ENCOURAGING NATURAL DEFENSES IN PECAN ORCHARDS

by

JOEY ROBERT WILLIAMSON

(Under the Direction of James D. Dutcher)

ABSTRACT

The pecan aphids- yellow pecan aphid (*Monelliopsis pecanis* Bissell), blackmargined aphid (*Monellia caryella* (Fitch)), and black pecan aphid (*Melanocallis caryaefoliae* (Davis))- are major pests in improved pecan (*Carya illinoinensis* (Wangenheim) K. Koch) orchards. It is believed that understory plants can enhance biological control of pecan aphids and other insect pests, as well as enhance soils. Previous studies confirm increased insect diversity in the understory and soil enhancement. However, evidence of aphidophaga migrating into trees to control pecan aphids is lacking. Since these studies were conducted, the multicolored Asian lady beetle (*Harmonia axyridis* Pallas) established in pecan and is credited with greatly increasing biological control. Our study looks further into soil enhancement and insect dynamics with understory plants in pecan since this introduction. First, we conducted a feeding preference bioassay with multicolored Asian lady beetle larvae, the three pecan aphids, and two aphid species common in understory plantings- crape myrtle aphid (*Sarucallis kahawaluokalani* (Kirkaldy)) and cowpea aphid (*Aphis craccivora* (Koch))- to determine if the beetles may be drawn out of pecan trees. Each beetle instar was offered one of three combinations of aphids in an arena: all of the same aphid species, the three pecan aphids, and all five aphid species together. Ladybeetle larvae showed several significant differences and a slight trend in feeding rates for the three pecan aphids and against cowpea aphid, when offered each species alone, but no significant differences with the three pecan aphids or all five aphid species together. With no observed preferences for understory aphids, we conducted our field study with eight different combinations of the following understory plants- mowed sod, crimson clover/hairy vetch, sesbania/hairy indigo, buckwheat, and crape myrtle- and observed pecan leaf nitrogen, soil organic matter, soil compaction, and population dynamics with the pecan aphids, coccinellid beetles, and parasitized pecan aphids. Results were highly variable, mostly insignificant, and inconclusive for all understory treatments in this two year study, for insect dynamics and soils. This study took place during the transitional stage of understory plantings in pecan orchards. We believe better results would occur beyond this transition stage.

INDEX WORDS: pecan, legume groundcovers, habitat manipulation, bioassay, *Harmonia axyridis*, biological control, pecan aphids

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CHAPTER 1

CONSERVATION BIOLOGICAL CONTROL IN PECAN ORCHARDS[1]

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ABSTRACT: Pecan (*Carya illinoinensis* (Wangenheim) K. Koch) orchards present unique challenges over annual row crops. Pests build up for many years on long-lived pecan cultivars. Broad-spectrum insecticide sprays limit biological control, as does the monoculture design. However, monoculture effects in orchards may be mitigated with diverse plantings in the understory. Cool-season legumes have been shown to provide soil enhancement qualities (higher nitrogen and organic matter levels, reduced compaction, and reduced mowing) in pecan orchards and some potential for biological control, especially of pecan pest aphids. Increased biological control has also been shown with select warm-season groundcovers and crape myrtle shrubs. The plants provide alternate prey and nectar sources for natural enemies between peaks of pecan insect pests. Growers have been hesitant to use the groundcovers due to limited experience and confidence with biological control and the long-term experience utilizing low-cost conventional fertilizers and pesticides. However, growers are increasingly interested due to rapidly-increasing prices on fertilizers, pesticides, and fuel. Biological control in pecan orchards has become more effective in general due to the establishment of an aggressive aphid predator, *Harmonia axyridis* Pallas. Novel narrow-spectrum controls can replace conventional insecticide sprays for lepidopteran pests, and predatory mites can minimize the need for pest mite sprays. Routine broad-spectrum sprays are still required for pecan aphids in the mid-season, and aphids plus pecan weevil in the late season (for orchards that have pecan weevil). Greater biological control of pecan aphids will further reduce dependence on broad-spectrum insecticides, and possibly eliminate routine sprays in orchards *sans* pecan weevil. The article reviews the literature on conservation biological control in pecan and discusses the possibilities of new techniques in pecan orchards.

Key words: pecan, agroecosystems, groundcovers, natural defenses, habitat manipulation, integrated pest management, integrated production

INTRODUCTION

Pecan (*Carya illinoinensis* (Wangenheim) K. Koch) is an economically important food crop originating from North America (Flack 1970, Wood et al. 1990). Its native range is an extensive area along the river bottoms of the Mississippi River system and the rivers of central and eastern Texas and northern Mexico (Sparks 2005a). Pecan still exists in its native habitat. This allows the rare opportunity to observe pecan in its natural and domesticated habitat, both native trees and the most modern cultivars that science can produce (Harris 1983). Pecan is now harvested commercially in its native area as well as many parts of the southeastern and southwestern United States and northern Mexico, where it is now an important horticultural enterprise (Diver and Ames 2000). According to 1997 Agricultural Census information, pecan production in the United States takes place on 199,168 ha (492,137 acres), dispersed among 19,900 farm operations in 24 states, with about 158,757 t (350,000,000 lbs) of in-shell nuts produced annually. Mexico produces about 54,000 t (120,000,000 lbs) of in-shell nuts annually on about 61,107 ha (150,998 acres) (Wood 2003).

Pecan presents unique challenges relative to annual row crops, especially in regards to pest management. The extraordinary lifespan of pecans, individual trees often live more than one hundred years, affords pests tremendous opportunity to adapt. Most pecan pests, on the other hand, have one or more generations each year, and a more flexible genotype that can adapt to natural pecan defenses (Harris and Jackman 1991). Most pecan agroecosystems further limit genetic diversity by using one to several improved cultivars. The growing season for pecan is over seven months long. There are more than 180 species of phytophagous arthropod pests that feed on pecan (Payne and Johnson 1979, Harris 1983), and each is associated with a diverse array of natural enemies (Tedders 1983). Besides the cost and inconvenience to growers, heavy use of prophylactic sprays greatly reduces control from natural enemies (Mizell and Schiffhauer 1990) and contributes to insecticide resistance (Dutcher and Htay 1985). Pecan insect management strategies have shifted in recent years from static reliance on broad-spectrum insecticides to an integration of chemical, cultural, and biological controls. Further advances in biological controls should help growers reduce inputs, increase profits, and meet demands from consumers and regulating agencies for lower pesticide residues.

Fruit and nut trees are fixed in the same location for their entire productive life, providing great temporal and spatial stability. This provides opportunities for adopting ecological approaches to orchard agroecosystems (Brown 1999). One ecological approach is to mimic natural systems wherever possible. Such agricultural mimics often exhibit high protection from pests, low requirements for fertilizer, and high use of available nutrients (Sanchez 1995). This study highlights the natural defenses of pecan in its natural forest habitat, and presents practical ways in which to introduce and capitalize on these features in pecan orchards.

PECAN ECOSYSTEMS

Pecan exists in a diversity of habitats, along a gradient from natural, undisturbed pecan forests to intensively managed orchards with improved cultivated varieties of pecan trees. The preferred natural habitat for pecan is on bottom land that is well-drained, with occasional but not prolonged flooding. Pecan is the climax vegetation on preferred sites, comprising more than 50 percent of the forest biomass (Diver and Ames 2000, Sparks 2002a). Tree size can be extremely large with heights up to 180 feet and trunk diameter up to 7.0 feet (Boisen and Newlin 1910, Fowells 1965, Sargent 1933). Number and kinds of sympatric species in pecan forests increase from semi-arid to humid climates, with mostly grasses and very few sympatric tree species in arid regions and increasingly more sympatric tree species as one moves towards more humid regions (Sparks 2005a). Pecan is a major component of the sycamore-sweet gum-American elm forest type, and also a component of the cottonwood type and black willow type forests (Huenneke 1981). Other sympatric tree species include hackberry, green ash, box elder, and water oak. Common native understory plants include pawpaw, giant cane, pokeweed, poison ivy, grape, Alabama supplejack, and greenbriers (Snyder 1993).

Pecan natural forests are highly productive systems in many ways, including a bountiful crop of nuts in most years. Native Americans harvested pecan in its natural habitat, as did explorers and early settlers (Sparks 2005a). Pecan has adapted to a wide range of climatic conditions between 30° and 42° North latitude (Sparks 1991a), suggesting substantial genetic diversity. Genetic diversity is high within each forest also, and is considered a key component of natural defense from many stressors. This genetic diversity diminishes as you go from the natural forest to domesticated groves to orchards, and reliance on human inputs increases to maintain the life and harvests of pecan trees. Pecan is an entirely North American species, as are most of its pests (Harris 1983). Obviously, pests do not limit pecan perpetuation within its native habitat. This successful coexistence implies mechanisms that allow pecan and its pests to survive (Sparks 2005a).

Regardless of the surplus nuts provided by pecan trees in their forest habitat, certain conditions preclude their harvest on a large scale to meet consumer demand. Developed pecan systems are classified as either groves or orchards. Trees set in their natural position by nature are referred to as groves and those planted by man are referred to as orchards (Stucky and Kyle 1925). In grove production, native stands of pecan are developed to maximize cultivation, harvest efficiency, and overall yields. First, all non-pecan trees are removed, then a permanent groundcover is established. Further thinning takes place to remove old, weak, and diseased trees and allow adequate space for younger, more productive trees. A fertilization program replaces nutrient recycling from fallen leaves and shucks and provides optimal nutrition for maximum tree growth and yield. An insect management program prevents serious yield losses from nut feeding insects (Reid and Eikenbary 1991). Livestock sometimes graze in native pecan groves, which is the oldest and largest example of agroforestry in North America (Diver 2000). About one-third of in-shell nut production in the United States is from native groves (Thompson 1984, Wood 2001). Wholesale value and overall yields are much lower (one-third to one-half) in native groves than in orchards, so they receive fewer husbandry inputs (Wood 2003). Trees are under greater stress in native groves, and cost of management inputs becomes critically important in the development of arthropod management strategies (Reid and Eikenbary 1990).

With human design and intentions, orchards have less similarity to natural pecan forests than commercial groves. Trees are usually arranged in straight rows without vegetation beneath the trees in-row and closely mowed sod between tree rows (Figure 1). Straight rows allow efficient use of space, especially as trees grow and mature (Herrera 1995). The mowed sod and bare soils is considered the best compromise to decrease competition for water and nutrients yet minimize problems from soil erosion and nitrate leaching (Worley 2002).

The closely mowed sod and bare soils in-row under trees is also required for mechanical harvesting. Mechanical harvest machinery shakes pecan nuts off of trees, gathers nuts into windrows, and then picks them up for sorting and selling. High vegetation and debris prevents these harvesters from gathering and picking up nuts (Worley 2002). These machines also tear up many groundcovers. Some annual and perennial grasses recover after mechanical harvest. Crimson clover is almost completely destroyed (Apel et al. 1979).

Intensely managed pecan orchards consist of clonal populations of usually one to three cultivars (Wood 2003). They have the least resemblance to natural pecan forests and the greatest reliance on human inputs. Nuts from these orchards are of greatest value to commerce, however. They make pecan an important horticultural enterprise in non-native states like Georgia, Texas, and New Mexico (Diver and Ames 2000). About 70% of pecans produced in the United States and 95% of those produced in Mexico originate from orchards (Woods 2003).

Resemblance to natural pecan forests and functioning of natural biological processes diminish as one transitions from the natural pecan forest to native groves to orchards (Sparks 2005). Genetic diversity is often reduced to one or several cultivars. Natural processes of fertilization are replaced with external subsidies of nitrogen and other major nutrients. Broad-spectrum insecticide sprays help by subduing key pecan pests, but they also harm natural enemies of pecan pests. These issues make growers more reliant upon external inputs for profits (Harris and Jackman 1991).

As one transitions from the native grove to orchards, value and returns increase (Woods 2003). Intensive cultural practices and pest management also increase. But resemblance to natural pecan forests and functioning of natural biological processes diminish. A larger investment in pest management and cultural practices can often be justified by a higher crop value. But certain conditions make orchards more prone to arthropod attack. Orchards are monoclonal, or nearly so, and thus the near absence of genetic diversity in the host population results in arthropod populations being of a greater potential threat to profitability (Woods 2003). Because trees are managed to maximize cropping, trees are subjected to physiological conditions where damage by arthropods can have great impact on both current and future yields and profits via effects on alternate bearing related physiological and developmental processes (Wood and

Reilly 2000). And the high level of nitrogen received by these trees can have significant impact on populations of certain arthropods and subsequent damage (Wood 2003).

PECAN ARTHROPODS

In-depth study of insect pest interactions in undisturbed native pecan forests are largely lacking, but natural stands share most of the same major pests as commercial pecan groves and orchards. Pecan trees are susceptible to nut and foliage feeding arthropods from budbreak to nut maturity (Moznette et al 1940). The major arthropod pests are classified according to control measures used and listed in Table 1. Hickory shuckworm (*Cydia caryana* (Fitch)) and pecan nut casebearer (*Acrobasis nuxvorella* Neunzig) feed on and destroy nuts early in development. Pecan weevil (*Curculio caryae* (Horn)) feeds on and destroys nuts later in development (Mizell 2002). Pecan weevil is common throughout the native range of pecan. But it is absent from all growing regions west, and a few localities east, of the native range (Harris 1983). Many hemipterans feed on developing kernels, including Southern green stink bug (*Nezara viridula* (L.)), brown stink bug (*Euschistus servus* (Say)), dusty stink bug (*Euschistus tristigmus* (Say)), green stink bug (*Acrosternum hilare* (Say)), and leaf-footed bug (*Leptoglossus phyllopus* (L.)) (Worley 2002). The most important foliar feeding pests are the pecan aphids- black pecan aphid (*Melanocallis caryaefoliae* (Davis)), yellow pecan aphid (*Monelliopsis pecanis* (Bissell)), and blackmargined aphid (*Monellia caryella* (Fitch)), and the pecan leaf-scorch mites (*Eotetrancychus hicoriae* (McGregor)) (Wood 2003). Pecan phylloxera (*Phylloxera devastatrix* (Pergande)), pecan spittlebug (*Clastroptera achatina* (Germar)), and pecan serpentine leafminer (*Stigmella juglandifoliella* (Clemens)) are considered minor pests, but often require insecticides to prevent production losses in commercial pecan systems (Payne et al 1979).

There is a strong research focus on biologically-based and narrow-spectrum pest control measures, though growers typically often rely on broad-spectrum conventional pesticides. Grower loyalty on older, broad-spectrum insecticides is not without logic. These materials offer ease of use, often controlling multiple life stages, which makes time of application less sensitive due to their high efficacy, low cost, and long history of control (Altieri and Nicholls 2006). However, the popularity of broad-spectrum insecticides is waning as more effective alternatives become available. Insecticide use has been reduced by more than 50% in pecan over the last 30 years, in large part to selective insecticides that minimize mortality to natural enemies (Bugg et al 1991a). Today, orchard growers typically apply one to seven insecticide sprays per season, with a median of five (Dutcher 2005). Growers in the southeast typically apply one spray for pecan nut casebearer, one spray for early season hickory shuckworm, and three sprays for the late season pest complex (pecan weevil, kernel-feeding hemipterans, leafminers, aphids, mites, and late season hickory shuckworm) (Dutcher 1998). In orchards in the western states, natural enemies may provide adequate control of pecan aphids without need for late season insecticides (LaRock and Ellington 1996). Orchards in the eastern states could rely more on biological control if more effective alternative controls could be found for hickory shuckworm, pecan aphids, and pecan weevil (Dutcher 2005).

PECAN APHID CONTROL IN ORCHARDS

The three primary pest aphids of pecans are blackmargined aphid, yellow pecan aphid, and black pecan aphid (Dutcher 1998). All three pecan aphid species occupy their own feeding niche and can coexist on leaves at the same time (Tedders 1978). Aphid feeding removes carbohydrates from leaves, destroys cells, and damages the leaf vascular system (Tedders and

Thomson 1981). These aphids feed at the same time fruits are developing, causing great stress to the tree. Heavy aphid damage can reduce or eliminate the next season's crop, from carbohydrate depletion by feeding from one or more of the three species (Dutcher 1985, Dutcher et al 1984, Wood et al 1987).

Insecticides are a popular and often effective option for pecan aphid control. However, control with certain foliar insecticide applications has become ineffective (Dutcher and Htay 1985, Dutcher 1997) and costly for producers (Dutcher 1998). Pecan aphids have increasingly become more significant pests of pecan since early in the 20th century (Tedders 1983). Black pecan aphid problems were mostly limited to the late season during the late 1960's, but are now a problem earlier in the season as well, indicating an important biological association may have been disrupted (Sparks 2005). According to Dutcher (1998), aphid control declines in four stages following insecticides. First, populations of aphidophaga are destroyed by the insecticide. Second, pest aphids develop to unusually high numbers in the absence of natural control. Third, more insecticide is applied and insecticide resistant aphids become the dominant genotype. Ultimately, the grower may be left without adequate aphid control, natural or chemical. Aphid resurgence following destruction of natural enemies by broad-spectrum insecticides in pecan aphids is quite common (Dutcher and Htay 1985) and underscores the importance of natural enemies in the pecan system and the interactions between insecticides and natural enemies (Dutcher 1998).

Biological control of the pecan aphid complex is a viable option since these species do not transmit pernicious diseases and the trees can withstand some aphid feeding damage (Dutcher 2004). Aphid predators include spiders (Bumroongsook et al 1992), the lady beetles (primarily *Olla v-nigrum* (Mulsant), *Coccinella septempunctata L.*, *Hippodamia convergens*

Guerin-Mineville, *Cycloneda sanguinea (L.),* and *Harmonia axyridis* Pallas), and lacewings (primarily *Chrysoperla rufilabris* (Burmeister), *C. quadripunctata* (Burmeister), and *Micromus posticus* (Walker)) (Dutcher 1998). Fungal entomopathogens effectively control pecan aphids when environmental conditions favor them, and can cause high mortality when fungicide applications are reduced (Pickering et al 1990). Red imported fire ant (*Solenopsis invicta* Buren) interferes with aphid predators, leading to aphid outbreaks (Tedders et al 1990).

Many methods have been introduced in pecan orchards to increase biological control of pecan aphids and other pests. An insecticide trunk spray keeps red imported fire ants out of trees, where they interfere with aphidophaga, without precluding the ants in the understory, where they are effective predators of pecan weevil (Dutcher and Sheppard 1981, Dutcher et al 1995). Low plant diversity and broad-spectrum insecticides have long been perceived as the greatest sources of adversity to biological control in pecan (Dutcher 2004). Enhancement of natural enemy habitat with groundcover management programs has had limited success. However, broad-spectrum insecticide use can be minimized as more effective pest monitoring enables growers to rely more on as-needed insecticide use. Narrow-spectrum insecticides, such as insect growth regulators, now provide non-disruptive control for early-season control of pecan nut casebearer and hickory shuckworm, further reducing disruption to natural enemy processes (Dutcher 2005).

NATURAL ECOSYSTEM DEFENSES

Pecan production presents unique challenges over annual row crops. Trees are long-lived (potentially more than 100 years) with an essentially fixed genetic makeup (Wood 2003). The trend in orchards is toward a narrower genetic base, with several advanced cultivars. This trend, coupled with the high genetic diversity and flexibility of pest pathogens and arthropods, creates a potential ‘time bomb’ (Harris and Jackman 1991). Pesticide sprays are the most practical short-term solution to keep pecan pests below an economic threshold. However, pesticide coverage is limited in the upper strata of large trees (often 30-50 meters tall). Despite their obvious virtues, long-term pesticide use almost always introduces additional problems into agro-ecosystems, including reduced species diversity, lower biological control potential, pest resurgence, pesticide resistance, and secondary pest outbreaks (Barrett 1969, Stern et al 1959).

A fundamental principle of agroecology is that agroecosystems should mimic the diversity and functioning of local ecosystems, exhibiting complex structure and enhanced biodiversity (Nicholls and Altieri 2004). Agricultural mimics should be productive, pest-resistant, and conservative of nutrients and biodiversity, similar to their natural counterparts. Natural pecan forests have persisted for many thousands of years, and produced pecans to feed local, native populations without need for management (Harris and Jackman 1991). Orchards are ideal systems for mimicking nature and maximizing natural defenses, as they are semi-permanent, relatively undisturbed, and not readily amenable to fallow or crop rotation in the short term (Nicholls and Altieri 2004). Pecan may offer better opportunity to mimic their own natural forest conditions due to the very long life of trees (often more than 100 years), and shucks and shells which resist attack from many polyphagous insects that damage fleshy crops. None-the-less, current pecan culture has little resemblance to natural pecan forests and make limited use of natural processes. Degrees of manipulation are required to maximize production, streamline harvests, and make profits. But grower manipulations have inadvertently led to high input systems. This section categorizes natural defenses of pecan, and details how to maximize natural processes without interfering with grower operations.

Pecan trees, and plant species in general, utilize five defense mechanisms to survive arthropod attack in its natural environment- escape in space, escape in time, confrontation, accommodation, and biological associations (Harris 1980). Confrontation and accommodation also apply to microbial pests (Sparks 2005a). These five categories do not act independently, but rather with synergism for greater overall effect (Harris 1983).

Pecan trees may have high density in both native pecan forests and orchards. However, native pecan forests have higher genetic diversity. Many pecan genotypes are naturally resistant to pecan twig phylloxera (Calcote and Hyder 1980, Harris 1982). In native stands, this insect must expend considerable energy and time to find host trees to infest. This is one example of escape in space (Sparks 2005a). The defense is forfeited in orchards where all or most genotype is susceptible to the phylloxera.

Escape in time is the major defense mechanism against fruit-feeding insects (Harris 1983). Pecan weevils have approximately three weeks to oviposit in fruits, from the gel stage and shuck split (Harris and Ring 1979). Weevils generally emerge from the soil when the gel stage begins. Ovipositing females only live for a few weeks (Harris 1983), so late-maturing genotypes escape damage (Calcote and Hyder 1981). Irregular fruiting allows escape in time among years. One year of low fruiting starves weevils, followed by a heavy fruiting year that satiates weevils. This keeps population levels of weevils low enough that enough fruits can escape damage during high fruiting years (Sparks 2005). This irregular bearing also works with pecan nut casebearer (Sparks 2005b) and squirrels (Nixon et al 1975).

Some pests are genotypic specific, such as pecan scab and pecan phylloxera. Thus, where trees with a certain genetic profile may succumb, the species as a whole is protected from an epidemic (Harris 1983). Scab on the fruit of a highly susceptible genotype prevents viable seed production during highly infectious years, thus reducing a genetic predisposition to scab to potential offspring. Severe scab also suppresses tree growth and over time gradually suppresses tree vigor to a less competitive position in the forest canopy. When the scab mutates, only a small portion of the diverse seedling population becomes severely infected and natural selection persists. Similarly, a genotype highly susceptible to southern pecan leaf phylloxera has less survival chance. This insect induces severe premature, late summer defoliation. Reproductive opportunity is reduced for the genotype by producing poor quality seed in the current year and diminishing tree vigor and seed production the following year (Sparks 2005a).

Accomodation operates when the tree produces more of a plant part than it needs to remain biologically viable (Harris 1983). The lost part has a minimal impact on the tree's ability to compete with other trees in the forest. Accommodation occurs mainly for leaves countering damage by foliar feeding insects and pathogens but also to a limited extent for fruit countering damage by kernel-feeding hemipterans (Sparks 2005a).

Biological associations beneficial to pecan consist mainly of parasites, diseases, and predators that attack the phytophagous insect and mite fauna of pecan insects. Biological associations are typically quite important in the control of pecan leaf scorch mites, black pecan aphids, black margined aphids, yellow pecan aphids, pecan serpentine leafminer, and pecan upper surface blotchy leafminer (Harris 1983). Associations are very effective most years, but periodically the associations break down and epidemic outbreaks occur over wide geographic areas. Epidemics occurred with yellow and blackmargined pecan aphids in 1984 and 1985 (Sparks 1991b), blotchy leaf miner in southwest Texas in 1986 (Sparks 2005b), and walnut caterpillar in 1973 in Texas (Harris 1982). All trees are more or less equally stressed during these outbreaks and the competitive advantage among genotypes remains similar (Sparks 2005a).

Masting, or irregular bearing (variation in yield from year to year), is a principal defense feature to escape primary nut feeders by periodic satiation and starvation (Worley 2002). Universal susceptibility to periodic foliage feeders preserves the masting cycle. With a diverse population, individual trees may succumb to certain pests, but epidemics are uncommon. And natural enemies keep pests in check most of the time (Harris 1980).

Pecan utilizes all five defense mechanisms in its natural environment. Growers can also rely on these defenses in orchards and groves, although this is far more challenging in heavily manipulated systems. Orchard design and management may not intentionally rely on natural defenses, but often they inadvertently allow the defenses to occur. Reliance on natural defenses reduces as human inputs become more available. This is probably why natural defenses have reduced in pecan systems over time. Now, with greater costs of petroleum and labor, and better alternatives to broad-spectrum pesticides, natural defenses should become more attractive.

Escape in space is reduced by eliminating poor-performing trees in groves, or selecting few select cultivars for orchards. However, the escape in space defense is still there with some varieties. Growers fertilize trees to maximize growth of trees and nuts, primarily to maximize yields. Heavy growth can also help with the accommodation defense, allowing heavy herbivory without dire consequences to pecan trees. There is much current research on the confrontation defense, especially in genetic manipulation of commonly planted annual crops, i.e. cotton and corn. This has been limited in pecan and other perennial plants, but may be more common as methods prove effective in other crops. In time, growers may be able to induce resistance mechanisms into existing pecan trees or plant resistant trees. Biological control is one of the larger and older subsets of entomology, an example of biological associations. Pecan growers try to limit insecticide sprays, knowing that they negatively impact biological control. Predators are sometimes released to improve biological control, as occurred successfully in the southeast with *Harmonia axyridis* for control of pecan aphids. Early and late maturing pecan cultivars have been developed, in part to reduce infestation by pecan weevil. This is a great example of escape in time.

Escape in time via masting is an excellent defense ecologically but is not tolerable with pecan growers for economic reasons. Low numbers of high quality nuts alternating with high number of low quality nuts meets neither grower nor market demands. Great amplitude of this biennial cycling creates major revenue and marketing problems. Reasons for alternate bearing in pecan is largely unknown, but is best explained by the phytohormone carbohydrate theory (Wood et al 2003). This theory explains the regulation of flowering and fruiting occurring at two levels- within the flowering structures in the previous season and in the dormant season carbohydrate pool in the bud break stage. With relatively higher inputs of water, light, and nitrogen, highly managed orchards are at greater risk of masting than native groves. Optimal management of inputs and pest management mitigates masting, although this neutralizes a key natural defense mechanism (Wood 2003).

Pecan growers are limited in how much they can mimic natural pecan forests. Diverse, randomly scattered plantings throughout the orchard interferes with cultivation and harvest. Pecan trees in orchards are aligned in straight lines to maximize efficiency of space. A clean orchard floor is required during harvest, as nuts are picked mechanically from the ground under trees (Worley 2002). Impact of alternative plantings on mature pecan trees is not well known, although reduced growth is evident when young trees are associated with weeds (Patterson and Goff 1994, Wolf and Smith 1999) and cover crops (Foshee et al 1995). Genetic diversity is often limited in pecan orchards because growers have relatively few proven cultivars. And many growers have demands from their markets for only a few select cultivars. Despite progress with a number of pests, pesticides remain the primary focus for pecan pest management, greatly diminishing control from biological associations (Dutcher 1998). High yielding, profitable pecan orchards would not be able to maintain yields and profits without pesticides, even though reliance on pesticides greatly diminishes biological control.

But pecan orchards can mimic natural pecan forests more so than they do now, allowing the opportunity for greater use of natural defenses. Failure to solve pest problems has eliminated some crops from wide production areas, i.e. sugar beets, sugar cane, cotton, and sunflower (Harris and Jackman 1991). Production systems that do not capitalize on all natural defense mechanisms compatible with commercial production increasingly risk failure. The desire to have genetically uniform pecan trees with limited groundcover creates a monoculture system (Harris 1991), which greatly reduces natural defenses. It may be possible to optimize natural defenses in pecan orchards without impairing commercial production by using: a greater variety of pecan cultivars, greater use of alternative narrow-spectrum insecticides, and employment of diverse groundcovers and insectary plants under trees and between tree rows. A greater variety of pecan cultivars is dependent upon availability, as is greater use of narrow-spectrum insecticides. Planting of diverse groundcovers under pecan was common several decades ago (Bugg et al 1991a). Usage waned due to higher management inputs and the groundcovers' competition for water and resources (fuel, fertilizers, and labor). With greater irrigation and rising costs of resources, groundcovers are being considered once again. The following section highlights recent research on groundcovers and insectary plants.

HABITAT MANIPULATION IN ORCHARDS

Broad-spectrum sprays and monocultures create the two major sets of adverse conditions for natural enemies of insect pests (Dutcher 1998). Native pecan groves receive less management than orchards, i.e. fewer sprays and a more diverse groundcover (Reid and Eikenbary 1991). Orchards respond positively to higher input management, but can use augmentative and conservation techniques to increase biological control. Understory plant diversity can be artificially increased in southeastern orchards with cover crops, intercrops, and banker plants (see Figure 2) (Tedders 1983, Mizell and Schiffhauer 1987, Bugg and Waddington 1994). *Harmonia axyridis* has relatively recently been successfully introduced into pecan orchards in the southeast and southwest (Quattro 1995, LaRock and Ellington 1996), changing the dynamics of aphid management. This highly effective predator has since been established throughout the United States in many orchard and field crops (Dutcher 2004).

Besides potentially enhancing beneficial insects, diverse understory plantings may also enhance soils by increasing levels of nitrogen (Gardner and Boundy 1983, Hargrove 1986) and promoting better soil structure (Elliott et al 1987). Both warm and cool-season groundcovers have been used in the past in pecan. But self-seeding cool-season legumes can be integrated most easily into conventional systems (Bugg et al 1991a). Competition for water, nutrients, and light can be minimized by retaining an herbicide strip in tree rows (Patterson and Goff 1994), although cool-season annual covers receive adequate light under dormant pecan trees in mild winters typical of southern production regions (Bugg et al 1991a).

Cool-season cover crops were studied in pecan orchards in Georgia and Oklahoma, and were found to consistently produce aphidophaga on the pecan orchard floor (Bugg et al 1991a, 1991b, Rice et al 1998). Similar studies have taken place in almond, walnut, apple, pear, cherry, peach and citrus (Bugg and Waddington 1994). Impact of groundcovers on insect abundance and species composition in the pecan tree canopy is highly variable. In Oklahoma, only *C. rufilabris* abundance was higher in pecan trees with a legume cover crop than mowed sod, during midsummer, and no other effects were found (Smith et al 1996). Vetch/clover groundcovers did have the additional benefit of improving soil fertility (Smith et al 1996). In Georgia, rye/vetch groundcovers enhanced density of lady beetles in the understory. But no evidence of higher densities of lady beetles or improved biological control of pecan aphids in pecan trees was observed (Bugg et al. 1991b).

Crape myrtle, a low-maintenance ornamental shrub, may also have potential as an intercrop insectary plant (Stacey 1977). Crape myrtle aphid (*Sarucallis kahawaluokalani* (Kirkaldy)) is a major arthropod pest of crepe myrtle, and shares most of the same predators as pecan aphids. Mizell and Schiffhauer (1987) planted crape myrtle in rows of mature pecan trees. They found crape myrtle aphid populations to peak approximately two weeks before peaks of pecan aphids, and peak populations of predators- Coccinellidae, Syrphidae, Chrysopidae, and Anthocoridae- to coincide with crape myrtle aphid peaks. Although further testing was not conducted, it was speculated that crape myrtle shrubs might serve to draw predators into pecan orchards at optimal timing for control of pecan aphids.

The above research took place prior to establishment of *H. axyridis*. Results may have been quite different had this highly effective aphid predator been established in pecan at this time. A seven year period of enhancement and inoculative release of *H. axyridis, C. rufilabris,* and *H. convergens* in a large New Mexico pecan orchard effectively reduced pecan aphid populations (the only major insect pests in that orchard), and predator release rates declined over years, indicating that the predators were becoming established in the orchard. Costs of chemical aphid control are now greater than the benefits in this orchard, and rarely used (LaRock and Ellington 1996). *Harmonia axyridis* was released into Georgia pecan orchards from 1978 to 1980, and was credited with much greater biological control of pecan aphids ten to fourteen years after its introduction (Quattro 1995). Aphid abundance is now generally lower across the southeastern United States and aphid outbreaks are less common (Dutcher 2004). But very little is known about the response of these beetles to habitat enhancement techniques in managed pecan orchards.

CURRENT RESEARCH NEEDS

For several decades, entomologists and other pest management specialists have focused on integrated pest management (IPM) for control of pests in an economically and ecologically sound manner (Kogan 1998). The traditional (top-down) approach to IPM takes a conventionally managed agricultural ecosystem and, in a stepwise fashion, reduces the total amount of external inputs and controls imposed upon the system while gradually advancing the influence of natural control processes (Lawton 1999). In theory, chemical control is used as a last resort with IPM (Stern et al 1959). However, in high value crops with diverse pest fauna, chemical control is most often the first resort and primary focus of growers for pest management (Koul et al 2004). An alternative (bottoms-up) approach starts with a more natural ecosystem and adds external inputs only as needed and only in quantities necessary to augment natural ecological processes and overcome biological barriers to attaining marketable products (Prokopy 2003). The bottoms-up approach may reduce pesticide use significantly, but complete elimination is unlikely with high-value crops and heavy pest pressure. For example, Prokopy (2003) was able to obtain 92% clean (free of any pest injury) fruit in Massachusetts apple orchards, with two insecticide and two fungicide sprays, using this bottoms-up approach. In comparison, 86% clean fruit was obtained from traditional IPM, with similar yields, using seven insecticide and nine fungicide sprays, and control orchards without any sprays yielded 0% clean fruit.

A more recent trend in sustainable agriculture is integrated production (IP), a holistic systems approach that integrates IPM with production and socioeconomic factors (Boller et al 2004, Cross and Kickler 1994, Sansavini 1997). There is much similarity between IP and advanced IPM (Sansavini 1997). Whichever term is used, both methods acknowledge that agroecosystems are complex systems that often require a multi-pronged strategy for responsible management.

My research focuses on IP. In my current project, I seek to study the impact of aphidophaga on pecan aphids since the introduction of *H. axyridis*. My study consists of four projects: 1) conduct bioassays to determine the feeding behavior of *H. axyridis* with the three pecan aphids, cowpea aphid (*Aphis craccivora* Koch), and crape myrtle aphid (two non-pest aphids common on alternative understory plants), 2) evaluate various groundcovers on aphidophaga and pecan aphids (mowed sod, mowed sod to cool-season clover/vetch, and cool-season clover/vetch to warm-season sesbania/indigo), 3) evaluate crape myrtle as an intercrop plant on aphidophaga and pecan aphids with each of the above groundcover treatments, and 4) evaluate various groundcovers on soil enhancement and nutrient availability.

The primary focus of this project is on biological control. The understory plants will likely provide habitat and alternate prey for aphidophaga. Proper selection of understory plants may enhance soil conditions and fertility as well as biological control of pest aphids. Integrating cover crops into the pecan understory could be an important evolutionary step away from monoculture and towards a natural pecan forest. If biological control is effective, insecticide sprays can be reduced, increasing ecosystem stability. If pecan yields are increased from reduced herbivory and enhanced soils, this would provide growers with an economically and environmentally attractive alternative to current practices.

References Cited

Altieri, M.A. and C.I. Nicholls. 2006. Agroecology in action: Applying agroecological concepts to the development of ecologically pest management strategies. <http://www.cnr.berkeley.edu/~agroeco3/applying_agroecological_concepts.html>

Apel, G.W., M.W. Smith, and H.A. Hinrichs. 1979. The effect of ground covers on pecan tree performance and mechanical harvesting. Pecan South 6: 11.

Barrett, G.W. 1969. The effects of an acute insecticide stress on a semi-enclosed grassland ecosystem. Ecology 49: 1019-1035.

Boisen, A.T. and J.S. Newlin. 1910. The commercial hickories. U.S.D.A. Forest Service Bull. 80.

Boller, E.R., J. Avilla, and E. Joerg. 2004. Integrated production principles and technical guidelines. IOBC/WPRS Bull 27(2): 54.

Brown, M.W. 1999. Applying principles of community ecology to pest management in orchards. Agric., Ecosys. Environ. 73: 103-106.

Bugg, R.L. and C. Waddington. 1994. Using cover crops to manage arthropod pests of orchards: a review. Agric., Ecosys. Environ. 50: 11-28.

Bugg, R.L., M. Sarrantonio, J.D. Dutcher, and S.C. Phatak. 1991a. Understory cover crops in pecan orchards: possible management systems. Amer. J. Alternative Agric. 6(2):50-62.

Bugg, R.L., J.D. Dutcher, and P.J. McNeill. 1991b. Cool-season cover crops in the pecan orchard understory: effects on Coccinellidae (Coleoptera) and pecan aphids (Homoptera: Aphididae). Biol. Control 1: 8-15.

Bumroongsook, S., M.K. Harris, and D.A. Dean. 1992. Predation on blackmargin aphids (Homoptera: Aphididae) by spiders on pecan. Biol. Control 2: 15-18.

Calcote, V.R. and D.E. Hyder. 1981. Pecan weevil preference for various pecan cultivars. J. Econ. Entomol. 74: 223-226.

Calcote, V.R. and D.E. Hyder. 1980. Pecan cultivars tested for resistance to pecan phylloxera. J. Ga. Entomol. Soc. 15: 428-431.

Cross, J.V. and E. Dickler. 1994. Guidelines for integrated production of pome fruits in Europe, 2nd ed. IOBC/WPRS Bull 17(9): 1-8.

Diver, S. and G. Ames. 2000. Sustainable pecan production. Horticulture Production Guide, ATTRA, Fayetteville, AR.

Dutcher, J.D. 2005. Personal communication.

Dutcher, J.D. 2004. Habitat manipulation for enhancement of aphidophagous insects in pecan orchards. Intl. J. Ecology and Environ. Sciences 30: 13-22.

Dutcher, J.D. 1998. Conservation of aphidophaga in pecan orchards, pp. 291-305. In: P. Barbosa [ed.]. Conservation Biological Control. Academic Press, San Diego, CA.

Dutcher, J.D. 1997. Loss of pyrethroid efficacy to black margin aphid (Homoptera: Aphididae) populations on pecan, pp. 195-204. In: K. Bondari [ed.]. New Developments in Entomology. Research Signpost, Trivandrum, India.

Dutcher, J.D. 1985. Impact of late season aphid control on pecan tree vigor parameters. J. Entomol. Sci. 20: 55-61.

Dutcher, J.D. and T. Htay. 1985. Resurgence and insecticide resistance problems in pecan aphid management, pp. 17-19. In: W.W. Neal, W.L. Tedders, and J.D. Dutcher [eds.]. Aphids and Phylloxeras of Pecan. Univ. of Georgia.

Dutcher, J.D. and D.C. Sheppard. 1981. Predation of pecan weevil larvae by red imported fire ants. J. Ga. Entomol. Soc. 16: 210-213.

Dutcher, J.D., P.M. Estes, and R.E. Worley. 1995. Enhancement of aphidophaga with summer cover crops in pecan – a SRIPM project. Final report to U.S.D.A. Coop. State Res. Serv. Southern Region IPM Program. Project No. GEO-RF330-206. 116 pp.

Dutcher, J.D., R.E. Worley, J.W. Daniel, R.B. Moss, and K.F. Harrison. 1984. Impact of six insecticide-based arthropod pest management strategies on pecan yield and quality and return bloom under four irrigation-soil fertility regimes. Environ. Entomol. 13: 1644-1653.

Elliott, L.F., R.I. Papendick, and D.F. Bezdicek. 1987. Cropping practices using legumes with conservation tillage and soil benefits, pp. 81-89. In: J.F. Power [ed.]. The Role of Legumes in Conservatoin Tillage Systems. Soil Conservation Society of America, Ankeny, Iowa.

Flack, J.R. 1970. The spread and domestication of the pecan in the United States. PhD diss. Univ. of Wisconsin, Madison.

Foshee, W.G., W.D. Goff, M.G. Patterson, and D.M. Ball. 1995. Orchard floor crops reduce growth of young pecan trees. HortScience 30: 979-980.

Fowells, H.A. 1965. Silvics of the forest trees of the eastern U.S. U.S.D.A. Handbook 271.

Gardner, W.K. and K.A. Boundy. 1983. The acquisition of phosphorus by Lupinus albus L. The effect of interplanting wheat and white lupin on the growth and mineral composition of the two species. Plant and Soil 70: 391-402.

Hargrove, W.L. 1986. Winter legumes as a nitrogen source for no-till grain sorghum. Agronomy J. 78: 70-74.

Harris, M.K. 1991. Pecan arthropod management, pp. 6-15. In: B. Wood and J.A. Payne [eds.]. Pecan husbandry challenges and opportunities. 1st Natl. Pecan Workshop. Proc. U.S.D.A., Agric. Res. Serv., ARS-96.

Harris, M.K. 1983. Pecan natural defense mechanisms. Ann. Report Northern Nut Growers Assn. 74: 73-76.

Harris, M.K. 1982. Genes for resistance to insects in agriculture with a discussion of host-parasite interactions in *Carya*, pp. 72-83. In: H.M. Heybroek, B.R. Stephan, and K. von Weissenberg [eds.]. Proceedings third international workshop on the genetics of host-parasite interactions in forests. Wageningen, Netherlands.

Harris, M.K. 1980. Biology and breeding for resistance to arthropods and pathogens in agricultural plants. Agric. Comm. Tex. A and M Univ. MP 1451.

Harris, M.K. and J.A. Jackman. 1991. Pecan Arthropod Management, pp. 6-15. In: B.W. Wood and J.A. Payne [eds.] Pecan Husbandry: Challenges and Opportunities. First National Pecan Workshop Proceedings. U.S. Dept. of Agriculture, Agriculture Research Service, ARS-96.

Harris, M.K. and D.R. Ring. 1979. Biology of pecan weevil from oviposition to larval emergence. Southwest Entomol. 4: 73-85.

Herrera, E.A. 1995. Economic comparison of removing pecan trees and planting young trees and transplanting established, mature trees. HortTechnology 5: 212-214.

Huenneke, L.F. 1981. Forest cover types of the United States and Canada. Ecology 62: 1694-1696.

Kogan, M. 1998. Integrated pest management: historical perspectives and contemporary developments. Ann. Rev. Entomol. 43: 243-270.

Koul, O., G.S. Dhaliwal, and G.W. Cuperus. 2004. Integrated pest management: potential, constraints, and challenges. CABI, Wallingford, UK.

LaRock, D.R. and J.J. Ellington. 1996. An integrated pest management approach emphasizing biological control for pecan aphids. Southwest. Entomol. 21: 153-166.

Lawton, J.H. 1999. Are there general laws in ecology? Oikos 84: 177-192.

Mizell, R.F. 2002. Overview of pecan arthropod pest management. Proc. Southeastern Pecan Growers Assn. 95: 78-87.

Mizell, R.F. and D.E. Schiffhauer. 1990. Effects of pesticides on pecan aphid predators *Chrysoperla rufilabris*, *Hippodamia convergens*, *Cycloneda sanguinea*, *Olla v-nigrum*, and *Aphelinus perpallidus*. J. Econ. Entomol. 83: 1806-1812.

Mizell, R.F. and D.E. Schiffhauer. 1987. Seasonal abundance of the crape myrtle aphid, *Sarucallis kahawaluokalani*, in relation to the pecan aphids, *Monella caryella* and *Monelliopsis pecanis* and their common predators. Entomophaga 32: 511-520.

Moznette, G.F., C.B. Nickels, W.C. Pierce, T.L. Bissell, J.B. Demaree, and J.R. Cole. 1940. Insects and diseases of the pecan and their control. U.S. Dept. Agric. Farmers' Bull. 1829, 60 p.

Nicholls, C.I. and M.A. Altieri. 2004. Agroecological bases of ecological engineering for pest management, pp. 33-54. In: G.M. Gurr, S.D. Wratten, and M.A. Altieri [eds.]. Ecological Engineering for Pest Management: Advances in Habitat Manipulation for Arthropods. Comstock, Ithaca, NY.

Nixon, C.M., M.W. McCain, and R.W. Donohoe. 1975. Effects of hunting and mast crops on a squirrel population. J. Wildlife Mgmt. 39: 1-25.

Patterson, M.G. and W.D. Goff. 1994. Effects of weed control and irrigation on pecan (Carya illinoinensis) growth and yield. Weed Tech. 8: 717-719.

Payne, J.A. and W.T. Johnson. 1979. Plant pests, pp. 314-395. In: R.A. Jaynes [ed.]. Nut Tree Culture in North America. Northern Nut Growers Association, Hamden, Conn.

Payne, J.A., H.L. Malstrom, and G.E. Knight. 1979. Insect pests and diseases of pecan. U.S. Dept. Agric. Ref. Man. S-5, 43 p.

Pickering, J., J.D. Dutcher, and B.S. Ekbom. 1990. The effect of a fungicide on fungal-induced mortality of pecan aphids (Homoptera: Aphididae) in the field. J. Econ. Entomol. 83: 1801-1805.

Prokopy, R.J. 2003. Two decades of bottom-up, ecologically based pest management in a small commercial apple orchard in Massachusetts. Agri., Ecosys, Environ. 94: 299-309.

Quattro, J.R. 1995. Gotcha! Tiny lady beetles have big biocontrol potential. Agri. Research 43: 4-8.

Reid, W. and R.D. Eikenbary. 1991. Developing low input management strategies for native pecan orchards, pp. 69-76. In: B.W. Wood and J.A. Payne [eds.]. Pecan Husbandry: Challenges and Opportunities. ARS-96. USDA-Agriculture Research Service, Washington, D.C.

Rice, N.R., M.W. Smith, R.D. Eikenbary, D. Arnold, W.L. Tedders, B. Wood, B.S. Landgraf, G.G. Taylor, and G.E. Barlow. 1998. Assessment of legume and nonlegume ground covers on Coleoptera: Coccinellidae density for low-input pecan management. Amer. J. Alternative Agric. 13: 111-123.

Sanchez, P.A. 1995. Science in agroforestry. Agroforestry Systems 30: 5-55.

Sargent, C.S. 1933. Manual of the trees of North America. Houghton Mifflin, Boston.

Smith, M.W., D.C. Arnold, R.D. Eikenbary, N.R. Rice, A. Shiferaw, B.S. Cheary, and B.L. Carroll. 1996. Influence of ground cover on beneficial arthropods in pecan. Biol. Control 6: 164-176.

Snyder, S.A. 1993. Southern floodplain forest. In: Fire Effects Information System, (online). United States Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (producer). <http://www.fs.fed.us/database/feis/>

Sparks, D. 2005a. Adaptability of pecan to its native range. HortScience 40: 1175-1189.

Sparks, D. 2005b. Unpublished data.

Sparks, D. 2002. Rainfall governs pecan stand homogeneity in native, wild habitats. J. Amer. Soc. Hort. Sci. 127: 860-868.

Sparks, D. 1991a. Geographical origin of pecan cultivars influences time required for fruit development and nut size. J. Amer. Soc. Hort. Sci. 116: 627-631.

Sparks, D. 1991b. Cultural practices, pp. 22-33. In: B. Wood and J.A. Payne [eds.]. Pecan husbandry challenges and opportunities. 1st Natl. Pecan Workshop. Proc. U.S.D.A., Agric. Res. Serv., ARS-96.

Stacey, D.L. 1977. Banker plant production of *Encarsia formosa* and its use in the control of glasshouse whitefly on tomatoes. Plant Pathol. 26: 63-66.

Stern, V.M., R.F. Smith, R. van den Bosch, and K.S. Hagen. 1959. The integrated control concept. Hilgardia 29: 81-101.

Stucky, H.P. and E.J. Kyle. 1925. The MacMillan Company. New York, NY.

Tedders, W.L. 1983. Insect management in deciduous orchard ecosystems: habitat manipulation. Environ. Man. 7: 29-34.

Tedders, W.L. 1978. Important biological and morphological characteristics of the foliar-feeding aphids of pecans. U.S.D.A. Agric. Research Service, Tech. Bull. 1579.

Tedders, W.L. and J.M. Thompson. 1981. Histological investigation of stylet penetration and feeding damage to pecan foliage by three aphids, pp. 69-83. In: Johnson, D. [ed.]. Tree Fruit

Pest Management in the Southeastern United States. Misc. Publications of the Entomological Society of America, Lanham, MD.

Tedders, W.L., C.C. Reilly, B.W. Wood, R.K. Morrison, and C.S. Lofgran. 1990. Behavior of *Solenopsis invicta* (Hymenoptera: Formicidae) in pecan orchards. Environ. Entomol. 19: 44-53.

Thompson, T.T. 1984. Pecan cultivars: current use and recommendations. Pecan Q. 18: 20-26.

Wolf, M.E. and M.W. Smith. 1999. Cutleaf evening primrose and palmer amaranth reduce growth of nonbearing pecan trees. HortScience 34: 1082-1084.

Wood, B.W. 2003. Pecan production in North America, pp. 1-20. In: Dutcher, J.D., M.K. Harris, and D.A. Dean [eds.]. Integration of Chemical and Biological Insect Control in Native, Seedling, and Improved Pecan Production. Southwestern Entomologist Supp. 27, Dallas, TX.

Wood, B.W. 2001. Production unit trends and price characteristics within the United States pecan industry. HortTechnology 11: 110-118.

Wood, B.W. and C.C. Reilly. 2000. Pest damage to pecan is affected by irrigation, nitrogen application, and fruit load. HortScience 35: 669-671.

Wood, B.W., P. Conner, and R. Worley. 2003. Relationship of alternate bearing intensity in pecan to fruitand canopy characteristics. HortScience 38: 361-366.

Wood, B.W., J.A. Payne, and L.J. Grauke. 1990. The rise of the U.S. pecan industry. HortScience 25: 594, 721-723.

Wood, B.W., W.L. Tedders, and J.D. Dutcher. 1987. Energy drained by three pecan aphid species (Homoptera: Aphididae) and their influence on in-shell pecan production. Environ. Entomol. 5: 1045-1056.

Worley, R.E. 2002. Floor management, pp. 342-361. In: Compendium of Pecan Production and Research. Edwards Bros., Ann Arbor, MI.

Table 1. Major arthropod pests of pecan (modified from Wood 2003).

Common and Scientific names	Typical Control Methods
Pecan weevil (*Curculio caryae* (Horn))	Broad-spectrum insecticides for adults, natural enemies of larvae
Pecan aphids: black pecan aphid (*Melanocallis caryaefoliae* (Davis)), yellow pecan aphid (*Monelliopsis pecanis* (Bissell)), and blackmargined aphid (*Monellia caryella* (Fitch))	Broad-spectrum insecticides, systemic insecticides, natural enemies, insecticidal soap
Nut-feeding Lepidopterans: pecan nut casebearer (*Acrobasis nuxvorella* Neunzig), hickory shuckworm (*Cydia caryana* (Fitch))	Biorational insecticides with a sophisticated monitoring system
Pecan leaf scorch mite (*Eotetranychus hicoriae* (McGregor))	Selective miticides, natural enemies, predatory mite release
Kernel feeding hemipterans: southern green stink bug (*Nezara viridula* (L.)), brown stink bug (*Euschistus servus* (Say)), green stink bug (*Acrosternum hilare* (Say)), and leaf-footed bug (*Leptoglossus phyllopus* (L.))	Broad-spectrum sprays, trap crops, natural enemies

Figure 1. Typical modern orchard of pecan cultivars.

Figure 2. Pecan orchard with diverse understory plantings (recently planted).

CHAPTER 2

APHID FEEDING PREFERENCE OF MULTICOLORED ASIAN LADY BEETLE, *Harmonia axyridis* Pallas (Coleoptera: Coccinellidae)[1]

[1] Williamson, J.R., and J.D. Dutcher. To be submitted to *Journal of Entomological Science*.

ABSTRACT: A feeding preference bioassay was conducted with larvae of the multicolored Asian lady beetle (*Harmonia axyridis* Pallas) and aphid species common in pecan (*Carya illinoinensis* (Wangenheim) K. Koch) orchards. The aphid species tested were the three pecan pest aphids - yellow pecan aphid (*Monelliopsis pecanis* Bissell), blackmargined aphid (*Monellia caryella* (Fitch)), and black pecan aphid (*Melanocallis caryaefoliae* (Davis)) - crape myrtle aphid (*Sarucallis kahawaluokalani* (Kirkaldy)), and cowpea aphid (*Aphis craccivora* (Koch)). Crape myrtle aphid and cowpea aphid are potentially important alternate prey aphids for ladybeetles in pecan orchards. Each instar of the multicolored Asian lady beetle was offered one of three combinations of aphids in an arena: fifteen of the same aphid species, five of each of the three pecan pest aphids, and three each of the five aphids together. Lady beetle larvae showed several significant differences and a slight trend favoring heavier feeding on the three pecan aphids in preference to cowpea aphid, when offered each species alone. There were no significant differences in multicolored Asian lady beetle consumption of aphid species in bioassays offering the three pecan aphids or with all five aphid species together.

Key words: *Harmonia axyridis*, pecan aphids, aphidophaga, bioassay

Multicolored Asian lady beetle (*Harmonia axyridis* Pallas (Coleoptera: Coccinellidae)) is an arboreal species from Asia that feeds on aphids and other soft-bodied insects (Gordon 1985). It was introduced and successfully established in pecan (*Carya illinoinensis* (Wangenheim) K. Koch (Fagales: Juglandaceae)) orchards in Georgia from 1978 to 1981 (Tedders and Schaefer 1994), and has greatly improved the overall effectiveness of biological control, especially of pecan aphids (Dutcher 2004). It has since spread and been introduced to other areas, so that multicolored Asian lady beetle now occurs throughout most of the United States (Koch 2003).

The pecan pest aphid complex (Hemiptera: Aphididae) consists of three species: yellow pecan aphid (*Monelliopsis pecanis* Bissell), blackmargined aphid (*Monellia caryella* (Fitch)), and black pecan aphid (*Melanocallis caryaefoliae* (Davis)). These aphids are good candidates for biological control since they do not transmit diseases, and modest aphid feeding damage does not harm the trees (Dutcher 2004). Multicolored Asian lady beetle migrates into pecan from surrounding habitats when pecan aphid populations are peaking, but often after the aphids reach damaging levels. Select understory insectary plants can harbor alternate prey that may attract multicolored Asian lady beetle into pecan orchards for more effective pecan aphid control.

We conducted a comprehensive research project on enhanced biological control in pecan orchards with understory plants. We first wanted to determine if multicolored Asian lady beetle larvae would have a preference for aphids common to these understory plants. Our objective was to measure preference of multicolored Asian lady beetle for the three pecan aphid species and two aphid species common on understory plants: crape myrtle aphid (*Sarucallis kahawaluokalani* (Kirkaldy)), from crape myrtle (*Lagerstroemia indica* (L.)), and cowpea aphid (*Aphis craccivora* (Koch)), from hairy vetch (*Vicia villosa* Roth). We hypothesized that no significant preferences would be found for any of these aphid species.

Methods and Materials

Multicolored Asian lady beetle eggs were collected from pecan orchards in Tift and Peach counties in Georgia during the 2004, 2005, and 2006 growing seasons. Egg masses were held in Petri dishes until hatch (25±3º C and 12:12 (L:D) h photoperiod). Pecan pest aphids were collected from pecan trees across southern Georgia. Crape myrtle aphids were collected from ornamental crape myrtle plantings and cowpea aphids were collected from fava beans and cowpea plants grown in a greenhouse in Tift County, Georgia. Each bioassay was initiated with first instar multicolored Asian lady beetle, after they left the egg cluster and began actively searching for food. One beetle larva was placed in an arena made from a 35 X 10 mm Petri dish with moist filter paper and a total of 15 immature aphids of all instars for each treatment. Three different bioassays were conducted to determine the feeding preference of first, second, third, and fourth instar larvae of multicolored Asian lady beetle for prey aphids commonly found in pecan orchards. In the first bioassay, a beetle larva of each instar was placed in an arena with 15 aphids, all of one species, for each of the five aphid species. This was replicated three times. In the second bioassay, a beetle larva of each instar was offered five individuals of each of the three species of pecan pest aphids in an arena. This was replicated six times. In the third bioassay, a beetle larva of each instar was offered three individual prey aphids of each of the five aphid species together in an arena. This was replicated six times. All aphids were apparently healthy, wingless adults or nymphs, and randomly picked to get a relatively even distribution of size and developmental stages. Numbers of aphids eaten were recorded hourly for 24 h. Then, each multicolored Asian lady beetle larva was placed into a 60 X 15 mm Petri dish with moist filter paper and more than enough aphids (of the same combination) to feed continuously and molt to the next instar. The bioassay continued for the next instar when the newly emerged beetle larva resumed feeding again. This cycle continued for each of the four instars of multicolored Asian lady beetle. The same beetle larva was used from first to fourth instar. Mean number of aphids eaten for each time interval and each instar were analyzed for significant differences using SAS 9.1 software (SAS Institute, Inc., 2003).

Results

The cumulative numbers of aphids eaten by each instar for the 1 h intervals during the first 8 h, the 2 h intervals from 8-10 h and 10-12 h, and for the 12 h interval from 12-24 h of exposure to the beetle larvae indicate that all or nearly all of the aphids were eaten in 24 h by first instars, and all aphids were eaten within 24 h, 12 h and 5 h by second, third and fourth instars, respectively, for all three bioassays (Tables 1-3). The rate of consumption (aphids eaten per h) differed between aphid species during the time of exposure to actively feeding beetle larvae. There were significant differences for the number of aphids eaten per h, for each beetle instar, for at least one time interval for each instar in the bioassay offering fifteen of each aphid species alone (Table 1). Preferences were hard to determine, as consumption rates differed between developmental stages, but a general trend favored higher consumption of the three pecan aphids compared to consumption of cowpea aphid (Fig. 1). There were no significant differences in mean consumption rates for any beetle instar in the other two bioassays (Tables 2 and 3), and preferences between aphid species could not be determined (Fig. 2 and 3). Refer to Tables 1-3 for exact values and Fig. 1-3 for trends over time for each of the three bioassays.

Discussion

Significant differences were found for several time intervals, and a general trend favoring consumption of the three pecan aphid species relative to consumption of cowpea aphid was observed, but only with the bioassay using fifteen aphids of the same species. Differences were insignificant for all time intervals for each developmental stage, and preferences hard to determine, for the bioassays with the three pecan aphids and with all five aphid species together. Therefore, we partially accept our hypothesis and disregard our original concern of alternative prey aphids drawing multicolored Asian ladybeetle out of pecan trees.

Optimal foraging theory (Stephens and Krebs 1986) states that predators utilize the different prey types available so as to maximize their rate of energetic gain, which favors selection for larger prey (Charnov 1976). But smaller prey may be more advantageous, when factoring better defense responses, escape abilities, and handling time of larger prey (Pastorok 1981, Sabelis 1992, Chow and Mackauer 1997). This may explain why our results showed least preference for the cowpea aphid, the largest prey in our bioassay, especially with first instar larvae.

With this study, it appears that crape myrtle aphid may possibly draw multicolored Asian lady beetle out of pecan trees, but not cowpea aphid. However, Mizell and Schiffhauer (1987) observed crape myrtle aphids to peak and decline on crape myrtle shrubs shortly before pecan aphids. They believed this would be perfect timing for bringing aphidophaga into pecan orchards, which would subsequently migrate to pecan trees and prevent pecan pest aphids from reaching economic thresholds (this research was conducted prior to establishment of multicolored Asian lady beetle). Cowpea aphid is one of three aphid species abundant in clover/vetch groundcovers (Bugg et al. 1990). The other two are blue alfalfa aphid

(*Acyrthosiphon knodoi* Shimji) and pea aphid (*Acyrthosiphon pisum* (Harris)). A bioassay testing these other two aphid species would better determine ability to recruit multicolored Asian lady beetle out of trees, but our resources did not allow it. Regardless, with a slight preference shown for pecan aphids, we feel confident testing crape myrtle shrubs and clover/vetch groundcovers for our comprehensive study of understory plantings in pecan orchards.

There is little information on feeding preferences of multicolored Asian lady beetle. Kalaskar and Evans (2001) tested larvae of multicolored Asian lady beetle and *Coccinella septempunctata* L. lady beetle for survivorship and preference on pea aphids (*Acyrthosiphon pisum* (Harris)) and alfalfa weevil larvae (*Hypera postica* Gyllenhal). They found pea aphids to be more preferred and superior to alfalfa weevil larvae for both beetles' survival and development, but suggested that weevil larvae would provide a suitable prey substitute in alfalfa fields when aphid populations are at low levels. Hazzard and Ferro (1991) tested adult *Coleomegilla maculata* (DeGeer) lady beetles preference with Colorado potato beetle eggs (*Leptinotarsa decemlineata* (Say)), green peach aphids (*Myzus persicae* (Sulzer)), and corn pollen. They found these beetles to prefer green peach aphids over Colorado potato beetle eggs when both were presented at high densities, but observed no preference at low densities. The aphids were a better food source for beetle development and female oviposition. Complementary feeding of both species without suppression of egg feeding would occur at low prey densities, which would benefit the lady beetles. Lab studies by Soares et al. (2004) found a mixed diet of green peach aphid (*Myzus persicae* (Sulzer)) and black bean aphid (*Aphis fabae* Scopoli) to cause an increase in voracity among the *aulica* phenotype of multicolored Asian ladybeetle, compared to a single diet of either species. This allows the benefit of maximum energy gain and nutrient ingestion, and also increased reproductive capacity of females. Various seed weevil larvae and other alternative prey for aphidophaga occur in pecan orchard groundcovers, and we believe this diversity would be beneficial for multicolored Asian ladybeetle, other generalist predators, and biological control in general.

Acknowledgements

We thank the Georgia Agricultural Commodity Commission for Pecans for funding; Ted Cottrell for providing *Harmonia axyridis* egg clusters and several *Melanocallis caryaefoliae* specimens; Mary Jo Townsend for record keeping; Mary Jo Townsend, Eric Goodwin, Sam Richardson, Nikki Bowman, David Stokes, and Tyler Hood for planting and sampling of research plots.

References Cited

Bugg, R.L., S.C. Phatak, and J.D. Dutcher. 1990. Insects associated with cool-season cover crops in southern Georgia: Implications for pest control in truck-farm and pecan agro-ecosystems. Biol. Agric. Hort. 7: 17-45.

Charnov, E.L. 1976. Optimal foraging, the marginal value theorem. Theoretical Population Biology 9: 129-136.

Chow, A. and M. Mackauer. 1991. Patterns of host selection by four species of aphidiid (Hymenoptera) parasitoids: influence of host switching. Ecological Entomology 16: 403-410.

Dutcher, J.D. 2004. Habitat manipulation for enhancement of aphidophagous insects in pecan orchards. Intl. J. Ecol. Environ. Sci. 30: 13-22.

Gordon, R.D. 1985. The Coleoptera (Coccinellidae) of North America north of Mexico. J. New York Entomol. Soc. 93:1-912.

Hazzard, R.V. and D.N. Ferro. 1991. Feeding responses of adult *Coleomegilla maculata* (Coleoptera: Coccinellidae) to eggs of Colorado potato beetle (Coleoptera: Chrysomelidae) and green peach aphids (Homoptera: Aphididae). Environ. Entomol. 20: 644-651.

Kalaskar, A. and E.W. Evans. 2001. Larval responses of aphidophagous lady beetles (Coleoptera: Coccinellidae) to weevil larvae versus aphids as prey. Ann. Entomol. Soc. Am. 94: 76-81.

Koch, R.L. 2003. The multicolored Asian lady beetle, *Harmonia axyridis*: A review of its biology, uses in biological control, and non-target impacts. J. Insect Sci. 3: 1-16.

Mizell, R.F. and D.E. Schiffhauer. 1987. Seasonal abundance of the crape myrtle aphid, *Saracallis kahawaluokalani*, in relation to the pecan aphids, *Monellia caryella* and *Monelliopsis pecanis* and their common predators. Entomophaga 32: 511-520.

Pastorok, R.A. 1981. Prey vulnerability and size selection by *Chaoborus* larvae. Ecology 62: 1311-1324.

Sabelis, M.W. 1992. Predatory arthropods, pp. 225-264. In: M.J. Crawley [ed.]. Natural Enemies. Blackwell Scientific Publications, Oxford.

SAS Institute, Inc. 2003. SAS/C Online Doc™, VER. 9.03. Cary, NC, SAS Institute.

Soares, A.O., D. Coderre, and H. Schanderl. 2004. Dietary self-selection behaviour by the adults of the aphidophogous ladybeetle *Harmonia axyridis* (Coleoptera: Coccinellidae). J. Anim. Ecol. 73: 478-486.

Stephens, D.W. and J.R. Krebs. 1986. Foraging theory. Princeton University Press, Princeton.

Tedders, W.L. and P.W. Schaefer. 1994. Release and establishment of *Harmonia axyridis* (Coleoptera: Coccinellidae) in the Southeastern United States. Entomological News 105: 228-243.

Table 1. The consumption rate of each instar of *Harmonia axyridis* was measured as the mean number of aphids eaten from the start of the bioassay to the end of the indicated interval. Each ladybeetle larva was placed in an arena with fifteen prey aphids of the same species and observed for 24 h.

Aphid stage and species	Hour interval* 1	2	3	4	5	6	7	8	10	12	24
1st instar											
Black pecan	1.0	1.7	3.7^{a}	5.7^{a}	6.7^{a}	8.7^{a}	10.7^{a}	10.9^{a}	11.5^{a}	12.0^{a}	14.7
Yellow pecan	0.67	1.0	2.3^{ab}	4.0^{b}	5.7^{a}	7.3^{a}	8.0^{b}	8.7^{b}	11.7^{a}	12.3^{a}	15.0
Blackmargined	0.33	0.7	1.3^{bc}	1.7^{c}	2.3^{b}	2.7^{b}	3.7^{c}	5.2^{c}	8.3^{b}	11.0^{a}	14.0
Crape myrtle	0.33	1.0	1.0^{bc}	1.0^{c}	1.3^{b}	1.7^{b}	2.0^{c}	2.7^{d}	5.0^{c}	6.0^{b}	15.0
Cowpea	0.00	0.0	0.0^{c}	0.3^{c}	1.0^{b}	1.3^{b}	1.7^{c}	2.0^{d}	2.3^{d}	3.3^{c}	14.0
2nd instar											
Black pecan	3.7	9.3^{ab}	10.0^{ab}	11.7^{a}	13.3^{a}	14.3^{a}	14.7^{a}	15.0^{a}	15.0	15.0	15.0
Yellow pecan	4.7	5.3^{bc}	6.0^{bc}	7.0^{b}	7.7^{b}	8.6^{b}	9.5^{b}	10.5^{bc}	12.3	13.0	15.0
Blackmargined	1.7	3.0^{c}	4.0^{c}	5.7^{b}	7.3^{b}	9.7^{b}	11.7^{ab}	12.7^{abc}	13.7	14.0	15.0
Crape myrtle	3.3	10.0^{a}	12.3^{a}	13.3^{a}	13.7^{a}	13.7^{a}	13.7^{a}	13.7^{ab}	13.7	15.0	15.0
Cowpea	2.0	4.3^{c}	6.3^{bc}	7.0^{b}	7.7^{b}	9.0^{b}	9.3^{b}	10.0^{c}	12.3	15.0	15.0
3rd instar											
Black pecan	6.7^{a}	11.7^{a}	15.0^{a}	15.0^{a}	15.0^{a}	15.0	15.0	15.0	15.0	15.0	15.0
Yellow pecan	5.7^{a}	8.3^{b}	12.7^{ab}	14.0^{ab}	14.3^{ab}	15.0	15.0	15.0	15.0	15.0	15.0
Blackmargined	8.0^{a}	10.3^{ab}	12.0^{ab}	14.0^{ab}	14.7^{ab}	15.0	15.0	15.0	15.0	15.0	15.0
Crape myrtle	1.7^{b}	5.2^{c}	9.0^{b}	10.0^{bc}	11.7^{bc}	13.0	13.3	13.7	15.0	15.0	15.0
Cowpea	1.0^{b}	3.0^{c}	4.7^{c}	6.3^{c}	9.0^{c}	11.7	13.3	14.3	15.0	15.0	15.0
4th instar											
Black pecan	12.0^{a}	14.3	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
Yellow pecan	10.7^{a}	14.7	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
Blackmargined	13.3^{a}	14.7	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
Crape myrtle	12.0^{a}	14.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
Cowpea	6.3^{b}	11.0	12.3	14.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0

* Means in the same hour interval and for the same instar with the same letter as a superscript are not significantly different between aphid prey species. In groups of means in the same hour interval and for the same instar without the letters as superscripts the means are not significantly different in the group (ANOVA df=4,10, LSD Test, $P<0.05$).

Table 2. The consumption rate of each instar of *Harmonia axyridis* was measured as the mean number of aphids eaten from the start of the bioassay to the end of the indicated interval. Each ladybeetle larva was placed in an arena with fifteen prey aphids, five aphids from each of the three pecan aphid species, and observed for 24 h.

	Hour interval*										
Aphid stage and species	1	2	3	4	5	6	7	8	10	12	24
1st instar											
Black pecan	0.00	0.33	0.67	1.0	1.5	1.5	2.0	2.2	2.3	2.3	4.0
Yellow pecan	0.33	0.50	1.0	1.0	1.3	2.0	1.3	1.3	1.7	2.0	2.8
Blackmargined	0.50	0.83	0.83	1.5	1.8	1.3	2.0	2.0	2.3	2.5	3.5
2nd instar											
Black pecan	0.67	2.0	2.7	3.2	3.7	4.0	4.3	4.3	4.8	4.8	5.0
Yellow pecan	0.83	1.8	2.3	3.2	3.2	3.3	4.2	4.5	5.0	5.0	5.0
Blackmargined	0.83	1.7	2.2	2.8	3.0	3.2	4.2	4.7	4.8	4.8	5.0
3rd instar											
Black pecan	2.3	2.8	3.5	4.2	4.5	4.7	4.7	5.0	5.0	5.0	5.0
Yellow pecan	1.5	2.5	3.5	4.3	4.3	4.7	5.0	5.0	5.0	5.0	5.0
Blackmargined	2.2	2.8	3.5	4.0	4.2	4.7	5.0	5.0	5.0	5.0	5.0
4th instar											
Black pecan	4.7	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Yellow pecan	4.8	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Blackmargined	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0

* No significant differences were found in this test for means in the same hour interval and for the same instar (ANOVA df = 2,15, LSD Test, $P<0.05$).

Table 3. The consumption rate of each instar of *Harmonia axyridis* was measured as the mean number of aphids eaten from the start of the bioassay to the end of the indicated interval. Each ladybeetle larva was placed in an arena with fifteen prey aphids, three aphids from each of the five aphid species, and observed for 24 h.

	Hour interval*										
Aphid stage and species	1	2	3	4	5	6	7	8	10	12	24
1st instar											
Black pecan	0.50	0.67	0.83	0.83	1.0	1.2	1.2	1.3	1.7	1.8	3.0
Yellow pecan	0.17	0.33	0.33	0.33	0.50	0.50	0.50	0.50	0.7	1.0	3.0
Blackmargined	0.33	0.50	0.67	0.67	0.67	1.2	1.3	1.8	2.0	2.0	3.0
Crape myrtle	0.17	0.50	0.67	0.67	0.67	0.83	1.0	1.0	1.2	1.7	3.0
Cowpea	0.00	0.17	0.33	0.50	0.50	0.50	0.83	1.0	1.0	1.2	2.8
2nd instar											
Black pecan	0.83	1.2	2.0	2.0	2.3	2.3	2.7	2.7	3.0	3.0	3.0
Yellow pecan	0.83	1.2	1.3	1.8	2.0	2.3	2.7	2.8	3.0	3.0	3.0
Blackmargined	1.5	1.8	2.2	2.3	2.5	2.7	2.7	2.7	3.0	3.0	3.0
Crape myrtle	1.0	1.2	1.5	2.2	2.2	2.3	2.3	2.5	3.0	3.0	3.0
Cowpea	1.7	1.8	1.8	2.0	2.2	2.3	2.5	2.7	3.0	3.0	3.0
3rd instar											
Black pecan	1.3	2.2	2.7	2.8	2.8	2.8	3.0	3.0	3.0	3.0	3.0
Yellow pecan	1.7	2.7	2.7	2.7	2.8	2.8	2.8	2.8	2.8	3.0	3.0
Blackmargined	2.0	2.5	2.8	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Crape myrtle	1.5	2.3	2.7	2.8	2.8	2.8	3.0	3.0	3.0	3.0	3.0
Cowpea	1.3	2.3	2.7	2.7	2.7	2.8	3.0	3.0	3.0	3.0	3.0
4th instar											
Black pecan	2.5	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Yellow pecan	2.7	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Blackmargined	2.7	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Crape myrtle	2.7	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Cowpea	2.7	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0

* No significant differences were found in this test for means in the same hour interval and for the same instar (ANOVA df = 2,15, LSD Test, $P<0.05$).

Figure Legend

Figure 1. Total number of aphids eaten at each time interval from bioassay with each instar of multicolored Asian ladybeetle, one larva per fifteen aphids of the same species, for each aphid species tested (A-first instar, B-second instar, C-third instar, D-fourth instar).

Figure 2. Total number of aphids eaten at each time interval from bioassay with each instar of multicolored Asian ladybeetle, one larva per fifteen aphids, five aphids from each of the three pecan pest aphid species (A-first instar, B-second instar, C-third instar, D-fourth instar).

Figure 3. Total number of aphids eaten at each time interval from bioassay with each instar of multicolored Asian ladybeetle, one larva per fifteen aphids, three aphids from each of the five aphid species tested (A-first instar, B-second instar, C-third instar, D-fourth instar).

Figure 1

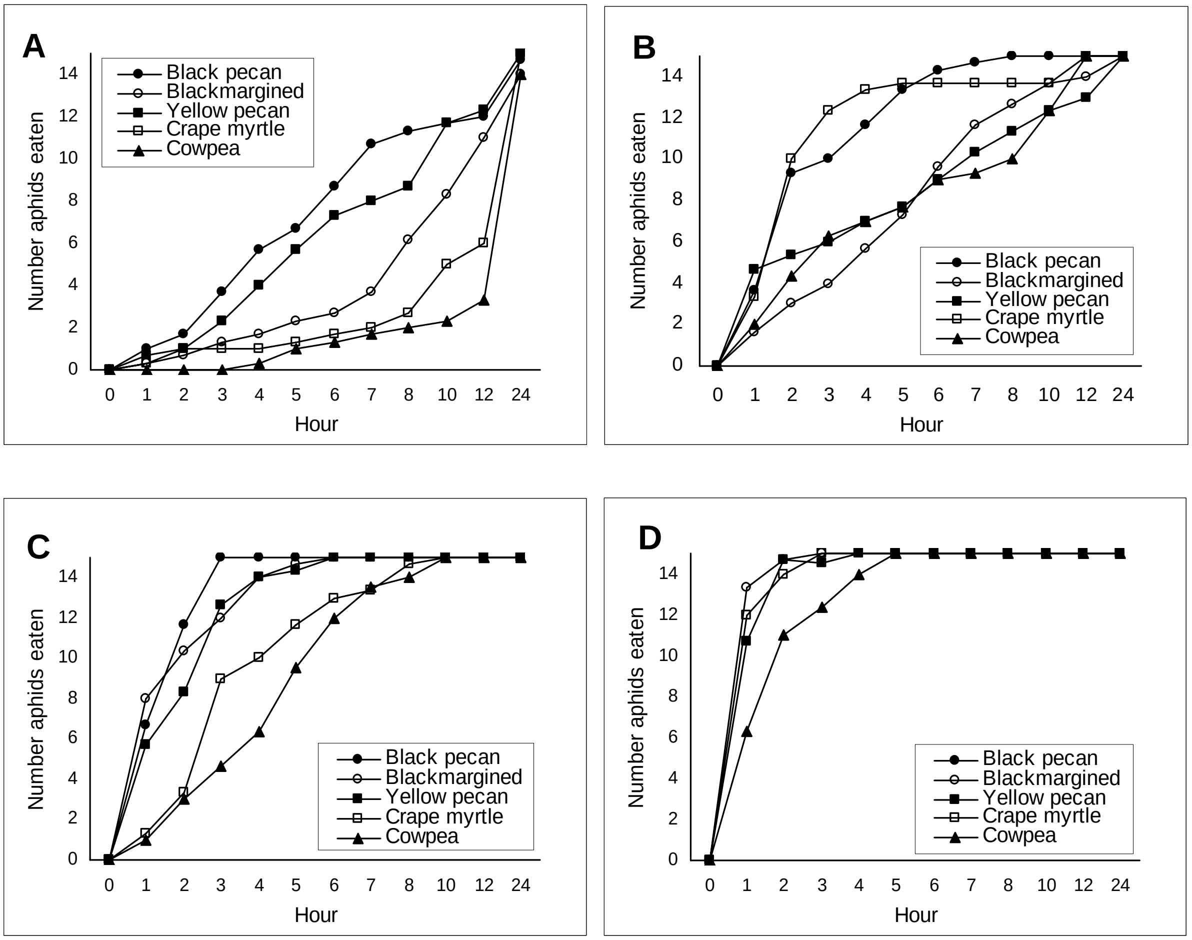

A
Black pecan
Blackmargined
Yellow pecan
Crape myrtle
Cowpea
Number aphids eaten
0
2
4
6
8
10
12
14
0 1 2 3 4 5 6 7 8 10 12 24
Hour
B
Black pecan
Blackmargined
Yellow pecan
Crape myrtle
Cowpea
Number aphids eaten
0
2
4
6
8
10
12
14
0 1 2 3 4 5 6 7 8 10 12 24
Hour
C
Black pecan
Blackmargined
Yellow pecan
Crape myrtle
Cowpea
Number aphids eaten
0
2
4
6
8
10
12
14
0 1 2 3 4 5 6 7 8 10 12 24
Hour
D
Black pecan
Blackmargined
Yellow pecan
Crape myrtle
Cowpea
Number aphids eaten
0
2
4
6
8
10
12
14
0 1 2 3 4 5 6 7 8 10 12 24
Hour

Figure 2

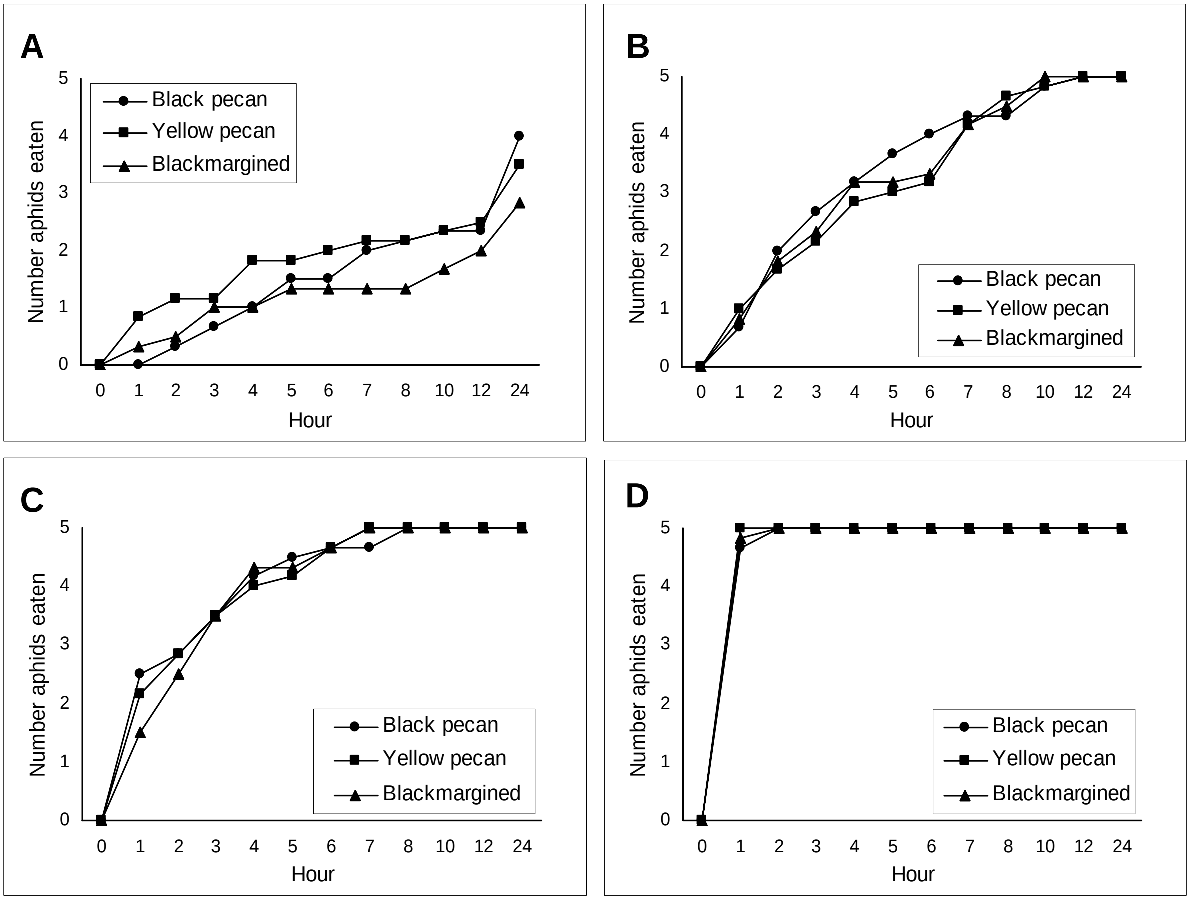
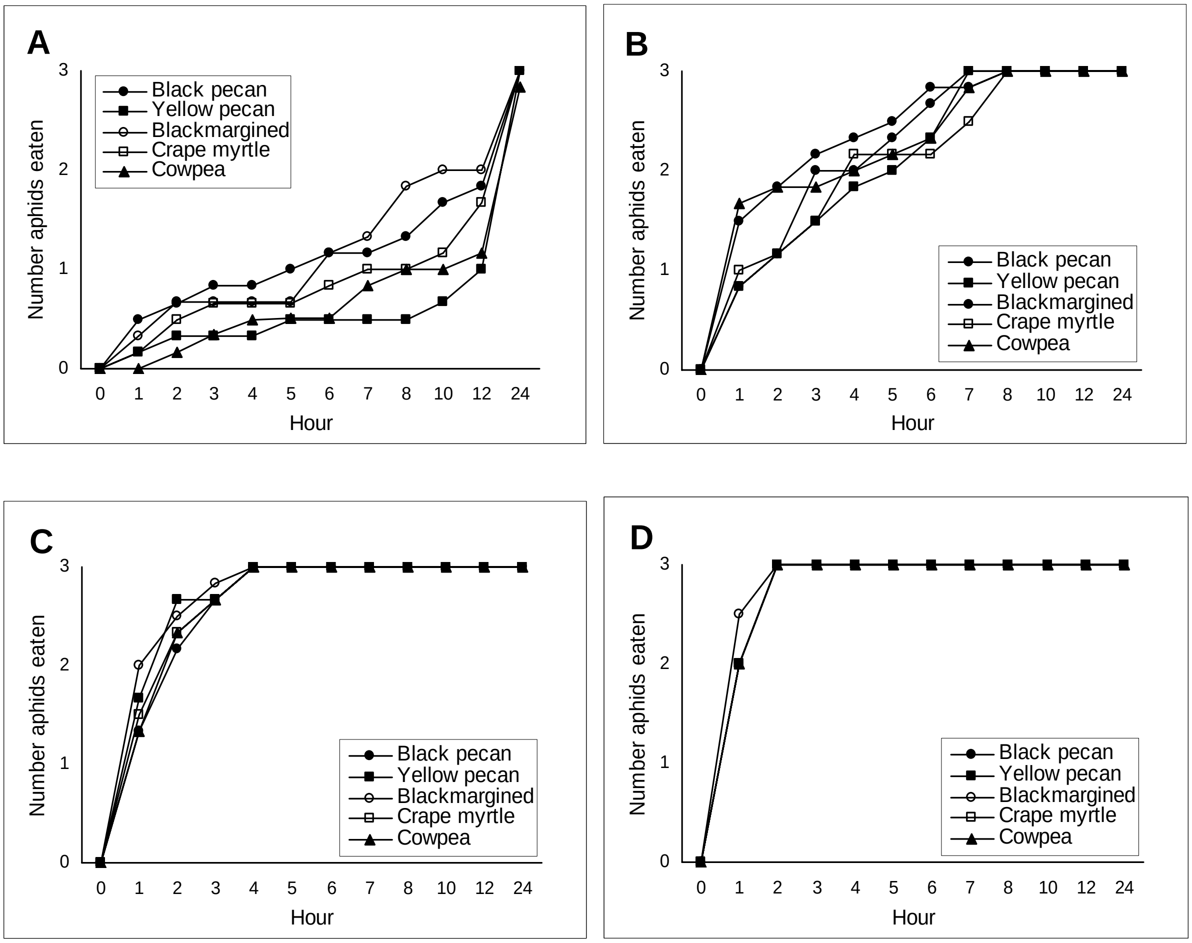

A
B
C
D
Number aphids eaten
Hour
Black pecan
Yellow pecan
Blackmargined
0
1
2
3
4
5
0 1 2 3 4 5 6 7 8 10 12 24

Figure 3


A
B
C
D
Number aphids eaten
Hour
Black pecan
Yellow pecan
Blackmargined
Crape myrtle
Cowpea
0
1
2
3
0 1 2 3 4 5 6 7 8 10 12 24

CHAPTER 3

SOIL ENHANCEMENT AND INSECT DYNAMICS WITH ALTERNATIVE UNDERSTORY MANAGEMENT IN PECAN ORCHARDS[1]

[1] Williamson, J.R., and J.D. Dutcher. To be submitted to *Journal of Sustainable Agriculture.*

ABSTRACT: Leguminous groundcovers and insectary plants were compared to the conventional mowed sod covers in the understory of pecan (*Caryae illinoinensis* (Wangenheim) K. Koch) orchards. Crimson clover (*Trifolium incarnatum* L.)/hairy vetch (*Vicia villosa* Roth), sesbania (*Sesbania exalta* (Raf.))/hairy indigo (*Indigofera hirsute* L.), buckwheat (*Fagopyrum sagittatum* Gilib), crape myrtle (*Lagerstroemia indica* L.), and sod were evaluated for contribution to pecan leaf nitrogen, soil organic matter, soil compaction, and population dynamics with the pecan aphids, coccinellid beetles, and parasitized pecan aphids. The legume covers improved pecan leaf nitrogen and soil organic matter in the first sampling period. But results became highly variable in the following sampling periods, mostly due to competition between pecan trees and covers for water and soil nutrients. Soil compaction results were highly variable in both seasons. Insect dynamics were highly variable both seasons also. Pecan aphid numbers were highly affected by precipitation, and this affected numbers of coccinellids and parasitized aphids. In summary, results were highly variable, mostly insignificant, and inconclusive for all understory treatments in this two year study, for both the soil enhancement and insect dynamics study. This study covered the initial two years of a pecan orchard transitioning from conventional mowed sod to diverse understory plantings. We believe that study beyond this transitional stage would yield more favorable results.

Key words: legume groundcovers, insectary plants, soils, biological control, pecan aphids

Legume and legume-grass mixtures were commonly used as cover or green manure crops under orchard trees before the development of inexpensive synthetic fertilizers and pesticides in the 1940's and 1950's (Tedders 1983). These covers enhanced soils and biological control by adding organic matter (Allison 1973), adding nitrogen and other plant nutrients (Sullivan 2003), improving soil structure (Elliott et al 1987), and providing habitat and alternate prey for beneficial insects (Altieri and Letourneau 1982, Bugg and Dutcher 1989, Bugg et al 1990, Bugg et al 1991a). Orchard floor covers should not be used indiscriminately, however, because they may compete with crop plants for water and nutrients (Sullivan 2003), interfere with harvesting, harbor pest insects (Bugg et al 1990), and draw beneficial insects out of trees to alternate prey within the covers (Bugg and Dutcher 1989). With increasing costs of fertilizers and environmental concerns over pesticide use, orchard floor covers are once again being evaluated to assess their contributions to soil and insect pest problems.

Depending on climate, leguminous groundcovers fix between 40 and 200 pounds of nitrogen per acre in cropping systems (Sullivan 2003). Pecan (*Caryae illinoinensis* (Wangenheim) K. Koch) orchards need 100-150 pounds of nitrogen per acre to maintain healthy, productive trees (Diver and Ames 2000). A cool season mixture of crimson clover/hairy vetch (*Trifolium incarnatum* L./*Vicia villosa* Roth) supplied 90-142 pounds of nitrogen per acre in an Oklahoma pecan orchard (Smith et al 1996). Other cool season covers, and warm season covers such as sesbania (*Sesbania exalta* (Raf).) and hairy indigo (*Indigofera hirsute* L.), also add nitrogen to soils (Bugg et al 1991b). However, cool season covers are more desirable in pecan. They peak before the pecan growing season, eliminating most problems of competition for water and nutrients. And they senesce when pest insects are building up in pecan trees, drawing beneficials up into trees (Bugg et al 1991b).

Yellow pecan aphid (*Monelliopsis pecanis* (Bissell)), blackmargined aphid (*Monellia caryella* (Fitch)), and black pecan aphid (*Melanocallis caryaefoliae* (Davis)) are foliar-feeding economic pests of pecan (Payne et al 1979). Feeding by pecan aphids depletes leaf carbohydrates and proteins (Mizell and Schiffhauer 1990), and reduces leaf chlorophyll (Wood and Tedders 1982, Tedders et al 1982, Wood et al 1987) and net photosynthesis (Wood et al 1985). Heavy feeding causes premature defoliation (Tedders 1978), decreases tree vigor (Dutcher 1985), and reduces yield (Dutcher et al 1984, Tedders and Wood 1985). Heavy reliance upon synthetic pesticides for control of pecan aphids has resulted in development of insecticidal resistance (Dutcher and Htay 1985), outbreaks of secondary pests (Ball 1981), and resurgence of aphids and mites following destruction of the natural enemy complex (Dutcher 1983). Biological control is a viable option since pecan aphid complex species do not transmit pernicious diseases and the trees can withstand some aphid feeding damage (Dutcher 2004). Entomologists conducted experiments in Georgia pecan orchards with cool season (Bugg et al 1991a, Bugg and Dutcher 1993) and warm season (Bugg and Dutcher 1989) covers, and found that the covers provided alternate prey for predators and parasitoids of pecan aphids. However, results were variable for biological control in pecan trees, with little measurable effect found from the covers (Dutcher 2004). Mizell and Schiffhauer (1987) found crape myrtle (*Lagerstroemia indica* L.) to harbor large numbers of crape myrtle aphid (*Tinocallis kahawaluokalani* (Kirkaldy)) prior to peaks of pecan aphids, which may help draw aphidophaga into pecan orchards at an optimal time. This would make crape myrtle an ideal understory insectary plant, but further research was not conducted.

Since these studies were conducted, the multicolored Asian lady beetle (*Harmonia axyridis* Pallas) has been successfully introduced and established into the pecan production region of the southeastern United States and is now considered the most effective predator of pecan aphids (Quattro 1995). Therefore, we sought to re-initiate experiments with these alternative understory plants and this beneficial, with hopes for more successful results of biological control, and to further document changes to pecan soils. Working with the philosophy of Integrated Fruit Production (Boller et al 2004), we sought to combine soil enhancement and biological control, as the two disciplines are interlinked when using leguminous groundcovers.

Methods and Materials

Study site. The study was conducted in an experimental pecan orchard in Tift county, part of the Ponder Farm unit of the University of Georgia research farms in south Georgia. Drainage within the orchard varies from well to poor, but all sampling took place in well-drained, fine-loamy Tifton (Plinthic: Paleadults) soil. Most trees were either 'Stuart' or 'Desirable' cultivars, 20-25 years old. Rows of trees were spaced 12.2m apart (5.5m tree rows plus 6.7m traffic rows). Tree rows were kept free of understory vegetation with glyphosate herbicide. The standard orchard floor cover in the vegetated traffic rows consisted of a mixed Bermuda-Johnson grass sod, mowed periodically to remain at 5-15cm height. Experimental treatments for the 2005 season consisted of the standard mowed sod, clover/vetch covers drilled into sod, clover/vetch to buckwheat drilled into sod, and a clover/vetch to buckwheat to sesbania/indigo cover sequence planted into sod. Additionally, four 5-gallon crape myrtle shrubs were planted in each sod and clover/vetch to sod plot, spaced evenly in tree rows between trees. This gave a total of 18 plots (three replications in each of six groundcover treatments). Experimental treatments for 2006 were similar *sans* buckwheat and planting of four 5-gallon crape myrtle shrubs in half of the clover/vetch to sesbania/indigo to sod treatments. Each plot consisted of three pecan trees within a tree row. Plots were separated from each other by at least one pecan tree within the row and a traffic row on either side.

Before planting cover crops, sod strips were mowed to about 3cm height. Legume seed was inoculated with Nitragin AB® (EMD Crop BioScience, Brookfield, WI), then planted with a drill planter. A mixture of 'Dixie' crimson clover and hairy vetch was planted in early winter of 2004 and 2005, shortly after pecan harvest, for maximum growth in late winter and early spring of the following season. These cool season covers were mowed as late in the spring as possible, when the hairy vetch began to senesce. For transition covers, a mixture of sesbania and hairy indigo was planted in late spring of each season, for maximum growth in late summer, then mowed shortly before the fall harvest. In 2005, buckwheat was planted between clover/vetch and sesbania/indigo covers, and between clover/vetch and sod, where indicated. Mowing of experimental covers was done with a sickle bar mower, with plant residue remaining on the soil surface. Seeding rate was 13.4kg/ha for crimson clover, hairy vetch, hemp sesbania, and hairy indigo, and 30kg/ha for buckwheat. Trees had 1.1kg/ha of 10-10-10 fertilizer broadcasted on each side in spring 2005 and 2006. No supplemental water was provided to pecan trees or groundcovers during this experiment.

Soil study. Pecan leaf samples (middle leaflet pair from the middle leaf on current season's growth) were collected in July both seasons, from 100 leaves in each plot. Samples were dried, ground to pass a 20-mesh screen, and analyzed for percent nitrogen using Inductively Coupled Plasma-Emission Spectrometry (ICP). Soil samples were collected with a soil probe in February and July of both seasons, with 6 samples per treatment at 0 to 5cm, 5 to 10cm, and 10 to 15cm depths. Samples were weighed, dried in an oven for 3h at 308°C, and weighed again to determine percent soil organic matter. Soil compaction (kg/cm^2) was measured with a soil penetrometer in July both seasons, with nine samples per treatment.

Insect Study. Three leaf shoots were randomly picked from the lower 4 meters of one pecan tree in each plot for numbers of yellow pecan aphids, blackmargined aphids, black pecan aphids, coccinellids, and parasitized aphids. Adults and nymphs of the yellow pecan aphid and blackmargined aphid were grouped together as the yellow aphid complex. Adults and nymphs of the black pecan aphid were grouped together as black pecan aphids. Adult and immature instars of all coccinellid species were grouped together as coccinellids, as well as egg masses (each egg mass was counted as one coccinellid). Aphid mummies were classified as parasitized aphids. Counts occurred weekly from leaf break until nut harvest.

Statistical analysis. Means and standard error of the means were calculated for percent leaf nitrogen, percent organic matter, soil compaction, and numbers of the yellow aphid complex, black pecan aphids, coccinellids, and parasitized aphids per shoot for each groundcover treatment. In addition, analysis of variance (ANOVA, SAS Version 9.1, 2007) was used to determine least significant differences (Fisher's LSD test) between leaf nitrogen, organic matter, soil compaction, and numbers of the yellow aphid complex, black pecan aphids, coccinellids, and parasitized aphids in each groundcover treatment.

Results and Discussion

Soil study. Leaf nitrogen results were favorable for groundcovers, even though not statistically significant, in our first sample from July 2005 (Figure 1). This trend did not continue for the following samples, however. We believe competition between trees and covers in our non-irrigated orchard was the major factor affecting results with these latter samples.

Pecan leaf nitrogen was generally lower with clover/vetch covers than with sod only, in December 2005. This was during the growth stage of clover and vetch, when it was a sink for soil nitrogen. But this was not critical, as it was near the dormant stage of pecan. Ideally, these and other cool season covers decompose in late spring, becoming a source of nitrogen in pecan's growing season, as initially occurred in our July 2005 sample. Smith et al (1996) found leaf nitrogen to stay above the minimal sufficiency level (2.25%) in Oklahoma pecan orchards when using either crimson clover/vetch or red clover/white clover covers. Our samples were often below the 2.25% minimal sufficiency level (Table 1). But our covers were also lacking in stand density, relative to the Oklahoma study.

In July 2006, our study found leaf nitrogen to be lower where the cool season covers were used, and lowest in treatments combining cool and warm season covers (Figure 1). These warm season covers were in their growth stage and competing with pecan trees for nitrogen, during a critical stage for pecan. Drought was a problem in 2006 (45.1cm precipitation versus 79.6cm in 2005, from March 1 to October 31, AEMN 2008), so these covers were likely competing with pecan trees for water as well. This supports the presumption by Bugg et al (1991b) of warm season covers being detrimental to pecan due to competition for soil water and nutrients. The sesbania/indigo covers did not establish well in 2006, so they could not be an optimal source of nitrogen for pecan in the following dormant season (December 2006). We believed this and the drought to be the major causes for high variability in the latter two samples.

Our organic matter evaluation showed a favorable response in treatments using cool season and cool to warm season covers, during the initial sampling period made in February 2005 (Figure 2), with significant differences at 0-5cm depth (LSD=6.96) (Table 2). As with leaf nitrogen, this trend did not continue for the remaining samples. Differences were significant at

0-5cm (LSD=1.31) and 5-10cm (LSD=0.93) depths in the July 2005 sample, but highly variable. The drought and weak stands in 2006 were probably responsible for minimal effects with organic matter as well. Sod was mowed weekly in 2005 and biweekly in 2006. The continual mowing added organic matter, which negated short term benefits from the experimental covers.

Soil compaction results were highly variable and difficult to interpret in both seasons (Figure 3). Significant differences were found at the 5-10cm (LSD=5.11) and 20-25cm (LSD=7.88) depths in 2005 and 20-25cm (LSD=6.27) depths in 2006 (Table 3), but variability among treatments prevents any interpretation. Compaction peaked at the 20-25cm depth for all treatments both seasons, indicative of the fragipan layer. Neither buckwheat nor crape myrtle shrubs were shown to affect soil results.

Our soil study results aren't conclusively for or against the use of legume covers with pecan, although potential for warm season covers appears doubtful. Water would have been less limiting, and results might have been more favorable, with an effective irrigation system. Our work shows that comparisons of orchard floor covers will require longer evaluation periods- it is difficult to get short term results for a long term management solution. Generally, 40-60% of the nitrogen contained in a legume cover becomes available to a following crop, with the remainder released slowly over several years (Sullivan 2003). Accumulation of organic matter over time builds a healthy soil, which may help keep harmful nematodes and fungi under control (Yancey 1994). Switching to a whole-farm focus, using sustainable options such as legume covers, requires several years to implement. This study covered the initial two years of a pecan orchard transitioning from conventional mowed sod to diverse understory plantings. Impacts on nitrogen, organic matter, and soil compaction cannot be accurately accessed within a 2 year time frame. We believe that study beyond this transitional stage would yield more favorable results.

And we recommend using irrigation to minimize variability in dry seasons. Further study is needed, to provide more sustainable solutions for pecan growers.

Insect study. These results were also highly variable in both seasons (Figures 4 and 5), perhaps more so than with soil enhancement. There were significant differences with the yellow aphid complex on May 24 (LSD=3.38) and June 12 (LSD=4.79) in 2006 (Table 5), with coccinellids on June 1 (LSD=0.39) in 2005 (Table 8), and parasitized aphids on August 18 (LSD=11.23) in 2005 (Table 10). Both the yellow aphid complex and coccinellids were at very low levels. The parasitized aphids were at higher levels, between 29.67 and 3.33 parasitized aphids per shoot. But even these results showed too much variability for any interpretation. Therefore, our insect study results are also inconclusive for showing a benefit or hindrance with the use of legume covers.

Precipitation differences, 79.6cm in 2005 and 45.1cm in 2006 (AEMN 2008), for the March 1 to October 31 season, likely contributed to the variability of results. We feel an irrigation system would minimize variability of cover crop performance in dry seasons. Numbers of the yellow aphid complex and black pecan aphids correspond well with more succulent foliage in the wet year (2005) and less in the dry year (2006). Coccinellid beetles and parasitized aphid numbers followed trends similar to pecan aphid populations. Regardless of buckwheat's potential as an insectary plant (Bugg and Ellis 1990), we found no benefit of its use as a groundcover in pecan. Despite the speculation of crape myrtle to enhance biological control in pecan (Mizell and Schiffhauer 1987), we found no measurable effect. But we used transplanted 5-gallon shrubs under pecan trees about 15 meters tall. Mature crape myrtle would have more canopy volume and would be more likely to have a meaningful impact.

Despite the perceived potential of understory covers to enhance biological control in tree fruit and nut crops, our search of the literature could not find any evidence in a scientific study. Trees provide vertical strata that are more difficult to sample than most relatively horizontal crops. This is most pronounced in pecan, one of the largest crop plants. Mature pecan trees range from 30-50 meters in height (our trees were about 15 meters in height). Yet sampling rarely occurs above 4 meters. Cherry pickers are sometimes available and used for sampling above 4 meters, but are restricted from the interior and uppermost strata. This leaves a very large area and volume that cannot be sampled. More effective sampling methods are needed for fruit and nut crops, especially pecan. We believe a better sampling method would show more benefit of understory covers for biological control in pecan. Again, we recommend further study with orchard floor covers to provide more sustainable solutions for pecan growers.

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References

AEMN. 2008. Georgia Automated Environmental Monitoring Network. Complete URL address: <www.georgiaweather.net>.

Allison, F.E. 1973. Soil Organic Matter and Its Role in Crop Production. Elsevier Publishing, Amsterdam. 637 pp.

Altieri, M.A. and D.K. Letourneau. 1982. Vegetation management and biological control in agroecosystems. Crop Protection 1: 405-430.

Ball, J.C. 1981. Pesticide-induced differences in relative abundance of mites on pecan. Journal of Economic Entomology 74: 425-427.

Boller, E.F., J. Avilla, and E. Joerg. 2004. Integrated production principles and technical guidelines. International Organization of Biological Control (IOBC) Bulletin 27: 54.

Bugg, R.L. and J.D. Dutcher. 1993. Sesbania exaltata (Rafinesque-Schmaltz) Cory (Fabaceae) as a warm-season cover crop in pecan orchards: effects on aphidophagous coccinellidae and pecan aphids. Biological Agriculture and Horticulture 9: 215-229.

Bugg, R.L. and J.D. Dutcher. 1989. Warm-season cover crops for pecan orchards: Horticultural and entomological implications. Biological Agriculture and Horticulture 6: 123-148.

Bugg, R.L., and R.T. Ellis. 1990. Insects associated with cover crops in Massachusetts. Biological Agriculture and Horticulture 7: 47-68.

Bugg, R.L., J.D. Dutcher, and P.J. McNeill. 1991a. Cool-season cover crops in the pecan orchard understory: Effects on Coccinellidae (Coleoptera) and pecan aphids (Homoptera: Aphididae). Biological Control 1: 8-15.

Bugg, R.L., M. Sarrantonio, J.D. Dutcher, and S.C. Phatak. 1991b. Understory cover crops in pecan orchards: Possible management systems. American Journal of Alternative Agriculture 6: 50-62.

Bugg, R.L., S.C. Phatak, and J.D. Dutcher. 1990. Insects associated with cool-season cover crops in southern Georgia: Implications for biological control in truck-farm and pecan agroecosystems. Biological Agriculture and Horticulture 7:17-45.

Diver, S. and G. Ames. 2000. Sustainable pecan production. Appropriate Technology Transer for Rural Areas (ATTRA) Publication #IP077.

Dutcher, J.D. 2004. Habitat manipulation for enhancement of aphidophagous insects in pecan orchards. International Journal of Ecology and Environmental Sciences 30: 13-22.

Dutcher, J.D. 1985. Impact of late season aphid control on pecan tree vigor parameters. Journal of Entomological Science 20: 55-61.

Dutcher, J.D. 1983. Carbaryl and aphid resurgence in pecan orchards. Journal of the Georgia Entomological Society 18: 492-495.

Dutcher, J.D. and T. Htay. 1985. Resurgence and insecticide resistance problems in pecan aphid management. University of Georgia Experiment Station Publication #38.

Dutcher, J.D., R.E. Worley, J.W. Danniel, R.B. Moss, and K.F. Harrison. 1984. Impact of six insecticide-based arthropod pest management strategies on pecan yield, quality, and return bloom under four irrigation/soil fertility regimes. Environmental Entomology 13: 1644-1653.

Elliott, L.F., R.I. Papendick, and D.F. Bezdicek. 1987. Cropping practices using legumes with conservation tillage and soil benefits, pp. 81-89. In J.F. Power [ed.]. The Role of Legumes in Conservation Tillage Systems. Soil Conservation Society of America, Ankeny, Iowa.

Mizell, R.F. and D.E. Schiffhauer. 1990. Effects of pesticides on pecan aphid predators *Chrysoperla rufilabris* (Neuroptera: Chrysopidae), *Hippodamia convergens*, *Cycloneda sanguinea* (L.), *Olla v-nigrum* (Coleoptera: Coccinellidae), and *Aphelinus perpallidus* (Hymenoptera: Encyrtidae). Journal of Economic Entomology 83: 1806-1812.

Mizell, R.F. and D.E. Schiffhauer. 1987. Seasonal abundance of the crapemyrtle aphid, *Sarucallis kahawaluokalani*, in relation to the pecan aphids, *Monellia caryella* and *Monelliopsis pecanis* and their common predators. Entomophaga 32: 511-520.

Payne, J.A., H.L. Maltrom, and G.E. KenKnight. 1979. Insect pests and diseases of pecan. U.S.D.A. Agriculture Reference Manual S-5, 43 pp.

Quattro, J.R. 1995. Gotcha! Tiny lady beetles have big biocontrol potential. Agricultural Research 43: 4-8.

Smith, M.W., A. Shiferaw, and N.R. Rice. 1996. Legume cover crops as a nitrogen source for pecan. Journal of Plant Nutrition 19: 1117-1130.

Sullivan, P.G. 2003. Overview of cover crops and green manures. Appropriate Technology Transfer for Rural Areas (ATTRA) Publication #IP024.

Tedders, W.L. 1983. Insect management in deciduous orchard ecosystems: Habitat manipulation. Environmental Management 7:29-34.

Tedders, W.L. 1978. Important biological and morphological characteristics of the foliar feeding aphids of pecan. U.S.D.A. Technical Bulletin 1579.

Tedders, W.L. and B.W. Wood. 1985. Estimate of the influence of feeding by *Monelliopsis pecanis* and *Monellia caryella* (Homoptera: Aphididae) on the fruit, foliage, carbohydrate reserves, and tree productivity of mature 'Stuart' pecans. Journal of Economic Entomology 78: 642-646.

Tedders, W.L., B.W. Wood, and J.W. Snow. 1982. Effects of feeding by *Monelliopsis nigropunctata*, *Monellia caryella*, and *Melanocallis caryaefoliae* on growth of pecan seedlings in the greenhouse. Journal of Economic Entomology 75: 287-291.

Wood, B.W. and W.L. Tedders. 1982. Effects of an infestation of blackmargined aphid on carbohydrates in mature 'Stuart' pecan. HortScience 17: 236-238.

Wood, B.W, W.L. Tedders, and J.D. Dutcher. 1987. Energy drain by three pecan aphid species (Homoptera: Aphididae) and their influence on in-shell pecan production. Environmental Entomology 16: 1045-1046.

Wood, B.W, W.L. Tedders, and J.M. Thompson. 1985. Feeding influence of three pecan aphid species on carbon exchange and phloem integrity of seedling pecan foliage. Journal of American Horticultural Science 110: 393-397.

Yancey, C. 1994. Covers challenge cotton chemicals. The New Farm Newsletter, February: 20-23.

Figure 1. Nitrogen concentration (percent) in leaves of pecan trees bordered by six different groundcover treatments in 2005 and 2006. Treatments were 1=sod, 2=sod+crape myrtle, 3=clover/vetch to sod, 4=clover/vetch to sod+crape myrtle, 5=clover/vetch to buckwheat to sod (2005) or clover/vetch to sesbania/indigo to sod (2006), and 6=clover/vetch to buckwheat to sesbania/indigo to sod (2005) or clover/vetch to sesbania/indigo to sod+crape myrtle (2006).

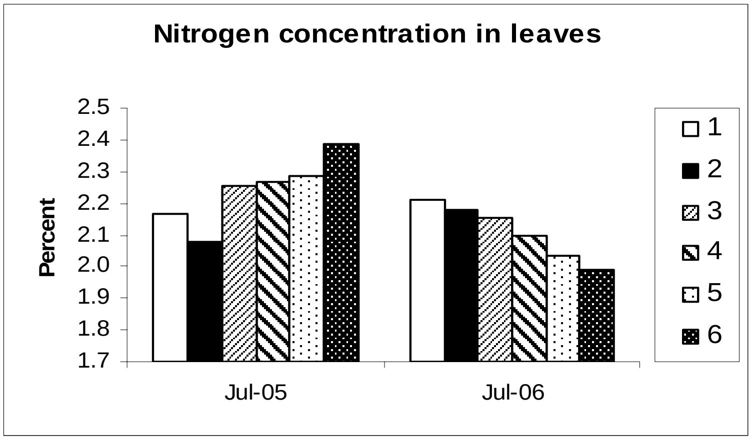


Figure 2. Organic matter content (percent) in soils with six different groundcover treatments at three different depths in 2005 and 2006. Treatments were 1=sod, 2=sod+crape myrtle, 3=clover/vetch to sod, 4=clover/vetch to sod+crape myrtle, 5=clover/vetch to buckwheat to sod (2005) or clover/vetch to sesbania/indigo to sod (2006), and 6=clover/vetch to buckwheat to sesbania/indigo to sod (2005) or clover/vetch to sesbania/indigo to sod+crape myrtle (2006). * indicates where significant differences were found between treatments (ANOVA, LSD test, $P<0.05$).

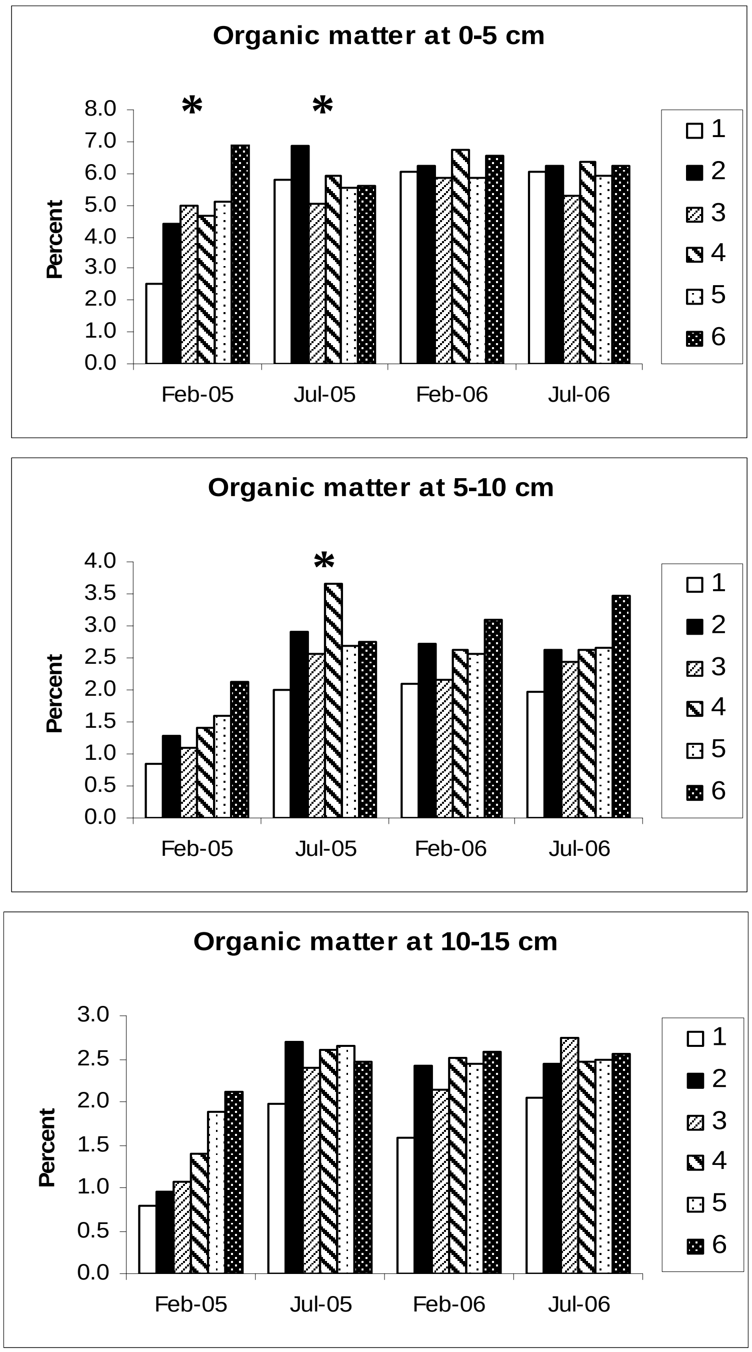
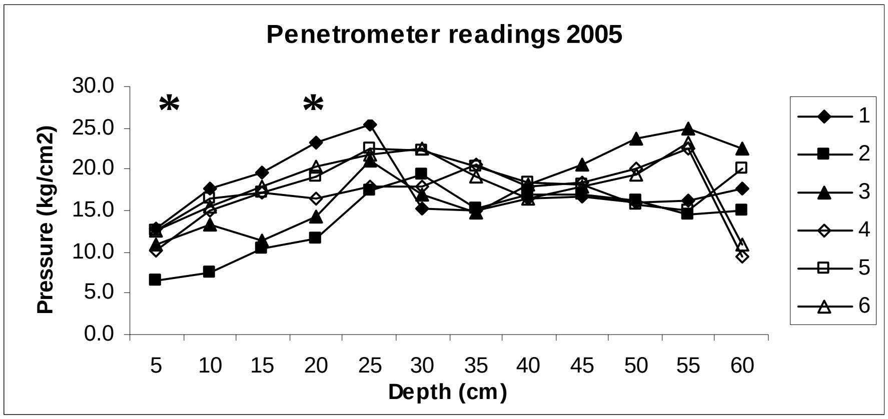


Figure 3. Soil compaction measurements (kg/cm^2) in soils with six different groundcover treatments at various depths (0-60 cm) in 2005 and 2006. Treatments were 1=sod, 2=sod+crape myrtle, 3=clover/vetch to sod, 4=clover/vetch to sod+crape myrtle, 5=clover/vetch to buckwheat to sod (2005) or clover/vetch to sesbania/indigo to sod (2006), and 6=clover/vetch to buckwheat to sesbania/indigo to sod (2005) or clover/vetch to sesbania/indigo to sod+crape myrtle (2006). * indicates where significant differences were found between treatments (ANOVA, LSD test, $P<0.05$).



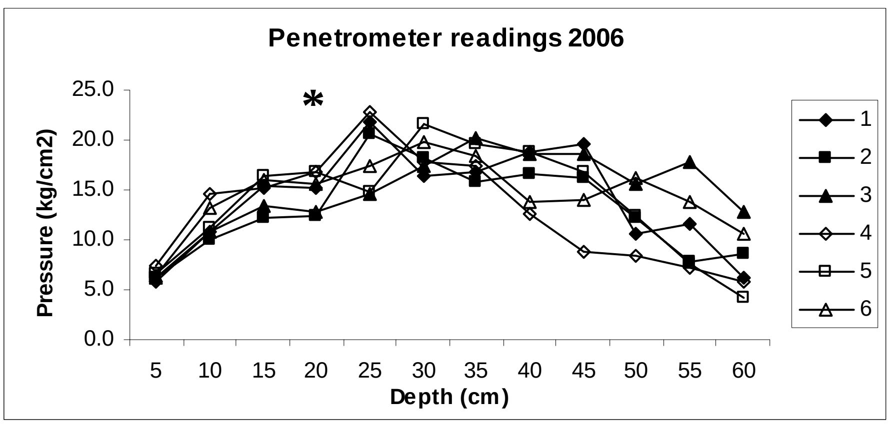


Figure 4. Number of aphids/shoot and coccinellid beetles/shoot in pecan trees bordered by six different groundcover treatments in 2005. Treatments were 1=sod, 2=sod+crape myrtle, 3=clover/vetch to sod, 4=clover/vetch to sod+crape myrtle, 5=clover/vetch to buckwheat to sod, and 6= clover/vetch to buckwheat to sesbania/indigo to sod.
* indicates where significant differences were found between treatments (ANOVA, LSD test, P<0.05).

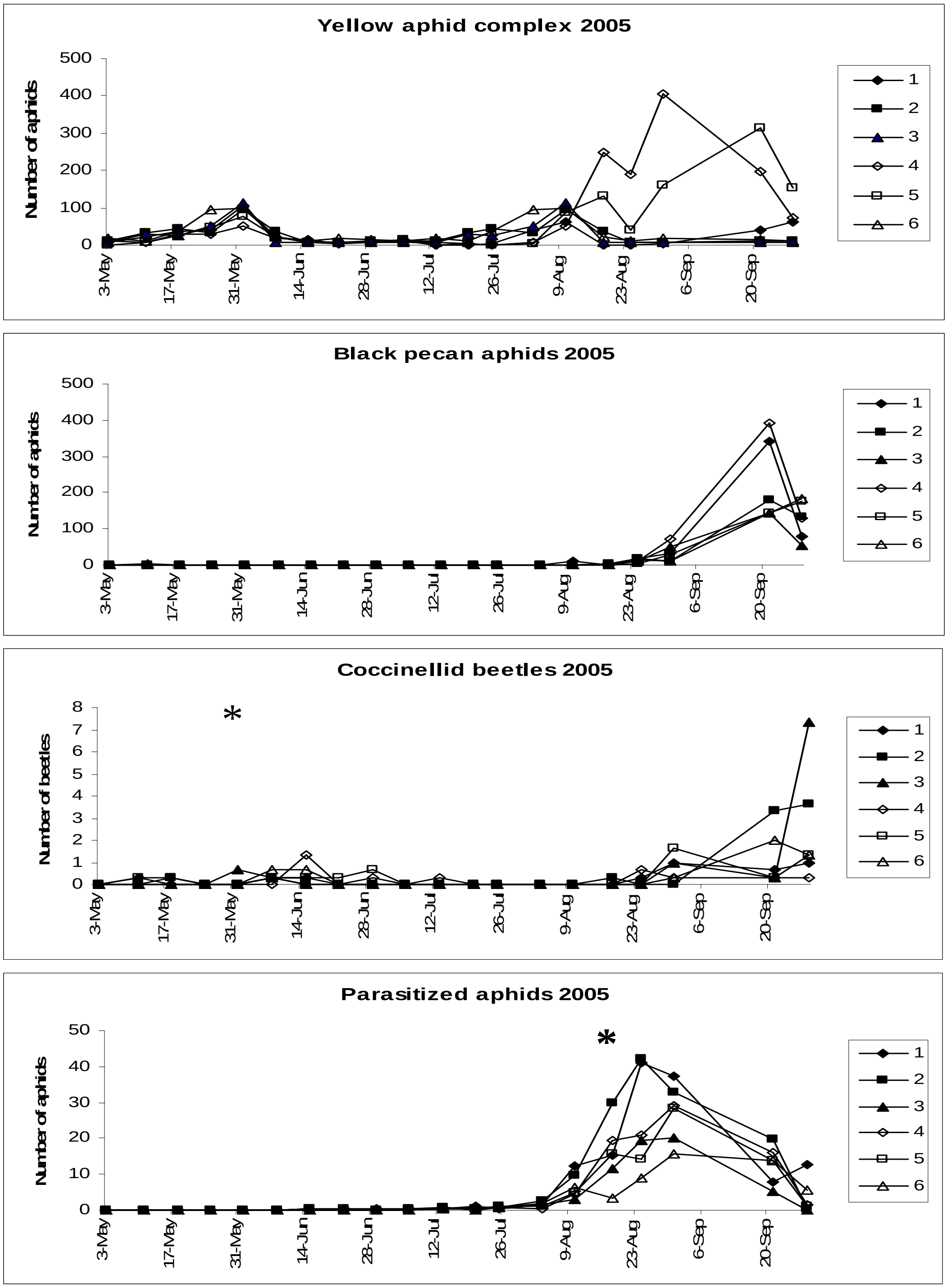


Figure 5. Number of aphids/shoot and coccinellid beetles/shoot in pecan trees bordered by six different groundcover treatments in 2006. Treatments were 1=sod, 2=sod+crape myrtle, 3=clover/vetch to sod, 4=clover/vetch to sod+crape myrtle, 5=clover/vetch to sesbania/indigo to sod, 6=clover/vetch to sesbania/indigo to sod+crape myrtle.
* indicates where significant differences were found between treatments (ANOVA, LSD test, P<0.05).

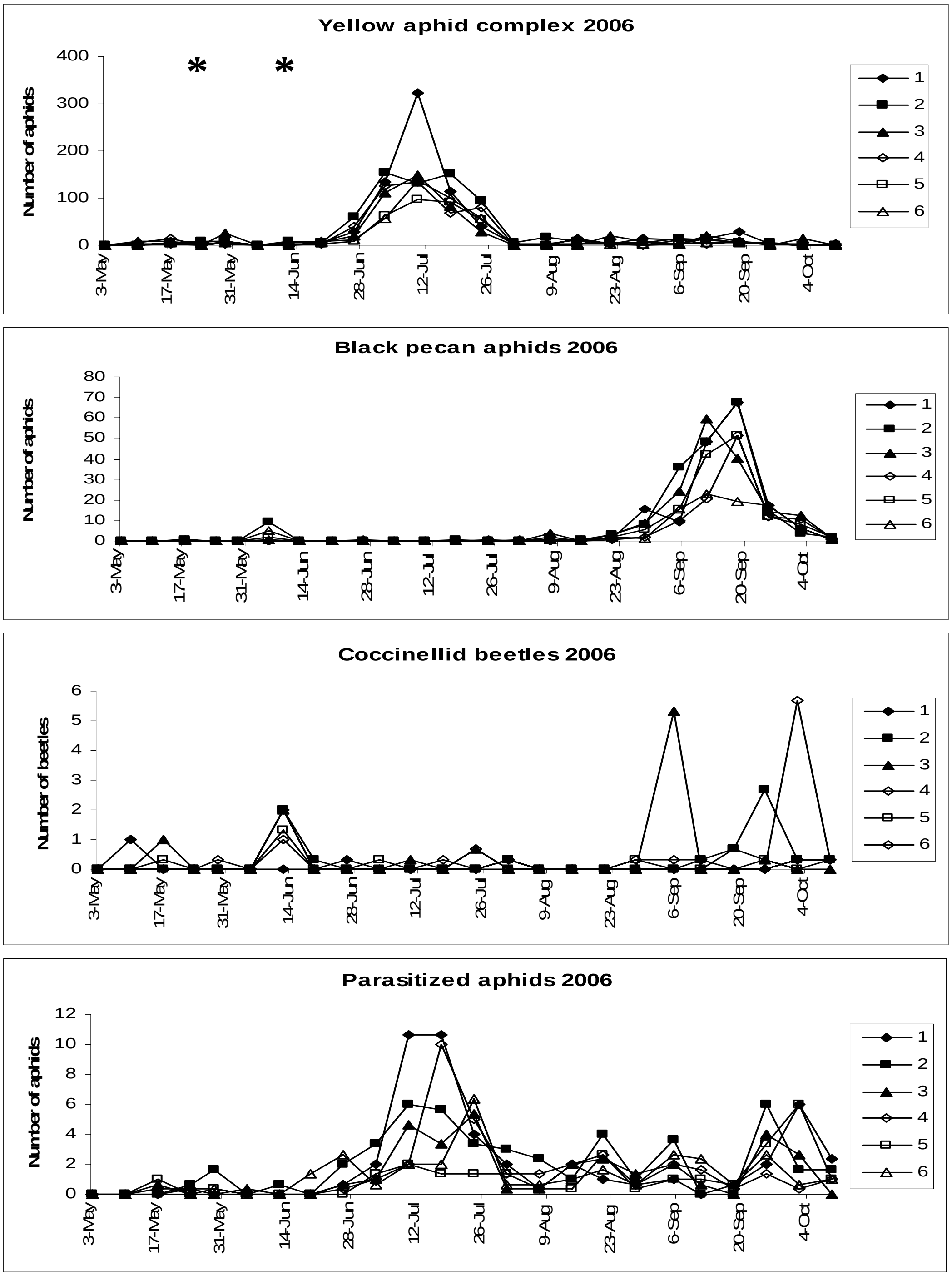


Table 1. Means (AVG) and standard deviation of the means (STD) for nitrogen concentration (percent) in leaves of pecan trees bordered by six different groundcover treatments[1] in 2005 and 2006.

	Groundcover Treatments											
	1		2		3		4		5		6	
Date	AVG	STD	AVG	STD	AVG	STD	AVG	STD	AVG	STD	AVG	STD
Jul-05	2.17	0.12	2.08	0.18	2.26	0.08	2.27	0.26	2.29	0.11	2.39	0.55
Jul-06	2.21	0.04	2.18	0.16	2.16	0.17	2.10	0.38	2.03	0.04	1.99	0.15

1. Treatments were 1=sod, 2=sod+crape myrtle, 3=clover/vetch to sod, 4=clover/vetch to sod+crape myrtle, 5=clover/vetch to buckwheat to sod (2005) or clover/vetch to sesbania/indigo to sod (2006), and 6=clover/vetch to buckwheat to sesbania/indigo to sod (2005) or clover/vetch to sesbania/indigo to sod+crape myrtle (2006).

Table 2. Means (AVG) and standard deviation of the means (STD) for organic matter content (percent) in soils with six different groundcover treatments[1,2] at three different depths in 2005 and 2006.

		Groundcover Treatments											
		1		2		3		4		5		6	
Date	Depth	AVG	STD	AVG	STD	AVG	STD	AVG	STD	AVG	STD	AVG	STD
Feb-05	0-5 cm	2.54^{b}	1.48	4.42^{b}	1.17	4.99^{ab}	1.54	4.68^{ab}	1.73	5.09^{ab}	2.30	6.96^{a}	3.27
	5-10 cm	0.85	0.36	1.27	0.32	1.09	0.21	1.40	0.41	1.60	0.32	2.11	0.47
	10-15 cm	0.80	0.70	0.95	0.70	1.07	0.19	1.40	0.37	1.89	0.50	2.11	0.43
Jul-05	0-5 cm	5.82^{ab}	0.87	6.85^{a}	1.15	5.03^{b}	1.93	5.9^{ab}	0.82	5.53^{b}	0.80	5.59^{ab}	0.57
	5-10 cm	2.00^{b}	0.25	2.91^{ab}	0.79	2.57^{b}	0.34	3.65^{a}	1.60	2.68^{b}	0.27	2.75^{ab}	0.47
	10-15 cm	1.98	0.46	2.70	0.90	2.39	0.33	2.61	0.48	2.65	0.56	2.47	0.42
Feb-06	0-5 cm	6.03	0.59	6.23	1.25	5.88	1.44	6.73	2.62	5.88	0.99	6.56	1.13
	5-10 cm	2.10	0.38	2.73	0.83	2.17	0.25	2.64	0.64	2.57	0.11	3.10	0.88
	10-15 cm	1.57	0.23	2.41	0.97	2.14	0.30	2.51	1.01	2.44	0.23	2.58	0.51
Jul-06	0-5 cm	6.02	1.02	6.22	1.61	5.31	0.97	6.38	0.91	5.94	1.04	6.24	0.56
	5-10 cm	1.98	0.50	2.61	0.86	2.45	0.51	2.64	0.56	2.65	0.34	3.48	1.15
	10-15 cm	2.05	0.80	2.44	1.02	2.75	1.09	2.46	0.66	2.48	0.20	2.55	0.35

1. Treatments were 1=sod, 2=sod+crape myrtle, 3=clover/vetch to sod, 4=clover/vetch to sod+crape myrtle, 5=clover/vetch to buckwheat to sod (2005) or clover/vetch to sesbania/indigo to sod (2006), and 6=clover/vetch to buckwheat to sesbania/indigo to sod (2005) or clover/vetch to sesbania/indigo to sod+crape myrtle (2006).
2. Means for treatments in the same sampling date that are labeled by different letters as superscripts show significant differences (ANOVA, LSD test, $P<0.05$).

Table 3. Means (AVG) and standard deviation of the means (STD) for soil compaction (kg/cm^2) in soils with six different groundcover treatments[1,2] at three different depths in 2005 and 2006.

		Groundcover Treatments											
		1		2		3		4		5		6	
Date	Depth	AVG	STD	AVG	STD	AVG	STD	AVG	STD	AVG	STD	AVG	STD
Jul-05	0-5 cm	12.78	3.73	6.44	3.05	11	6.82	10.11	5.37	12.67	7.52	12.56	5.08
	5-10 cm	17.56[a]	4.77	7.44[b]	2.96	13.22[ab]	7.34	15.00[ab]	6.6	16.44[ab]	6.56	15.44[ab]	5.08
	10-15 cm	19.67	4.92	10.33	4.33	11.33	6.16	17.11	5.46	17.22	8.2	17.89	6.13
	15-20 cm	23.11	7.74	11.67	5.02	14.33	6.61	16.44	4.59	19.22	9.07	20.22	6.92
	20-25 cm	25.33[a]	5.59	17.44[b]	8.28	21.11[ab]	5.37	17.89[ab]	5.78	22.56[ab]	7.8	21.89[ab]	6.55
	25-30 cm	15.33	8.47	19.44	6.09	16.89	7.29	18	6.33	22.33	9	22.44	5.66
	30-35 cm	15	8.37	15.33	5.29	14.67	6.38	20.44	6.6	20.22	7.53	19	4.06
	35-40 cm	16.44	6.6	16.89	6.13	18.22	5.29	17.94	8.47	18.44	7.5	16.33	5.77
	40-45 cm	16.67	6.75	16.89	5.18	20.44	6.88	18.39	9.83	18.22	8.24	18	3.46
	45-50 cm	16	4.12	16.11	7.99	23.78	6.26	20	9.26	15.67	7.31	19.44	5.05
	50-55 cm	16.22	4.89	14.56	8.49	24.89	7.41	22.56	7.11	15	7.25	23.11	13.35
	55-60 cm	17.78	6.82	14.89	9.23	22.5	0.71	9.33	3.21	20	8.67	10.78	6.99
Jul-06	0-5 cm	5.89	3.72	6.22	2.82	6.11	2.03	7.33	5	6.56	2.07	6.44	3.13
	5-10 cm	10.78	2.91	10	2.24	10.78	2.91	14.67	6.5	11.11	2.67	13.11	6.07
	10-15 cm	15.44	4.42	12.11	4.31	13.33	3.64	15.11	6.77	16.44	4.13	16	6.93
	15-20 cm	15.22	3.53	12.33	5.17	12.89	4.46	16.78	5.65	16.89	4.68	15.56	5.81
	20-25 cm	21.89[ab]	6.97	20.56[ab]	8.02	14.56[b]	6.5	22.89[a]	7.46	14.78[b]	6.16	17.44[ab]	5.03
	25-30 cm	16.33	10.75	18.22	5.83	17.33	7.4	17.89	13.21	21.67	8.83	19.89	6.29
	30-35 cm	16.78	10.52	15.78	8.96	20.11	6.37	17.33	12.05	19.56	11.78	18.44	8.47
	35-40 cm	18.89	10.93	16.67	9.07	18.61	8.12	12.67	12.25	18.89	11.36	13.89	9.31
	40-45 cm	19.67	11.86	16.22	9.92	18.61	9.92	8.89	9.49	16.89	11.92	14	8.67
	45-50 cm	10.67	12.91	12.11	10.15	15.67	7.85	8.44	8.89	12.33	12.45	16.22	10.03
	50-55 cm	11.67	13.95	7.89	7.39	17.89	9.18	7.11	8.91	7.67	7.45	13.78	11.2
	55-60 cm	6.11	12.19	8.67	7.19	12.78	12.14	5.78	9.2	4.11	5.34	10.67	11.31

1. Treatments were 1=sod, 2=sod+crape myrtle, 3=clover/vetch to sod, 4=clover/vetch to sod+crape myrtle, 5=clover/vetch to buckwheat to sod (2005) or clover/vetch to sesbania/indigo to sod (2006), and 6=clover/vetch to buckwheat to sesbania/indigo to sod (2005) or clover/vetch to sesbania/indigo to sod+crape myrtle (2006).
2. Means for treatments in the same sampling date that are labeled by different letters as superscripts show significant differences (ANOVA, LSD test, $P<0.05$).

Table 4. Means (AVG) and standard deviation of the means (STD) for number of aphids/shoot from the yellow aphid complex in pecan trees bordered by six different groundcover treatments[1] in 2005.

	Groundcover Treatments											
	1		2		3		4		5		6	
Date	AVG	STD	AVG	STD	AVG	STD	AVG	STD	AVG	STD	AVG	STD
3-May	7.67	8.02	11.33	9.29	6.00	5.20	12.67	15.53	1.33	2.31	16.67	14.47
11-May	23.00	18.52	33.00	10.39	27.67	31.01	7.00	6.56	8.00	11.36	12.00	7.55
18-May	38.00	35.51	42.33	36.69	26.00	10.58	29.00	6.24	25.67	22.30	36.00	30.41
25-May	41.67	2.08	31.33	8.50	52.33	28.15	28.00	11.14	48.00	30.32	94.67	45.65
1-Jun	105.67	87.36	95.67	3.21	112.33	81.86	51.67	7.64	78.33	27.06	97.67	29.26
8-Jun	22.00	5.57	36.67	24.54	8.33	7.09	19.67	17.04	23.00	11.27	21.00	21.00
15-Jun	8.33	5.13	7.33	5.77	8.67	2.52	13.33	16.44	5.67	4.51	12.67	10.97
22-Jun	4.00	3.00	6.67	6.11	5.67	3.06	3.67	2.08	6.33	7.57	19.00	23.39
29-Jun	12.67	7.37	9.67	6.03	8.33	5.69	6.67	5.86	9.00	5.00	15.33	2.08
6-Jul	11.67	6.43	12.33	11.85	7.33	4.16	14.67	6.11	13.00	7.55	11.67	9.87
13-Jul	1.33	1.15	0.33	0.58	8.00	13.00	1.00	1.73	5.67	2.89	1.00	1.00
22-Jul	0.67	0.58	1.67	2.08	5.33	9.24	3.67	4.04	2.00	1.73	0.67	0.58
25-Jul	2.33	1.15	6.67	3.21	6.00	1.73	1.33	2.31	0.67	1.15	2.67	3.79
3-Aug	38.33	42.59	47.00	56.35	11.67	8.02	7.33	3.79	4.00	1.73	18.00	15.00
10-Aug	60.33	42.44	113.33	93.63	26.00	26.91	50.33	15.63	86.00	74.84	14.00	7.94
18-Aug	46.33	28.99	187.00	120.95	86.33	76.17	248.67	286.41	132.33	115.09	47.33	13.58
24-Aug	134.00	77.54	256.67	138.24	94.33	43.11	189.67	132.20	39.33	36.50	126.00	75.35
31-Aug	285.33	378.86	150.00	251.15	195.67	319.93	403.67	350.80	162.00	136.59	99.00	124.74
21-Sep	104.33	109.29	115.00	71.02	254.00	229.29	196.67	143.54	313.00	251.08	226.67	311.15
28-Sep	18.00	26.00	26.67	41.10	6.33	8.39	73.33	64.01	154.33	98.50	50.33	69.30

1. Treatments were 1=sod, 2=sod+crape myrtle, 3=clover/vetch to sod, 4=clover/vetch to sod+crape myrtle, 5=clover/vetch to buckwheat to sod, and 6= clover/vetch to buckwheat to sesbania/indigo to sod.

Table 5. Means (AVG) and standard deviation of the means (STD) for number of aphids/shoot from the yellow aphid complex in pecan trees bordered by six different groundcover treatments[1,2] in 2006.

	Groundcover Treatments											
	1		2		3		4		5		6	
Date	AVG	STD	AVG	STD	AVG	STD	AVG	STD	AVG	STD	AVG	STD
3-May	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.58
10-May	1.67	1.53	0.67	0.58	0.67	1.15	6.33	8.39	1.33	1.53	10.00	14.80
17-May	2.67	0.58	7.00	3.61	6.00	3.00	13.00	6.08	3.67	3.21	7.33	6.11
24-May	4.33[b]	5.86	8.00[a]	1.73	1.33[bc]	1.53	1.33[bc]	1.15	0.67[c]	0.58	1.00[c]	1.73
29-May	4.00	2.00	9.00	13.89	24.67	13.58	5.00	1.00	10.00	7.00	4.67	4.16
5-Jun	1.00	1.73	0.33	0.58	0.67	0.58	0.33	0.58	1.00	1.00	1.00	1.00
12-Jun	0.00[b]	0.00	7.67[a]	4.04	0.00[b]	0.00	2.33[b]	2.08	0.00[b]	0.00	5.67[ab]	5.51
19-Jun	5.00	6.24	5.00	2.65	4.67	6.43	2.33	1.53	3.67	2.52	10.00	9.00
26-Jun	28.67	41.93	60.67	58.53	19.67	24.95	39.00	20.66	7.67	7.51	11.00	4.58
3-Jul	133.67	115.11	155.00	116.32	110.67	42.39	125.33	85.29	62.33	52.00	57.33	33.53
10-Jul	323.67	292.00	131.33	57.50	147.67	109.45	135.67	154.46	97.67	52.79	138.33	41.00
17-Jul	114.67	43.02	150.67	59.94	83.33	43.88	70.00	19.97	92.33	33.38	101.33	38.73
24-Jul	41.33	25.40	93.00	24.56	28.67	19.43	79.33	62.05	54.67	27.01	56.00	43.58
31-Jul	2.00	2.00	6.33	4.04	0.33	0.58	1.00	1.73	1.00	1.73	1.33	1.15
7-Aug	1.67	2.89	17.00	15.72	0.33	0.58	1.00	1.73	0.00	0.00	2.33	4.04
14-Aug	10.67	11.93	9.67	14.22	1.00	1.00	13.00	19.05	3.00	4.36	3.00	2.65
21-Aug	3.33	4.16	6.67	7.23	19.67	17.39	2.00	2.65	6.00	9.54	1.67	2.89
28-Aug	14.00	18.25	5.67	3.51	8.00	13.00	0.33	0.58	0.00	0.00	3.33	1.53
5-Sep	12.33	6.43	13.33	9.50	3.67	3.06	11.33	10.07	3.67	1.53	2.33	3.21
11-Sep	15.33	18.15	11.67	10.21	20.33	29.37	3.67	3.51	15.67	14.50	6.00	6.56
18-Sep	29.00	23.39	5.00	5.00	7.67	6.81	9.33	5.03	4.67	6.43	6.67	5.13
25-Sep	1.33	2.31	7.00	9.64	1.00	1.73	3.33	4.16	1.67	1.15	1.67	2.89
2-Oct	1.67	2.08	0.67	1.15	15.67	19.86	3.33	4.93	0.33	0.58	0.33	0.58
9-Oct	2.00	3.46	0.33	0.58	0.00	0.00	1.00	1.73	0.00	0.00	2.00	2.00

1. Treatments were 1=sod, 2=sod+crape myrtle, 3=clover/vetch to sod, 4=clover/vetch to sod+crape myrtle, 5=clover/vetch to sesbania/indigo to sod, and 6= clover/vetch to sesbania/indigo to sod+crape myrtle.
2. Means for treatments in the same sampling date that are labeled by different letters as superscripts show significant differences (ANOVA, LSD test, $P<0.05$).

Table 6. Means (AVG) and standard deviation of the means (STD) for number of aphids/shoot from black pecan aphids in pecan trees bordered by six different groundcover treatments[1] in 2005.

	Groundcover Treatments											
	1		2		3		4		5		6	
Date	AVG	STD	AVG	STD	AVG	STD	AVG	STD	AVG	STD	AVG	STD
3-May	0.00	0.00	0.00	0.00	0.33	0.58	0.00	0.00	0.00	0.00	0.00	0.00
11-May	0.00	0.00	0.67	1.15	0.67	1.15	0.67	0.58	0.33	0.58	2.67	4.62
18-May	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25-May	0.33	0.58	0.00	0.00	0.33	0.58	0.00	0.00	1.00	1.73	0.33	0.58
1-Jun	0.33	0.58	0.00	0.00	0.00	0.00	0.67	1.15	0.00	0.00	0.67	1.15
8-Jun	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.58	0.67	0.58	0.00	0.00
15-Jun	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22-Jun	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29-Jun	0.00	0.00	0.33	0.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6-Jul	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13-Jul	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22-Jul	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25-Jul	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3-Aug	1.00	1.73	0.33	0.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10-Aug	9.33	16.17	0.00	0.00	0.00	0.00	0.67	1.15	0.00	0.00	0.00	0.00
18-Aug	0.67	1.15	3.67	6.35	0.00	0.00	5.00	5.57	0.00	0.00	1.00	1.73
24-Aug	18.33	13.43	17.33	24.91	12.33	13.65	12.00	10.44	3.33	4.16	13.00	20.78
31-Aug	32.67	23.67	12.00	11.53	48.67	43.75	73.67	109.66	30.00	32.91	9.67	3.51
21-Sep	340.67	334.69	178.33	69.62	142.67	159.92	392.67	281.44	145.67	92.98	144.00	154.07
28-Sep	80.00	30.51	133.00	79.54	54.67	12.10	128.00	103.36	176.33	135.94	182.00	193.67

1. Treatments were 1=sod, 2=sod+crape myrtle, 3=clover/vetch to sod, 4=clover/vetch to sod+crape myrtle, 5=clover/vetch to buckwheat to sod, and 6= clover/vetch to buckwheat to sesbania/indigo to sod.

Table 7. Means (AVG) and standard deviation of the means (STD) for number of aphids/shoot from black pecan aphids in pecan trees bordered by six different groundcover treatments[1] in 2006.

	Groundcover Treatments											
	1		2		3		4		5		6	
Date	AVG	STD	AVG	STD	AVG	STD	AVG	STD	AVG	STD	AVG	STD
3-May	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10-May	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17-May	0.00	0.00	0.33	0.58	0.00	0.00	0.00	0.00	0.00	0.00	0.67	1.15
24-May	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29-May	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5-Jun	0.00	0.00	9.00	13.08	0.67	0.58	0.00	0.00	1.67	2.89	4.67	6.43
12-Jun	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19-Jun	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
26-Jun	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.58	0.00	0.00	0.00	0.00
3-Jul	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10-Jul	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17-Jul	0.00	0.00	0.67	1.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24-Jul	0.00	0.00	0.00	0.00	0.00	0.00	0.67	1.15	0.00	0.00	0.00	0.00
31-Jul	0.33	0.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7-Aug	0.33	0.58	0.00	0.00	4.00	6.93	0.00	0.00	1.67	2.89	0.33	0.58
14-Aug	0.33	0.58	0.67	1.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21-Aug	1.33	0.58	3.00	5.20	3.00	3.00	0.33	0.58	2.00	3.46	2.00	3.46
28-Aug	15.33	8.08	8.33	13.58	8.67	10.02	2.00	3.46	5.67	6.43	1.33	1.53
5-Sep	9.00	9.54	35.67	7.02	24.00	30.51	9.67	6.03	15.67	20.60	15.67	16.01
11-Sep	48.33	52.00	40.33	25.74	59.67	84.22	20.67	29.84	42.00	67.58	22.67	16.26
18-Sep	67.33	29.87	49.67	14.01	40.33	32.47	51.67	61.50	51.67	44.41	19.00	16.00
25-Sep	11.67	11.59	14.67	15.31	14.33	9.50	12.00	10.15	11.67	11.72	17.33	11.37
2-Oct	3.67	3.51	4.00	4.36	12.67	10.60	10.33	1.15	8.00	3.61	6.00	3.00
9-Oct	2.00	3.46	1.67	1.15	1.33	1.15	1.00	1.73	1.67	1.53	0.67	0.58

1. Treatments were 1=sod, 2=sod+crape myrtle, 3=clover/vetch to sod, 4=clover/vetch to sod+crape myrtle, 5=clover/vetch to sesbania/indigo to sod, and 6= clover/vetch to sesbania/indigo to sod+crape myrtle.

Table 8. Means (AVG) and standard deviation of the means (STD) for number of coccinellid beetles/shoot in pecan trees bordered by six different groundcover treatments[1,2] in 2005.

	Groundcover Treatments											
	1		2		3		4		5		6	
Date	AVG	STD	AVG	STD	AVG	STD	AVG	STD	AVG	STD	AVG	STD
3-May	0.00	0.00	0.00	0.00	0.33	0.58	0.00	0.00	0.00	0.00	0.00	0.00
11-May	0.33	0.58	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.58	0.00	0.00
18-May	0.00	0.00	0.33	0.58	0.00	0.00	0.00	0.00	0.33	0.58	0.00	0.00
25-May	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1-Jun	0.00[b]	0.00	0.00[b]	0.00	0.67[a]	0.58	0.00[b]	0.00	0.00[b]	0.00	0.00[b]	0.00
8-Jun	0.33	0.58	0.33	0.58	0.33	0.58	0.00	0.00	0.33	0.58	0.67	0.58
15-Jun	0.33	0.58	0.00	0.00	0.00	0.00	1.33	2.31	0.33	0.58	0.67	1.15
22-Jun	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.58	0.00	0.00
29-Jun	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.58	0.67	0.58	0.00	0.00
6-Jul	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13-Jul	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.58	0.00	0.00	0.00	0.00
22-Jul	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25-Jul	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3-Aug	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10-Aug	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18-Aug	0.00	0.00	0.33	0.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24-Aug	0.33	0.58	0.00	0.00	0.00	0.00	0.67	1.15	0.33	0.58	0.00	0.00
31-Aug	1.00	1.00	0.00	0.00	1.00	1.00	0.33	0.58	1.67	2.89	0.33	0.58
21-Sep	0.67	0.58	1.33	0.58	0.33	0.58	1.67	1.15	0.33	0.58	2.00	3.46
28-Sep	1.00	1.73	3.67	4.04	0.67	1.15	0.33	0.58	1.33	1.15	1.33	2.31

1. Treatments were 1=sod, 2=sod+crape myrtle, 3=clover/vetch to sod, 4=clover/vetch to sod+crape myrtle, 5=clover/vetch to buckwheat to sod, and 6=clover/vetch to buckwheat to sesbania/indigo to sod.
2. Means for treatments in the same sampling date that are labeled by different letters as superscripts show significant differences (ANOVA, LSD test, $P<0.05$).

Table 9. Means (AVG) and standard deviation of the means (STD) for number of coccinellid beetles/shoot in pecan trees bordered by six different groundcover treatments[1] in 2006.

	Groundcover Treatments											
	1		2		3		4		5		6	
Date	AVG	STD	AVG	STD	AVG	STD	AVG	STD	AVG	STD	AVG	STD
3-May	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10-May	0.33	0.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17-May	0.00	0.00	0.00	0.00	1.00	1.73	0.00	0.00	0.33	0.58	0.00	0.00
24-May	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29-May	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.58
5-Jun	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12-Jun	0.00	0.00	2.00	3.46	2.00	2.00	1.00	1.73	1.33	1.15	2.00	2.00
19-Jun	0.00	0.00	0.33	0.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
26-Jun	0.33	0.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3-Jul	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.58	0.00	0.00
10-Jul	0.00	0.00	0.00	0.00	0.33	0.58	0.00	0.00	0.00	0.00	0.00	0.00
17-Jul	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.58
24-Jul	0.00	0.00	0.00	0.00	0.67	1.15	0.67	0.58	0.00	0.00	0.00	0.00
31-Jul	0.33	0.58	0.33	0.58	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.58
7-Aug	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14-Aug	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21-Aug	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
28-Aug	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.58	0.33	0.58
5-Sep	0.00	0.00	0.00	0.00	5.33	9.24	0.00	0.00	0.00	0.00	0.33	0.58
11-Sep	0.00	0.00	0.33	0.58	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.58
18-Sep	0.00	0.00	0.67	1.15	0.00	0.00	0.00	0.00	0.67	0.58	0.00	0.00
25-Sep	0.33	0.58	2.67	4.62	0.33	0.58	0.00	0.00	0.33	0.58	0.00	0.00
2-Oct	0.33	0.58	0.33	0.58	0.00	0.00	5.67	8.96	0.00	0.00	0.33	0.58
9-Oct	0.00	0.00	0.33	0.58	0.00	0.00	0.33	0.58	0.33	0.58	0.33	0.58

1. Treatments were 1=sod, 2=sod+crape myrtle, 3=clover/vetch to sod, 4=clover/vetch to sod+crape myrtle, 5=clover/vetch to sesbania/indigo to sod, 6= clover/vetch to sesbania/indigo to sod+crape myrtle.

Table 10. Means (AVG) and standard deviation of the means (STD) for number of parasitized aphids/shoot in pecan trees bordered by six different groundcover treatments[1,2] in 2005.

	Groundcover Treatments											
	1		2		3		4		5		6	
Date	AVG	STD	AVG	STD	AVG	STD	AVG	STD	AVG	STD	AVG	STD
3-May	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11-May	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18-May	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25-May	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1-Jun	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8-Jun	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15-Jun	0.00	0.00	0.33	0.58	0.00	0.00	0.00	0.00	0.33	0.58	0.00	0.00
22-Jun	0.33	0.58	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.58	0.00	0.00
29-Jun	0.33	0.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6-Jul	0.33	0.58	0.33	0.58	0.00	0.00	0.33	0.58	0.00	0.00	0.00	0.00
13-Jul	0.33	0.58	0.67	1.15	0.67	1.15	0.33	0.58	0.33	0.58	0.33	0.58
22-Jul	1.00	1.73	0.33	0.58	0.00	0.00	0.33	0.58	0.33	0.58	0.67	1.15
25-Jul	0.33	0.58	0.67	0.58	0.67	1.15	0.67	0.58	1.00	0.00	0.67	1.15
3-Aug	1.67	2.08	2.67	3.79	1.33	1.15	0.33	0.58	1.00	1.73	2.00	1.73
10-Aug	12.33	8.96	9.67	8.33	3.00	1.73	4.33	4.93	4.67	5.51	6.33	5.69
18-Aug	15.33[b]	8.39	29.67[a]	7.57	11.67[bc]	10.69	19.33[ab]	1.53	15.67[b]	2.52	3.33[c]	2.52
24-Aug	41.00	23.26	42.33	24.85	19.33	12.66	21.00	6.08	14.33	4.16	9.00	3.46
31-Aug	37.33	26.08	32.67	14.19	20.00	17.35	29.00	16.09	28.33	32.15	15.67	10.69
21-Sep	12.67	19.40	0.33	0.58	0.00	0.00	1.33	2.31	1.00	1.73	5.00	6.24
28-Sep	12.67	19.40	0.33	0.58	0.00	0.00	1.33	2.31	1.00	1.73	5.00	6.24

1. Treatments were 1=sod, 2=sod+crape myrtle, 3=clover/vetch to sod, 4=clover/vetch to sod+crape myrtle, 5=clover/vetch to buckwheat to sod, and 6= clover/vetch to buckwheat to sesbania/indigo to sod.
2. Means for treatments in the same sampling date that are labeled by different letters as superscripts show significant differences (ANOVA, LSD test, $P<0.05$).

Table 11. Means (AVG) and standard deviation of the means (STD) for number of parasitized aphids/shoot in pecan trees bordered by six different groundcover treatments[1] in 2006.

	Groundcover Treatments											
	1		2		3		4		5		6	
Date	AVG	STD	AVG	STD	AVG	STD	AVG	STD	AVG	STD	AVG	STD
3-May	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10-May	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17-May	0.00	0.00	0.00	0.00	0.67	1.15	0.00	0.00	1.00	1.00	0.33	0.58
24-May	0.00	0.00	0.67	0.58	0.00	0.00	0.33	0.58	0.00	0.00	0.33	0.58
29-May	0.00	0.00	1.67	2.89	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.58
5-Jun	0.00	0.00	0.00	0.00	0.33	0.58	0.00	0.00	0.00	0.00	0.00	0.00
12-Jun	0.00	0.00	0.67	1.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19-Jun	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.33	2.31
26-Jun	0.67	0.58	2.00	1.00	0.67	1.15	0.33	0.58	0.00	0.00	2.67	4.62
3-Jul	2.00	1.00	3.33	3.21	1.00	0.00	1.00	0.00	1.33	1.53	0.67	0.58
10-Jul	10.67	12.50	6.00	3.00	4.67	4.16	2.00	2.00	2.00	1.73	2.00	2.00
17-Jul	10.67	0.58	5.67	4.73	3.33	1.53	10.00	8.72	1.33	0.58	2.00	1.73
24-Jul	4.00	2.65	3.33	4.93	5.33	6.11	5.00	3.61	1.33	2.31	6.33	5.86
31-Jul	2.00	3.46	3.00	2.65	0.33	0.58	1.33	1.15	1.33	1.53	0.67	0.58
7-Aug	0.33	0.58	2.33	4.04	0.33	0.58	0.33	0.58	0.33	0.58	0.67	1.15
14-Aug	2.00	1.00	1.00	1.73	2.00	2.65	2.00	1.73	0.33	0.58	1.00	1.73
21-Aug	1.00	1.00	4.00	3.46	2.33	4.04	2.67	3.06	2.67	2.31	1.67	1.53
28-Aug	0.67	1.15	1.00	1.00	1.33	1.15	0.67	0.58	0.33	0.58	0.67	1.15
5-Sep	1.00	1.00	3.67	2.89	2.00	2.00	2.00	2.00	1.00	1.73	2.67	0.58
11-Sep	0.00	0.00	0.00	0.00	0.67	0.58	1.67	2.89	1.00	1.73	2.33	3.21
18-Sep	0.67	1.15	0.00	0.00	0.00	0.00	0.33	0.58	0.67	1.15	0.67	1.15
25-Sep	2.00	2.00	6.00	10.39	4.00	4.58	1.33	1.53	3.33	2.89	2.67	3.06
2-Oct	6.00	1.73	1.67	1.53	2.67	2.31	0.33	0.58	6.00	6.56	0.67	1.15
9-Oct	2.33	2.08	1.67	0.58	0.00	0.00	1.00	1.00	1.00	1.00	1.00	1.73

1. Treatments were 1=sod, 2=sod+crape myrtle, 3=clover/vetch to sod, 4=clover/vetch to sod+crape myrtle, 5=clover/vetch to hemp/sesbania to sod, and 6= clover/vetch to sesbania/indigo to sod+crape myrtle.