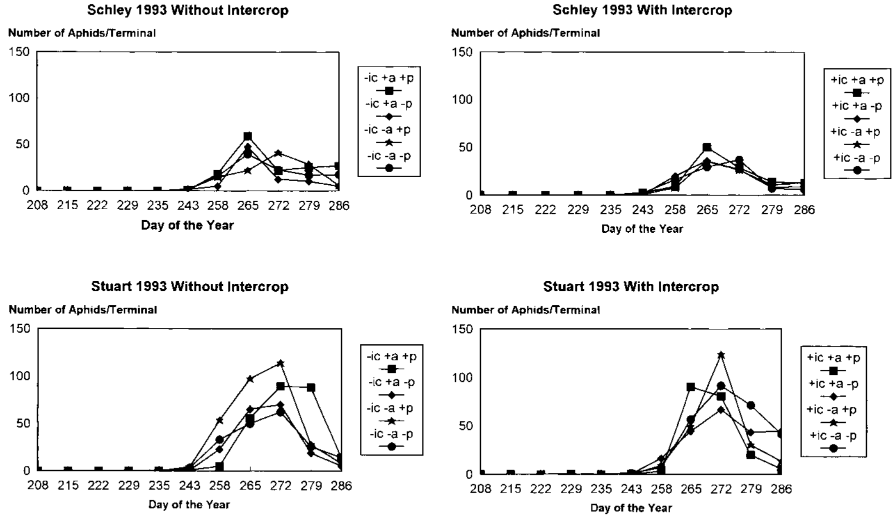

Fig. 1. Blackmargined aphid abundance in the Stuart than in the Schley cultivar trees at the Sumter orchard during 1993. Treatment designations are +ic/–ic = with/without summer intercrop; +a/–a = with/without chemical ant barrier; and +p/–p = with/without predator attractant spray.

cereale L.) to warm-season crop treatment to buckwheat (*Fagopyrum esculentum* Moench) and back to crimson clover. The main crops (crimson clover and the warm season crop) were planted in a strip down the middle of each alley. Relay crops (hairy vetch, cereal rye, and buckwheat) were planted in strips adjacent to the main crop. Approximate planting dates were: crimson clover in mid-December; hairy vetch and cereal rye in early-March; warm season crop treatments in mid-May; buckwheat in late-August. Sprays of fermented molasses as a predator attractant were applied (2% v/v aqueous solution of fermented molasses) to the tree crown (two trees with molasses (+p) and two trees without molasses (–p)). The attractant was applied in early August when ladybeetles begin to reproduce in the sesbania-indigo plots. Some extreme weather was encountered requiring some alteration in the research plan. During the summer of 1993 droughty conditions required direct watering of the intercrop plots. During the summer of 1994 excessive rainfall and flood conditions called for additional fungicide applications and a complete loss of one summer crop at Sumter. At Burke in 1994, excess rainfall and low sunlight over the season reduced intercrop growth. At Baldwin during 1994, excess rainfall inactivated the ant barriers and ruined the intercrops. The crops were replanted but were washed out by additional rain. Limited access to the orchard on public roads reduced sampling frequency during June, July and August of 1994 at Sumter with three missing sample dates. Summer intercrop plots at Tift were seeded in mid-May and harvested in October.

Experimental design and analysis.- A 2.5-m wide strip in the mowed sod strip between the tree rows was seeded by a no-till planter (Type Pasture Pleaser, Tye Farm Equip. Co.) with the appropriate intercrop on both sides of all trees in each plot. All crops were planted at a seeding rate of 12 kg/ha with the hairy indigo and sesbania

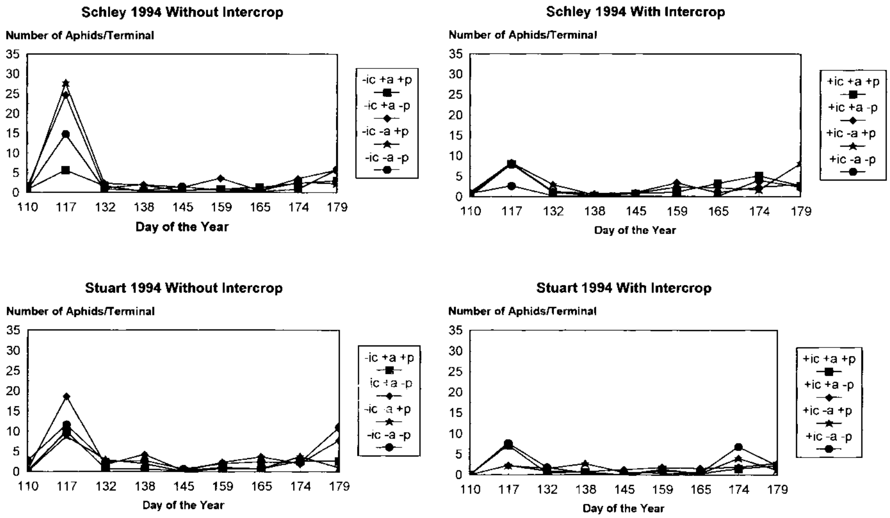

Fig. 2. Blackmargined aphid abundance in the Sumter orchard during 1994 until the orchard flooded on day 181. Treatment designations are +ic/−ic = with/without summer intercrop; +a/−a = with/without chemical ant barrier; and +p/−p = with/without predator attractant spray.

seeded at 6 kg/ha each in the combination treatment plots of hairy indigo + sesbania. At Sumter and Burke, the mixture of hairy indigo and sesbania was compared to a mowed sod, in four 20-tree (4 × 5 trees) plots per treatment. The two subplot treatments compared ant exclusion to no ant exclusion (eight trees with ant exclusion and eight trees without ant exclusion and four border trees). There were two subsubplot treatments with predator attractant and without predator attractant. Cowpea aphids naturally infested the intercrops in both seasons.

At Tift and Baldwin, a randomized complete block design was employed with four blocks or replicates, each with 30 trees (6 × 5 trees). The block was divided into four plots with six trees per plot with a row of untreated trees between adjacent plots. Three trees in each plot were treated with chlorpyrifos trunk spray to exclude red imported fire ants from the tree canopy. At Tift, when alternate prey populations were established and were increasing in mid-July, convergent ladybeetle adults were released in the intercrop. The convergent ladybeetles were purchased from an insectory (Rincon-Vitova Insectaries Inc., Oak View, CA) and were originally collected from hibernating sites in California. Each intercrop or mowed sod plot was innoculated with 250 adult convergent ladybeetles.

All trees at all orchards were sampled to determine the relative abundance of aphids and their associated beneficial insects and red imported fire ants on a weekly basis, unless environmental conditions prevented sampling. The foliage on the current year's shoot growth of one terminal was the sample unit to determine the number of pecan aphids and associated active stages of aphid predators. Samples were cut from the tree with a 6-m pruning pole. Five sample units were be collected from each tree on each date at all orchards. Beneficial insects are also counted on the five

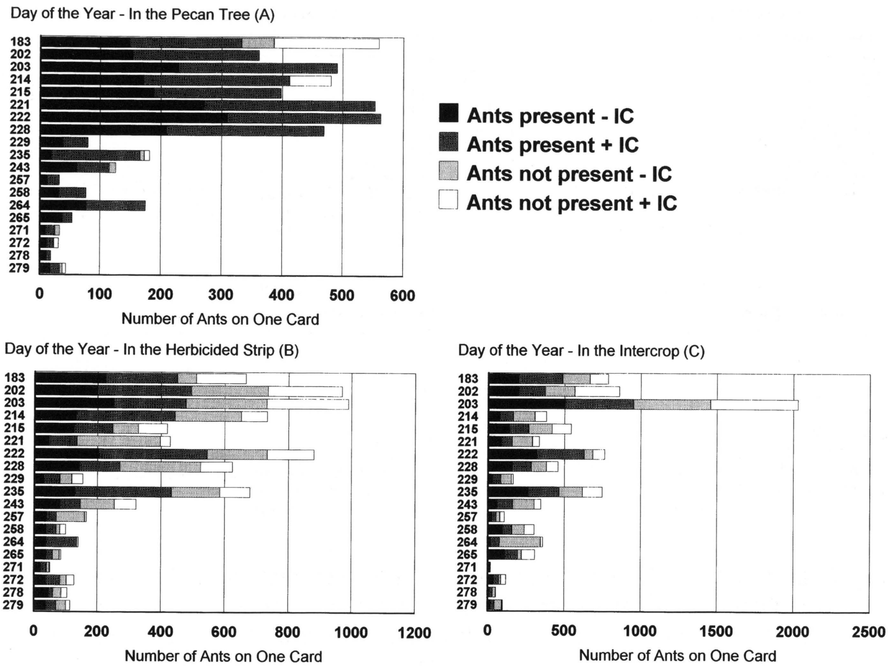

Fig. 3. Red imported fire ant activity as measured by oil soaked index cards in the Sumter orchard during the 1993 season. Cards were placed in the tree (A), in the intercrop (B), and in the herbicided strip (C) on each of the indicated days of the year. The results are presented as stacked bars for each date. The number of ants per card is represented by the length of the bar. The origin of the first bar is zero, and the origin of the next bar is the top of the first bar, and so on for the third and four bars. For example, the ants counts on day 183 in the pecan trees by treatment: ants present –ic = 147 ants; ants present +ic = 185 ants; ants not present –ic = 53; ants not present +ic = 173.

terminals. Counts of all life stages and species of ladybeetles were pooled before the data were graphed and analyzed. Red imported fire ants are sampled at all orchards by placing peanut oil soaked 7.5 × 12.5 cm paper cards on the tree trunk (above the treated area on sprayed trees) and on the soil near the tree trunk and counting ants on the cards 2 h after setting the cards out. Climatic conditions at all sites were monitored by an electronic weather stations that measured hourly temperature and rainfall at each site. Sampling data from Sumter and Tift orchards were analyzed by analysis of variance (Snedecor and Cochran 1967) for three factors (intercrop, ant spray and molasses spray) to determine differences in main plot, subplot, and sub-subplot differences on each sample date. At Baldwin, the average and standard error within each main plot (intercrop) and subplot (ant barrier) treatment were calculated for counts of aphids, ladybeetles and ants over the entire season for each season. Ant activity on the peanut cards was rated from 0 (no ants) to 5 (many ants/card) at Baldwin.

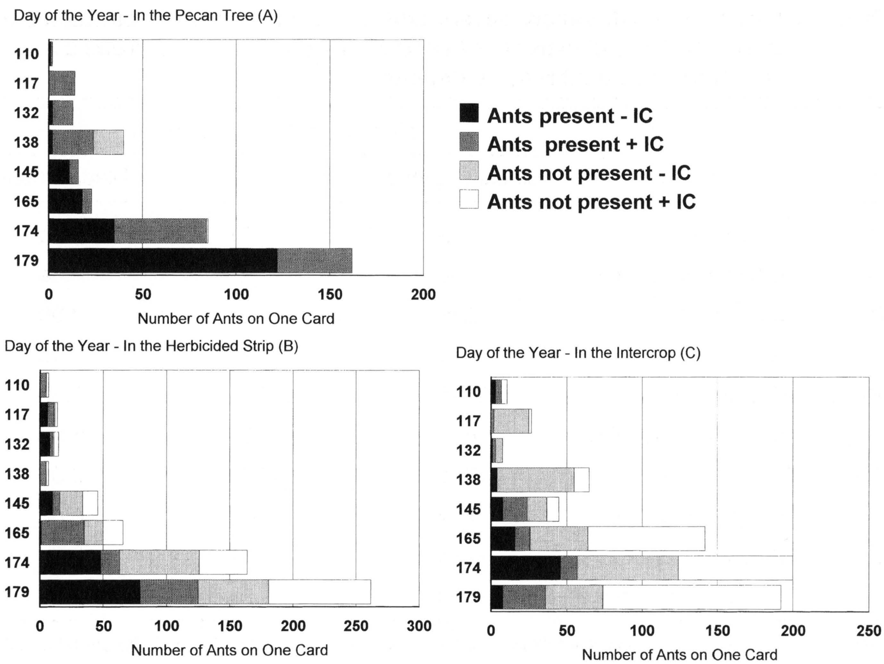

Fig. 4. Red imported fire ant activity as measured by oil soaked index cards in the Sumter orchard during the 1994 season. Cards were placed in the tree (A), in the intercrop (B), and in the herbicided strip (C) on each of the indicated days of the year. The results are presented as stacked bars for each date. The number of ants per card is represented by the length of the bar.

Observations of insect interactions. Convergent ladybeetle and multicolored Asian ladybeetles were observed in a series of experiments on a laboratory bench to compare the responses of the ladybeetles to cowpea aphid and red imported fire ant. Five red imported fire ant colonies were collected with a shovel from a pasture in Tift Co. and maintained in a 20-liter plastic bucket with a slippery coating (Fluon AD1. Northern Products, Inc., Woonsocket, RI) on the upper rim to prevent ants from escaping. Ants were fed live insects, 10% honey in distilled water and distilled water, without honey, and were placed on a laboratory bench and held at room temperature (80 to 85 F) for about 2 wks before the start of the experiment. Five arenas for observing aphids, ladybeetles and ants on the cowpea plants were set up around the ant colonies. Four cowpea plants were sown in each of 30 clay pots and grown in a greenhouse. After full size leaves formed, plants were infested with cowpea aphids. When large colonies of aphids were present, two pots of plants were placed on a glass plate, on top of a masonry block, set in a large bucket of water to prevent ants from leaving the arena. A wooden walkway connected the center of the ant colony to the center of the glass plate. Ants would walk out to the plants, attend the aphids and plant nectaries, forage in the soil around the plants and walk back to the colony. They could not escape from the arena. Ladybeetle adults were collected from pecan or-

Table 1. Blackmargined, yellow pecan, and black pecan aphid abundance at Burke Co. in 1993 in trees with and without summer intercrops over all subplot and subsubplot treatments

		Number of aphids/terminal*		
Day	Intercrop	Blackmargined	Yellow Pecan	Black Pecan
186	Mowed Sod	5a	0a	0.0b
	Indigo + Sesbania	3a	0a	3.8a
193	Mowed Sod	24a	2a	0.0b
	Indigo + Sesbania	13a	0a	2.9a
200	Mowed Sod	302a	13a	2.8b
	Indigo + Sesbania	87b	4a	5.8a
207	Mowed Sod	182a	122a	6.8a
	Indigo + Sesbania	77b	78b	6.9a
214	Mowed Sod	123a	78a	0.0b
	Indigo + Sesbania	55b	72a	7.8a

* Means in the same column and day followed by the same letter are not significantly different ($P < 0.05$, ANOVA).

chards and held in 40-liter glass arenas and fed aphids, insect eggs, and fresh beef liver and a daily aerosol spray of distilled water on the glass surface. Adult ladybeetles were placed on the cowpea plants in the arena with one beetle placed on each aphid infested-ant attended plant. The behavior of 100 beetles of each species was observed. Behavior was recorded for 15 min or until the beetle left the plant.

Results and Discussion

Weather measurements indicated that the 1993 season was extremely hot and dry; whereas, the 1994 season was cool and wet at all the research sites compared to average seasonal temperatures and rainfall for these areas. Therefore, the experiments test the treatment effects in two extremely different seasons. Lack of rainfall in 1993 reduced growth of the intercrops, necessitating plots to be irrigated each week. High ambient temperatures probably reduced pecan aphid densities below normal expected densities during June, July, and early August. Excess rainfall and flooding during 1994 caused some destruction of the intercrop strips in mid-July and again in mid-September. Due to destruction of treatments by the weather at Burke and Baldwin in 1994, we are only reporting the 1993 data in this paper.

Intercrops of the hairy indigo and hemp sesbania, grown as summer annuals in strips between the tree rows in the two pecan orchards, provided alternate prey for general predators that feed on pecan aphids. The chemical barrier sprayed on the trunk prevented foraging of the red imported fire ant in the tree crown. There was no indication that the predator attractant influenced the abundance of ladybeetles in the tree. Though some ants were occasionally found in trees with ant barriers, these trees

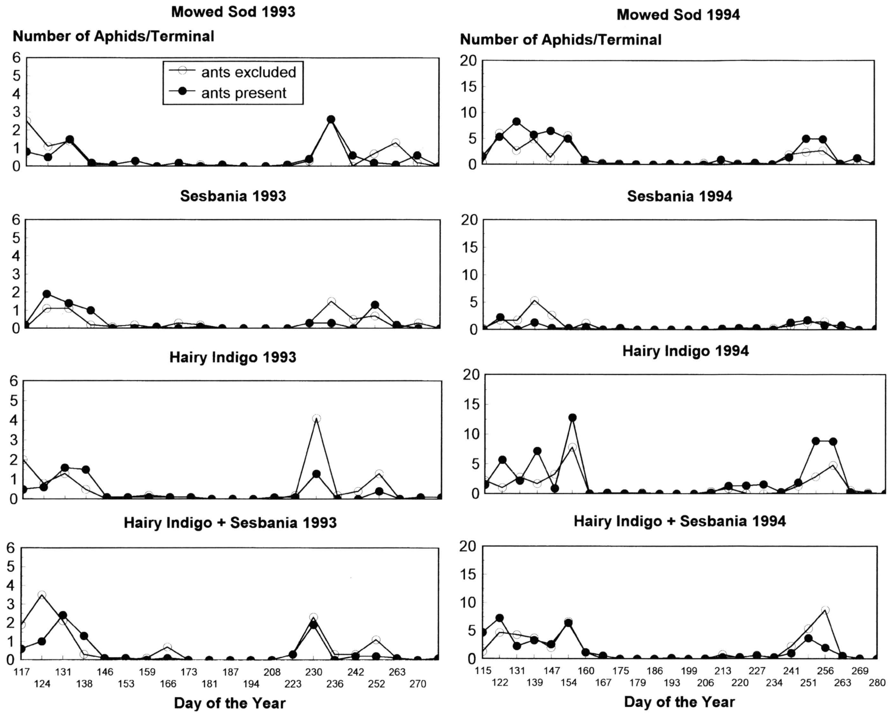

Fig. 5. Blackmargined aphid abundance in the pecan trees at the Tift orchard during the 1993 and 1994 seasons. The intercrop treatment and the year are listed above each graph and the day of the year of the bottom graph indicates values for days for all graphs above the axis.

were retreated after the ants were detected above the insecticide barrier. In 1993, there were few alternate prey aphids on the cover crops, probably resulting from high ambient temperatures, until the first week in October. At this time ambient temperatures were cooler and aphid densities increased in the cover crops and in the pecan trees. Pecan aphid densities peaked and declined before the first week in November and were not related to the intercrop and fire ant exclusion treatments. During the early fall 1993 at Tift and Sumter, hairy indigo and hemp sesbania sustained populations of the greenhouse whitefly which were associated with convergent ladybeetles. Significant populations of sevenspotted ladybeetle, *O. v-nigrum,* or *H. axyridis* were not found in the trees or intercrops.

Pecan aphid abundance, however, was influenced by the treatments on certain sampling dates over the two seasons of the experiment. At Sumter, blackmargined aphid abundance was significantly ($P < 0.05$, ANOVA) lower on days 265 and 272 in the Schley than in Stuart tree during 1993 (Fig. 1.), but intercrop differences were not significant ($P < 0.05$, ANOVA). Trees with the intercrop, ant barrier, and predator attractant had significantly fewer ($P < 0.05$, ANOVA) blackmargined aphids during the spring peak on day 117 of 1994 (Fig. 2). Trees with significantly higher ($P < 0.05$,

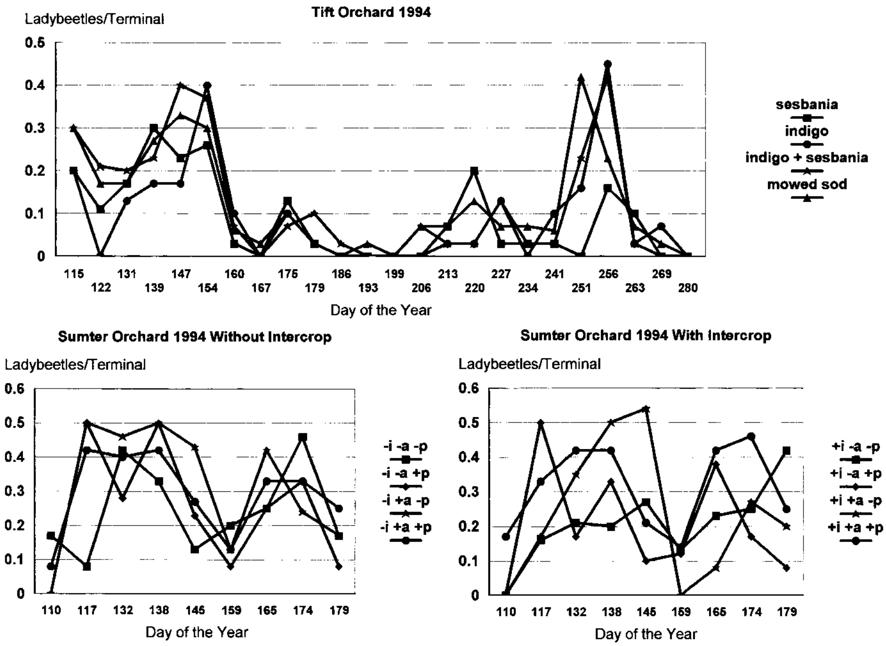

Fig. 6. Abundance of ladybeetles of all species in the pecan trees at Tift and Sumter in 1994 indicated the week to week fluctuation in populations and no significant differences between treatments. Treatment designations are: +ic/–ic = with/without summer intercrop; +a/–a = with/without chemical ant barrier; and +p/–p = with/without predator attractant spray.

ANOVA) blackmargined aphid counts were lacking one of the conservation methods. The one exception was the Stuart trees with a full compliment of conservation techniques which had significantly higher blackmargined aphid populations than all other Stuart trees with intercrops on day 265 of 1993. Aphids declined in these trees on day 272. Ant foraging activity at Sumter (Fig. 3) was highest during the first half of the summer in the trees, herbicided strips and the intercrops. A few ants foraged through the chemical barrier in the tree, and most barriers kept ants out of the tree for the entire season. The intercrop did not cause any significant ($P < 0.05$, ANOVA) differences between abundance of ants in the pecan trees without chemical barriers during 1993. In 1994, ant foraging (Fig. 4) was significantly higher ($P < 0.05$, ANOVA) in trees without ant barriers and without intercrops on days 145, 165 and 179 ($P < 0.05$, ANOVA) than in trees with all other combinations ant barriers and intercrops. Ant counts were significantly higher ($P < 0.05$, ANOVA) in the herbicided strip near trees without ant barriers (ants present) than in trees with ant barriers (ants not present) on days 222 and 235 of 1994. Ant foraging in the intercrop area between the trees at Sumter had the greatest range of counts among the three sampling areas. There were no significant differences in ant counts between the plots with and without intercrops in 1993 (Fig. 4). In 1994, the trees with ant barriers had significantly higher

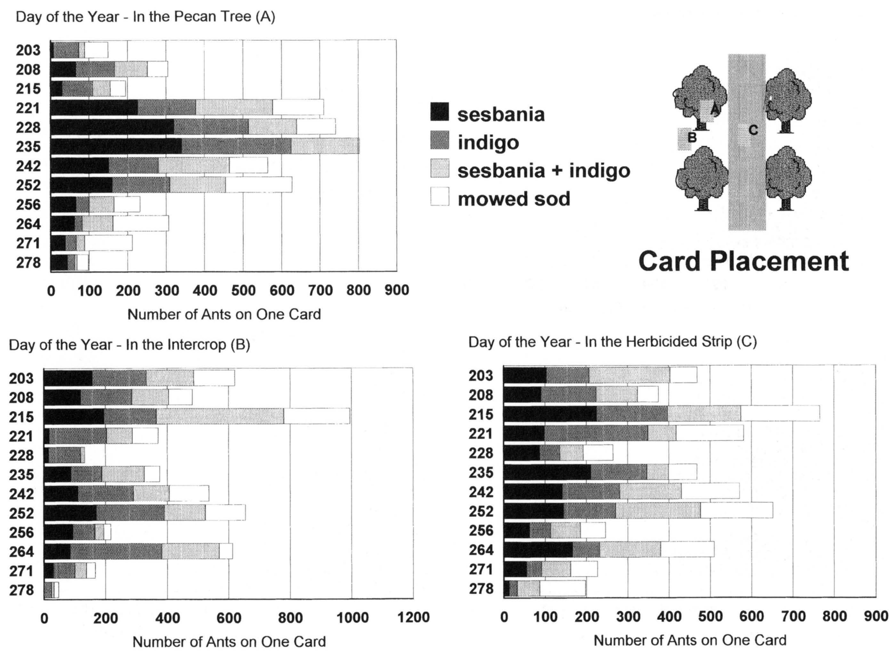

Fig. 7. Red imported fire ant activity as measured by oil soaked index cards in the Tift orchard during the 1993 season. Cards were placed in the tree (A) (activity in the graph is in the trees without ant barriers), in the intercrop (B), and in the herbicided strip (C) on each of the indicated days of the year.

($P < 0.05$, ANOVA) ant foraging in the intercrop area than in trees without the ant barrier.

At Burke in 1993, blackmargined aphids were up to 3 times more abundant in trees without the intercrop than in trees with the intercrop (Table 1). Yellow pecan aphids were significantly ($P < 0.05$, ANOVA) higher in the trees without intercrops on sample dates 207. Black pecan aphids were significantly higher in the trees with intercrops than in trees without intercrops on days 186, 193, 200 and 214. Black pecan aphid density was similar in trees with and without intercrops on day 207. Pecan leaf scorch mites were a significant problem at Burke in 1993, and intercrops did not appear to affect the incidence of damage. Ant barriers and predator attractants did not have any significant effect on the parameters measured at Burke in 1993.

At Tift, blackmargined aphid abundance was lower than typical aphid densities in young Georgia pecan orchards (Fig. 5). During 1993, this was probably due to higher than normal ambient temperatures for most of the year. During 1994, generally high ladybeetle populations (often exceeding 0.4 beetles/terminal) over the entire orchard may have contributed to lower aphid densities (Fig. 6). Blackmargined aphids were generally lower where sesbania was the intercrop and generally higher where hairy indigo was the entire or part of the intercrop. Ant exclusion also affected blackmargined aphid abundance. Specific differences during peaks of aphid activity occurred

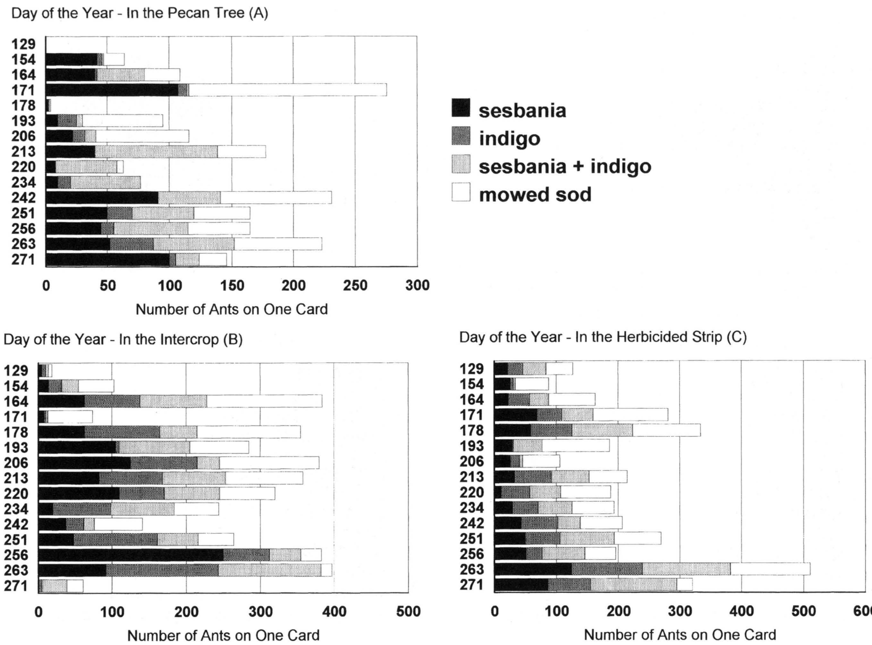

Fig. 8. Red imported fire ant activity as measured by oil soaked index cards in the Tift orchard during the 1994 season. Cards were placed in the tree (A) (activity in the graph is in the trees without ant barriers), in the intercrop (B), and in the herbicided strip (C) on each of the indicated days of the year.

between treatments on day 230 of 1993 and 139, 154, 251 and 256 of 1994. In 1993, on day 230, within the hairy indigo treated trees the aphids were significantly higher ($P < 0.05$, ANOVA) in trees without ant barrier than in trees with ant barriers. All other aphid counts in the pecan trees during 1993 were the same ($P < 0.05$, ANOVA). In 1994 on day 139 within the sesbania treatment, blackmargined aphid abundance was higher ($P < 0.05$, ANOVA) where ants were excluded than where ants were present. On day 154 and 251, within the hairy indigo treatment blackmargined aphid abundance was higher ($P < 0.05$, ANOVA) where ants were present than where ants were excluded. On day 256 within the hairy indigo + sesbania treatment, blackmargined aphid abundance was higher ($P < 0.05$, ANOVA) where ants were excluded than where ants were present. On day 251, blackmargined aphid abundance was lower ($P < 0.05$, ANOVA) in the sesbania treatment than all other intercrop treatments. Ant foraging treatments did not cause any further reduction in blackmargined aphids. Monitoring of ant foraging activity at Tift in 1993, found ants in all areas of the orchard with no consistent effect by intercrop treatment. During 1993 (Fig. 7), ant activity was highest in the trees during the mid summer; whereas activity in the intercrop and in the herbicided strip declined in the fall. During 1994 (Fig. 8), the ant activity was lower relative to 1993 and ant foraging in the trees with an hairy indigo intercrop were consistently and significantly lower ($P < 0.05$, ANOVA) than in trees with other inter-

Table 2. Mean (± SEM) number of insects over all sample dates at the Baldwin site during 1993. Intercrop treatments were mowed sod, hemp sesbania, hairy indigo, hairy indigo + hemp sesbania. Ant treatments were without (No) and with (Yes) an ant barrier on the trunk. Mean (± SEM) number of: blackmargined aphids per compound leaf (BMA/CL), black pecan aphids per compound leaf (BPA/CL); ladybeetles per terminal (LB/T); and, ant rating on a scale of 0 (no ants) to 5 (many ants)

Intercrop	Ant	BMA/CL	BPA/CL	LB/T	Ant Rating
mowed sod	No	17.22 ± 4.49	0.7 ± 0.7	1.44 ± 0.56	3.6 ± 0.8
	Yes	21.11 ± 4.07	4.0 ± 1.0	0.96 ± 0.19	0.7 ± 0.3
sesbania	No	24.10 ± 5.04	0.7 ± 0.5	0.44 ± 0.16	2.9 ± 0.8
	Yes	16.74 ± 4.25	1.3 ± 0.4	0.68 ± 0.17	0.5 ± 0.3
indigo	No	22.48 ± 5.17	0.7 ± 0.7	0.62 ± 0.19	2.1 ± 0.6
	Yes	17.12 ± 4.17	0.7 ± 0.5	0.86 ± 0.26	1.6 ± 0.6
indigo +	No	12.21 ± 3.24	1.2 ± 0.7	1.47 ± 0.31	4.3 ± 0.8
sesbania	Yes	13.94 ± 3.52	0.7 ± 0.7	0.62 ± 0.19	0.5 ± 0.3

crops over the entire season. Cowpea aphid-infested hairy indigo plants were highly attractive to red imported fire ant. Higher rainfall in 1994 in comparison to 1993 resulted in more vigorous growth of the intercrop plants and may explain the differences in results between years.

At Baldwin in 1993 (Table 2), among trees without ant barriers, overall blackmargined aphid abundance tended to be lower in trees with an intercrop of indigo + sesbania than in trees with either sesbania or indigo alone. However, all intercrop treatments without ant barriers in the tree had blackmargined aphid densities similar to the mowed sod treatment. Among trees with ant barriers, blackmargined aphid populations were similar. Ladybeetles were higher in the trees with mowed sod and without ant barriers or indigo + sesbania and with ant barriers than in all other treatments. Black pecan aphids were also higher in trees in the mowed sod and with ant barriers than in all other treatments.

Only an occasional ladybeetle was found on the pecan foliage during the 1993 season at all orchards, and the main aphidophagous insect artifacts found in the pecan terminal samples were the eggs of lacewings. These lacewings eggs were generally distributed over all the samples with 0 to 7 (usually 1 to 3 eggs) eggs on each terminal. No significant differences ($P < 0.05$, ANOVA) in beneficial insects in the trees could be ascribed to any of the treatments during 1993. No single species of ladybeetle was predominantly abundant in the trees during the 1994 season. Convergent ladybeetle, multicolored Asian ladybeetle and sevenspotted ladybeetle were the more common species and occasionally *O. v-nigrum* and *C. sanguinea* were found. Ladybeetle abundance was higher in 1994 (Fig. 6) than in 1993 at both orchards. At Sumter, in trees with intercrops, ladybeetle abundance was lower ($P <$ 0.05, ANOVA) in trees without ant barrier than in trees with ant barriers on day 132. On day 138 among trees without predator attractants ladybeetles were still lower (*P*

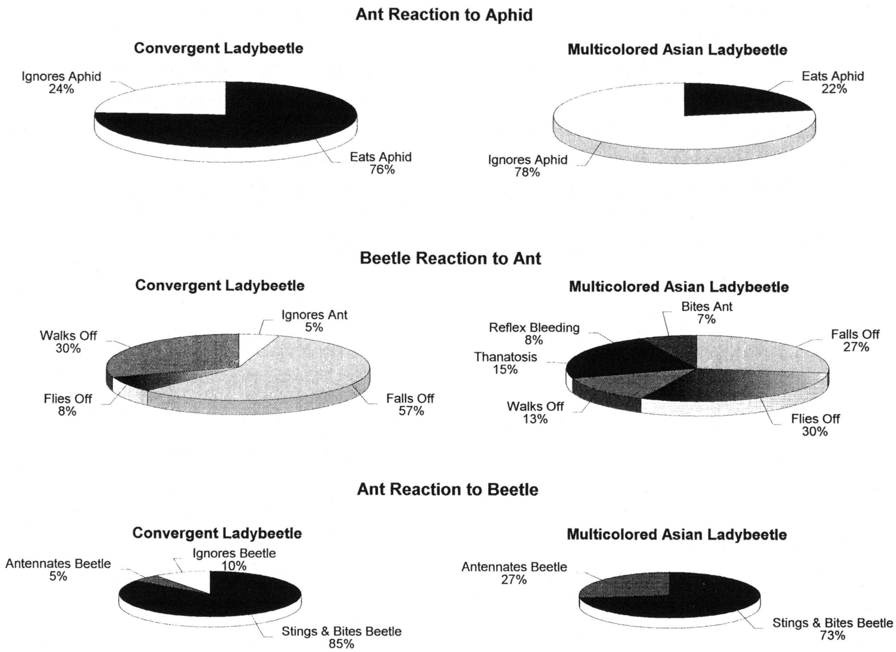

Fig. 9. Observations of ladybeetle and ant behavior on aphid infested cowpea plants.

< 0.05, ANOVA) in trees without ant barrier than in trees with ant barriers. On day 145, the highest ($P < 0.05$, ANOVA) ladybeetle abundance was in trees with ant barriers and without predator attractant. During 1994 at Sumter, multicolored Asian ladybeetle adults migrated into the pecan orchard in late August and began laying eggs with larva and pupae developing during September. On 28 September, multicolored Asian ladybeetle abundance was the same in trees with ant barriers (2 egg masses, 4 larvae and 43 pupae on 200 terminals) and trees without ant barriers (1 egg mass, 16 larvae and 45 pupae).

The behavioral interactions between ladybeetles - red imported fire ant, ladybeetles - cowpea aphids and red imported fire ant - cowpea aphid in the laboratory arenas indicated that there is a great difference between the two ladybeetles in their defense against aggressive ants and feeding on cowpea aphid (Fig. 9). Convergent ladybeetles were more likely than multicolored Asian ladybeetle to eat cowpea aphid when the beetles encountered aphids on the plants. A high percentage of convergent ladybeetles (95%) and multicolored Asian ladybeetles (70%) left the plant by flying, walking or falling off after an encounter with a red imported fire ant. A significant portion (30%) of the multicolored Asian ladybeetles, in contrast to convergent ladybeetles, displayed additional defensive behaviors of thanatosis, reflex bleeding and biting the ants. Ants were equally likely to bite and sting the two ladybeetle species. Ants did not ignore any of the multicolored Asian ladybeetles; whereas, some (10%) of the convergent ladybeetles were ignored (not encountered) by the ants during the entire 15-min observation time.

These results indicate that intercrops in combination with the ant barriers and predator attractants may take two or more seasons to cause reduction in pecan aphids. Interactions between the aphids, aphidophaga and ants were found that may influence the choice of conservation techniques for pecan management. Among the three conservation techniques, intercrops and ant barriers are more effective than predator attractants. Different interactions were significant on certain sample dates and locations indicating that the combination of enhancement techniques may be needed to conserve aphidophaga and reduce pecan aphid densities. Hairy indigo as a summer intercrop may be attracting beneficial insects and red imported fire ants out of the pecan tree. Ladybeetles attracted to hairy indigo may be killed by red imported fire ants attending the alternate prey aphids. Sesbania alone appears to be causing reductions in pecan aphids and has the added advantage of repelling red imported fire ants allowing ladybeetles to feed freely on alternate prey aphids. Hairy indigo + sesbania was associated with a significant reduction in blackmargined and yellow pecan aphids and a significant increase in black pecan aphid at Burke. Black pecan aphids were not a significantly abundant at Sumter or Tift. These conservation techniques are also less expensive than chemical controls and do not have the added problems of secondary pest resurgence and insecticide resistance development that are associated with the chemical controls (Dutcher and Htay 1985). Year-round management techniques to enhance aphidophaga in pecan (Bugg et al. 1990) did not consider the addition of multicolored Asian ladybeetle to the system. Multicolored Asian ladybeetle was an effective predator of pecan aphids and had effective defensive behavior against red imported fire ant. However, the alternate prey aphids in the herbaceous intercrops are not preferred by this ladybeetle and cowpea aphid is toxic to this species. Conservation of multicolored Asian ladybeetle may be possible with additional intercrops of perennial plants infested with preferred alternate prey items.

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