ASSESSMENT OF LEGUME AND NON-LEGUME GROUND COVERS AND AUGMENTATION OF APHID PREDATORS FOR LOW-INPUT PECAN MANAGEMENT

BY

NATASHA RAECHELL RICE

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Thesis approved:

Michael Smith
Thesis adviser

Brian A. Kahn

Raymond D. Eikenbary

Thomas C. Collins
Dean of the Graduate College

PREFACE

The purpose of this study was to evaluate a low-input pecan management system using a crimson clover and hairy vetch ground cover for nitrogen contribution and control of certain pecan pests. Also, this study evaluated the release of green lacewings as a biological control.

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CHAPTER I

INTRODUCTION

Pecan (*Carya illinoinensis* [Wangenheim] K. Koch, Juglandaceae) is the most important commercial horticultural tree crop indigineous to the U.S. (Brison, 1974). Production by the U.S. and Mexico accounts for more than 90% of the world crop. Pecan covers approximately 250,000 ha in the U.S. with annual production of 135 million kg (Harris, 1990).

There are two types of commercial pecan orchards in the U.S. One is based on wild trees that have been cleared of competing vegetation and in which trees are thinned to the correct tree density for optimum production. These trees and nuts are called natives (Harris, 1983). Native pecans from 1970 through 1990 accounted for 38% of the U.S. production, and for 92% of Oklahoma's production (Napper, 1991). The second type of orchard is planted to three or four different cultivars.

U.S. production of pecans occurs in the deep well-drained alluvial soils of the southeastern, southcentral and southwestern regions, stretching from North Carolina to southern California, where the average growing season has at least 200 frost free days. The pecan growing season extends from approximately mid-March to mid-November (Brison, 1974). The top pecan producing states are Georgia, Louisiana, Texas, New Mexico, Alabama and Oklahoma (Charlet and Henneberry, 1992).

Mexico, Brazil, Israel and South Africa also grow pecans commercially (Harris, 1983).

Pecan cultural practices are highly variable in both cultivar and native orchard types; however, current practices in most pecan orchards entail heavy applications of fertilizers and pesticides. Fertilization with nitrogen is conducted annually in the spring and is primarily applied to the soil at 100 kg/ha N or more (Harris, 1983). Permanent sods such as bermudagrass (*Cynodon dactylon* [L.] Pers.) have been grown as understorey cover in pecan orchards, but compete for moisture and nutrients, thus decreasing growth and yield of pecan trees (Gossard and Hammar, 1957; Ware and Johnson, 1958).

Concern over human health and the environmental consequences of conventional, chemically intensive, agricultural production has increased, fueling a reexamination of current agricultural practices (Nielsen and Lee, 1987; Mott, 1984). Intensive management practices with an emphasis on chemical use has created certain economic, environmental and social problems. While agricultural productivity has increased greatly in the last 30 years, current farming methods have been blamed for nitrate and pesticide contamination of groundwater (Hallberg, 1986; Edwards, 1989), and surface water (Myers et al., 1985; Edwards, 1989), plus increased soil erosion (Edwards, 1989). Awareness of the need to protect groundwater quality is increasing, and nitrate from agricultural fertilizers has been identified as a source of potential groundwater degradation.

Significant surface and groundwater contamination by nutrients and pesticides has been reported in 39 states in the continental U.S. (United States Department of Agriculture, 1987). Groundwater pollution by nitrate associated with agricultural production is currently regarded as a major national environmental problem (Benbrook, 1989). Nitrate-nitrogen readily moves through the soil, and in areas receiving high nitrogen fertilizer rates, may contaminate subsurface water (Logan et al., 1980). Increased nitrate in groundwater has been linked to nitrogen fertilization worldwide. Many shallow water supplies currently exceed the U.S. nitrate drinking water standard (Hallberg, 1987).

Interest in low-input or alternative agriculture systems has increased in response to these health, groundwater quality, environmental and social issues. Low- input or alternative agriculture systems refer to systems that reduce or eliminate high energy inputs and synthetic chemical use (Schaller, 1990). These strategies increase profitability by lowering input costs (Lockeretz and Wernick, 1983), and decrease the potential for environmental degradation.

In recent years, the development of low-input management for pecan orchards has received greater emphasis. Low-input management systems may offer the best avenue for pecan producers to increase profitibility and protect the environment, and native pecan agroecosystems appear especially suited for low-input production (Reid and Eikenbary, 1990). Legumes and mixtures of legumes can be grown as ground covers in pecan orchards and offer certain advantages compared to perennial grass sod, such as supplying nitrogen and increasing beneficial arthropods in the orchard to control certain pecan pests. Lower inputs of pesticides and nitrogen fertilizer in pecan orchards may be achieved by low-input integrated management using legume ground covers (Blackmon, 1948; Bugg et al., 1991b).

Legume Ground Covers

Using legumes as cover crops to enhance soil fertility and crop production is among the oldest of agricultural management practices. Ancient records from around the world indicate the use of legumes to enhance soil productivity (McKee, 1948). Interest in cover crops and green manure crops had declined after World War II, but recent environmental and social concerns have increased interest for soil conservation and improvement (Power, 1987).

In pecan producing areas, most water tables are usually shallow, and the potential for groundwater and surface water contamination by nitrate and pesticide pollution are high. Pesticide applications, mowing and harvesting, exposes pecan orchards to 15 to 30 trips annually by heavy machinery, compacting soil and reducing yields (Trouse, 1978). Economic, environmental and social concerns have resulted in a reevaluation of benefits from using cover crops such as legumes (Power and Follet, 1987) in pecan orchards. Winter cover crops increase soil organic carbon and total nitrogen compared to fields without cover crops (Lewis and Hunter, 1940; Barber, 1972; White et al., 1981; Wilson et al., 1982; Frye et al., 1988) which improves soil granulation, water storage, soil organism activity, and increases overall productivity (Reganold et al., 1987; Bolton et al., 1985; Smith et al., 1987; White et al., 1981).

Also, legumes improve or maintain fertility, conserve nutrients, improve soil structure, increase microbial activity and provide a mulch (White et al., 1981). The mulch formed by the cover crop may aid in decreasing water evaporation (Smith et al., 1987; Frye et al., 1988; Bond and Willis, 1969) and moderating soil temperature (Finch and Sharp, 1981).

Cool-season legume cover crops can reduce soil erosion, especially during the winter and early spring (Hall et al., 1984; Langdale and Leonard, 1983; White et al., 1981; Finch and Sharp, 1981; Power, 1987b). Legumes may reduce residual soil nitrates (Zachariassen and Power, 1991), increase water infiltration (Finch and Sharp, 1981; Smith et al., 1987; Wilson et al., 1982; Frye et al., 1988), increase soil aeration (White et al., 1981) and may improve weed control (Power, 1987; Frye et al., 1988). Reduced tillage and equipment travel has been cited as another advantage to using legumes (Finch and Sharp, 1981). Winter legumes also accumulate higher concentrations of P, K, Ca and Mg than grass ground covers, increasing P, K, Ca and Mg in the upper soil layers (Groffman et al., 1987).

One limitation of legumes could be nitrate leaching into the groundwater. Nitrate is highly mobile and if not absorbed by plants or microorganisms, it will be leached into ground waters (Delwiche, 1978). If nitrates are available, leaching is greatest during winter and early spring months (Owens, 1990). Either organic materials or synthetic nitrogen fertilizers have substantial potential for nitrate leaching losses (Magdoff, 1991). Soil nitrate concentrations were higher where winter legumes were used than where grass was used (Fowler and Lewis, 1934). Groffman et al. (1987) reported leaching losses of nitrate nitrogen were higher under clover plots than under fertilized nitrogen plots, although the total nitrogen leached was small.

Other limitations of using legume cover crops include competition with trees for water and nutrients (Finch and Sharp, 1981; Blackmon, 1948; Hardy, 1939) or possible enhancement of a particular pest. Cover crop liabilities also include costs such as seeding and possible depletion of stored soil water while the cover crop is growing (Frye et al., 1988; Finch and Sharp, 1981). These drawbacks can be reduced or eliminated with careful management and control practices.

Legume Nitrogen Value

Legume covers can supply significant amounts of biologically fixed atmospheric nitrogen to succeeding crops (Ebelhar et al., 1984; Holderbaum et al., 1990; Mitchell and Teel, 1977; Evans and Sturkie, 1974; Touchton et al., 1982). Legumes are characterized by their ability to fix atmospheric nitrogen through a symbiotic relationship with a bacteria called *Rhizobium* (Allen, 1962; Chapman and Carter, 1976). The legumes ability to fix nitrogen is greatly reduced by readily available nitrogen in the soil since legumes use available nitrogen rather than fixing more nitrogen (Allison, 1957; Erdman, 1967). Less than one third of the total nitrogen content of most legumes is contained in the roots (McKee, 1948; Mitchell and Teel, 1977).

Growth and nitrogen contribution from legume cover crops depends upon geographic location, management conditions, soil type and climatic conditions (Hoyt and Hargrove, 1986; Frye et al., 1988) which affect total legume dry matter production (Fribourgh and Johnson, 1955). Legumes differ substantially in nitrogen fixation capability (Heichel et al., 1981; Ham, 1978). Erdman (1967) showed estimates of nitrogen fixed by several legumes ranging from 57 to 207 kg/ha N. Results from other studies show an average legume fixation value is usually 57 to 111 kg/ha, depending on the kind of legume (Allison, 1957; Rogers and Giddens 1957). In one study 'Amclo' arrowleaf clover (*Trifolium vesiculosum* Savi cv 'Amclo') and 'Cahaba' white vetch (*Vicia sativa* L. X *V. cordata* cv 'Cahaba white' Wulf) contained 182 and 138 kg/ha N, respectively (White et al., 1981). The greater clover nitrogen production was due primarily to the greater biomass produced from clover (6389 kg/ha) than from vetch (4321 kg/ha). The overriding factor in total nitrogen produced has been shown to be biomass production (Allison, 1957; Fribourgh and Johnson, 1955; Holderbaum et al., 1990); whereas, the nitrogen concentration of a legume is related more to plant maturity (Fleming et al., 1981). Nitrogen concentration of crimson clover (*Trifolium incarnatum* L.) decreases as the plant matures (Akin & Robinson, 1982). As maturity approaches, most of the protein is translocated from the vegetative plant parts into the developing seeds (Allison, 1957; Atkins, 1986). Results indicate that crimson clover should attain the late bloom stage then be disked to maximize subsequent nitrogen release (Wagger, 1987; Wagger, 1989; Ranells and Wagger, 1992). Crimson clover residues incorporated into the soil decompose nearly twice as fast as crimson clover remaining on the surface (Groffman et al., 1987). Leguminous cover crops left on the surface typically contribute only about one-half as much nitrogen as those disked under (Zomer and Bugg, 1989). Incorporating a legume enhances its nitrogen contribution to the succeeding crop, but killing it for a surface mulch improves the soil and water conservation value (Frye et al., 1988).

Crimson clover and hairy vetch (*Vicia villosa* Roth) appear to be very suitable in the southern U.S., producing 70-180 kg/ha N (White et al., 1981; Wagger, 1989; Holderbaum et al., 1990; Boquet and Dabney, 1991; King and Buchanan, 1993; Erdman, 1967). Both crimson clover and hairy vetch are easily established, reasonably winter hardy, break dormancy early in the spring, grow rapidly, assimilate high amounts of nitrogen and result in good yield responses for summer crops (Frye et al., 1988). Hairy vetch has been superior in nitrogen concentration to other legume cover crops in most studies (Frye et al., 1988). The suitability of crimson clover is based on its higher acid tolerance, earlier date of full bloom, high dry matter production, high nitrogen accumulation and possible reseeding capability compared to other legumes that have been studied (Donnelly and Cope, 1961; Fleming et al., 1981; Hargrove, 1986; Leidner, 1987; Touchton et al., 1982; Boquet and Dabney, 1991). Crimson clover and hairy vetch generally perform better at low temperatures than many other legume species (Power, 1987) and are less competitive with pecan trees for soil moisture and nutrients than warm season legumes (Hardy, 1939). In addition crimson clover matures approximately three to four weeks earlier than hairy vetch (Wagger, 1989; Holderbaum et al., 1990). Erdman (1967) showed crimson clover fixed 95 kg/ha nitrogen and vetch fixed 92 kg/ha N. Smith et al., (1994) showed hairy vetch had 2.92% nitrogen concentration and produced 75 kg/ha N while crimson clover had 2.59% nitrogen concentration producing 89 kg/ha N. Biomass production by crimson clover and hairy vetch has been reported at 4,756 kg/ha and 3654 kg/ha respectively (Hoyt, 1987). Maximum biomass accumulation in one study was 5500 kg/ha for crimson clover (Boquet and Dabney, 1991).

Legume nitrogen production can be affected by time of planting (White et al., 1981) and harvest management of the legume (Groya and Sheaffer, 1985). Planting legumes in early fall in pecan orchards is necessary to obtain satisfactory biomass and nitrogen production. Forage yields of October planted 'Cahaba' white vetch and 'Amclo' arrowleaf clover doubled yields from December-January plantings (White et al., 1981).

Total nitrogen accumulation by succeeding crops is the simplest method of measuring the value of a legume cover but does not account for residual soil nitrogen; thus legume nitrogen is frequently underestimated (La Rue and Patterson, 1981). The amount of nitrogen fertilizer required in a fallow or crop treatment to give a yield equal to that obtained on the legume cover crop treatment without nitrogen fertilizer is termed the fertilizer-nitrogen equivalence of the legume crop (Hargrove, 1986; Smith et al., 1987). Legume nitrogen contribution to a succeeding crop is variable and dependent on many factors, including the soil nitrogen status, dry matter production and nitrogen concentration of the legume cover. Most nitrogen response data comes from row-crop studies where a preceding winter legume crop was plowed under as green manure. Summaries from many of these studies are in the literature (Allaway, 1957; Burton, 1976; Pearson and Ensminger, 1957; Rogers and Giddens, 1957). Published data have clearly shown that winter legume covers can replace significant amounts of nitrogen for production of subsequent crops (Mitchell and Teel, 1977; Ebelhar et al., 1984; Touchton et al., 1984; Hargrove, 1986; Neely et al., 1987).

Most studies show that a good winter legume cover turned under will increase yields of succeeding crops similar to 57-111 kg/ha N (Rogers and Giddens, 1957). The actual amount of nitrogen supplied by the legumes depends on cultural practices that enhance nitrogen availability to legumes and succeeding crops. Hairy vetch has supplied biologically fixed nitrogen equivalent to about 90-200 kg/ha N annually to corn (Ebelhar et al., 1984; Utomo, 1986) and 60 kg/ha N to grain sorghum (Herbek et al., 1987). Hairy vetch and crimson clover stands have produced grain yields comparable to the application of 112 kg/ha N (Mitchell and Teel, 1977).

Legume cover crops frequently increase leaf nitrogen concentrations of the pecan trees within one growing season (Bould and Jarrett, 1962; Bugg et al., 1991a; White et al., 1981). Additional increases in nitrogen may result during subsequent seasons. A five year study reported the nitrogen concentration of pecan leaves was higher in legume treatments than in grass sod treatments (Smith et al., 1960). In pecan trees, crimson clover has been shown to add 57-78 kg/ha N (Hunter, 1960). Pecan leaf nitrogen values of trees in legume plots were equivalent to those of trees receiving

111 kg/ha N using 'Amclo' arrowleaf clover and 'Cahaba' white vetch (White et al., 1981).

Growth and yield were improved over a two-year period when trees were cultivated with a winter legume turned into the soil during the spring compared to using a grass sod (Smith et al., 1960). Clover covers also had the least deleterious effect on tree growth compared to resident vegetation and resulted in the highest pecan yield (Bould and Jarrett, 1962).

Pecan Pest Management

In many pecan producing areas insect complexes present a continuing threat all season long to pecan production (Harris et al., 1992; Tedders, 1983). Pecan growers use intensive pest control programs with eight to 10 insecticide applications in the southeastern U.S. and five to seven insecticide applications in the southcentral U.S. (Tedders, 1983; Bugg et al., 1991b). In the east pecan growers use from six to eight applications of aphicides per year (Wood et al., 1983). Aphids (Homoptera: Aphididae) have high reproductive rates and rapid life cycles which enhance their genetic selection, resulting in tolerance or resistance to frequently used insecticides (Tedders, 1986). The frequent use of certain insecticides has led to development of pesticide resistance in aphids (Dutcher and Htay, 1985), causing a resurgence of the aphid complex (Dutcher, 1983; Dutcher and Payne, 1983), thus requiring even more insecticide applications. Excessive pesticide use has also resulted in outbreaks of secondary pests (Ball, 1981; Mizell, 1991) and reduces native beneficial arthropod populations that act as a natural control of pecan pests in the orchard (Mizell, 1991; Tedders, 1983; Dutcher, 1983; Dutcher and Payne, 1983). Insecticide applications promote these secondary pests, which are normally held in check by natural controls (Tedders, 1986).

The most damaging pecan insects in Georgia are a complex consisting of three aphid species (Homoptera: Aphididae) : the blackmargined aphid, *Monellia caryella* (Fitch), the yellow pecan aphid, *Monelliopsis pecanis* Bissell, and the black pecan aphid, *Melanocallis caryaefoliae* (Davis) (Tedders et al., 1982; Tedders, 1978; Tedders, 1983). Blackmargined aphids, and yellow pecan aphids, commonly called the yellow aphid complex, are the most common foliar-feeding aphids on pecans (Tedders, 1978; Payne et al., 1979) and are a limiting factor in pecan production (Neel et al., 1985). Black pecan aphid also causes economic loss (Moznette, 1934).

Yellow aphid complex populations exhibit bimodal seasonal abundance patterns with peak populations during May-June and August-October (Polles and Mullenix, 1977; Tedders, 1978; Leser, 1981; Edelson, 1982; Edelson and Estes, 1983; Shepard, 1973). Some researchers have suggested that these aphid population peaks coincide with an abundance of highly nutritious and young foliage in early and late season, while the midseason aphid population crash coincides with the presence of less nutritious mature leaves (Smith and Severson, 1992).

These three pecan aphids feed on and damage the vascular system of pecans (Tedders, 1978; Wood et al., 1985; Tedders and Thompson, 1981), reducing leaf chlorophyll and leaf area (Tedders et al., 1981; Tedders et al., 1982; Wood and

Tedders, 1982; Tedders and Wood, 1985; Wood et al., 1987; Wood et al., 1985) and decreasing leaf photosynthesis up to 75% (Wood and Tedders, 1982; Wood et al., 1988) thus depleting carbohydrate reserves in stem tissue (Tedders et al., 1981; Wood and Tedders, 1982). Loss of tree productivity is due in part to feeding damage by the three aphid species and their direct removal of carbohydrates (Wood and Tedders, 1982; Tedders et al., 1982; Wood et al., 1987) and to the apparent clogging of the phloem (Wood et al., 1985). These three aphids reduce growth of stems and roots (Tedders et al., 1981; Tedders et al., 1982) and decrease tree vigor (Dutcher, 1985). Pecan aphid damage decreases in-shell nut production, nut quality (Tedders and Wood, 1987; Wood et al., 1987) yield (Stone and Watterson, 1981; Dutcher et al., 1984; Tedders and Wood, 1985), nut size and nut weight (Tedders and Wood, 1985), presumably because of the depletion of tree energy reserves by feeding. When the densities of the three aphid species are below recommended threshold levels, few adverse effects on net photosynthesis have been observed (Wood and Tedders, 1986).

Damage by pecan aphids can be direct (depletion of carbohydrates) or indirect. Honeydew accumulation on leaves supports growth of a black sooty mold fungus that can reduce photosynthetic efficiency (Tedders and Smith, 1976; Smith and Tedders, 1980; Wood and Tedders, 1983). Sooty mold growth on pecan foliage reduced light transmission to the leaf by 25%-50% (Tedders and Smith, 1976). Heavy sooty mold growth can block upto 98% of the light, suppressing leaf photosynthesis upto 70% and decreasing tree carbohydrate reserves (Tedders and Wood, 1985; Wood et al., 1988). Reduction in leaf efficiency has also been blamed for early tree defoliation (Polles, 1975).

Pecan aphids may contribute to alternate bearing by their negative influence on tree energy reserves (Tedders and Wood, 1985) and general reduction in overall tree productivity (Tedders et al., 1981; Wood and Tedders, 1982; Dutcher et al., 1984; Tedders and Wood, 1985). Alternate bearing is a problem of pecan that is closely associated with tree energy reserves and the ratio of sink to source tissue (Sitton, 1931; Sparks and Brack, 1972; Worley, 1979a; Worley, 1979b; Wood and Tedders, 1982; Monselise and Goldschmidt, 1982). Factors which influence alternate bearing of pecans are those that affect the energy reserves within a tree (Sparks, 1983) such as feeding by aphids and mites that induce premature leaf abscission (Tedders et al., 1982; Wood et al., 1985; Tedders, 1978). Early defoliation of pecan trees reduces yield, nut size, kernel percent, and delays budbreak and inhibits flower formation the next year (Worley, 1971; Worley, 1979a).

Aphid control in pecans has been through foliar-applied insecticides. Apple and citrus studies have shown that some pesticides cause large reductions in photosynthesis (Ayers and Barden, 1975; Ferree and Hall, 1978; Ferree et al., 1976; Sharma et al., 1977; Wedding et al., 1952). Foliar sprays of pecan pesticides to pecan seedlings also reduces net photosynthesis for extended periods of time (Wood et al., 1983; Wood et al., 1984; Wood and Payne, 1984). Repetitive insecticide application, as is common for many pecan pest control programs at 10 to 14 day intervals, produces a sustained reduction in net photosynthesis and could be another factor reducing tree energy reserves. However, because of the adverse influence of insects and mites on pecan nut productivity (Wood and Tedders, 1983; Wood et al., 1985), it is essential that their levels be controlled for sustained production.

Biological control of pecan aphids is a pest management alternative in pecan orchards (Tedders, 1983; Liao et al., 1984,1985; Edelson & Estes, 1987; Mizell and Schiffhauer, 1987b; Bugg and Dutcher, 1989). Natural control can only be maximized in an agroecosystem if favorable habitats are provided for beneficial arthropods to complete their life cycles and exist in high densities. Diverse vegetation, preservation of areas which act as refuges and availability of hibernation sites as well as prey and possible alternative food sources are important components of natural control (Metcalf, 1980; Sotherton, 1985; Stechmann, 1986). Goals should be to establish long term pest control by maximizing the contribution of predators and parasitoids rather than relying upon more costly and possibly damaging inputs such as pesticides. For the enhanced stability of an agroecosystem it is necessary to preserve diversity among arthropod species by careful managment (Poehling, 1989; Metcalf, 1986).

Most deciduous fruit and nut orchards are rather permanent ecosystems with complex arthropod communities that grow well under diversified conditions, thus having a natural tendency towards ecological stability (Tedders, 1983). Pecan growers have abundant and diverse naturally occurring beneficial insects (Tedders, 1976). Natural enemies of the yellow aphid complex have been identified and shown to reduce aphid densities (Edelson, 1982; Flores ,1981; Leser, 1981; Tedders, 1978;

Watterson and Stone, 1982; Edelson and Estes, 1987). A study from Liao et al. (1985) indicates that natural enemies, especially chrysopids (Neuroptera: Chrysopidae) and spiders (Arachnida), play an important role in maintaining black-margined aphid densities at low levels in the field. Allowing natural enemies access to aphids always resulted in declining aphid numbers compared to aphids that were closed off to natural enemy access. Densities of black-margined aphids protected from natural enemies increased to 50 aphids/leaf or higher from June to August but predator densities of 1 per 10 leaves were sufficient to prevent such aphid outbreaks (Liao et al., 1985; Liao et al., 1984).

Cover crops may, in addition to soil improvements, prove useful in pest managment. Researchers have analyzed various management regimes and a range of different plant materials for their entomological consequences, such as winter cover crops (House & Alzugaray, 1989; Smith et al., 1988), summer cover crops (Bugg et al., 1989; Bugg and Ellis, 1990), living mulches (Andow et al., 1986; Ryan et al., 1980), and overseeded legumes (Lambert et al., 1987) and found that cover crops can sustain beneficial insects (Altieri and Letourneau, 1982; Bugg and Dutcher, 1989; Bugg et al., 1990a; Bugg et al., 1991a). Most commercial pecan orchards have grass understoreys that harbor few suitable alternative prey such as aphids and seldom have large numbers of aphidophagous lady beetles (Coleoptera: Coccinelidae) (Tedders, 1983; Bugg and Dutcher, 1989; Bugg et al., 1990a, 1991a,b) or other natural aphid enemies. Evidence suggests that selective vegetational diversification can lead to enhanced biological control of pest species, and that diversification may be important in the activity of natural enemies (Russell, 1989). When pests are scarce or absent, several important predators can subsist on alternative prey associated with cover crops. This could lead to enhanced biological control on associated beneficiary crops (Altieri & Letourneau, 1982; Altieri & Schmidt, 1985; Bugg & Dutcher, 1989) such as pecan.

Cool season legume cover crops are a passive method to enhance biological control, because as they senesce the predators and parasitoids associated with the legumes disperse as the pecan is becoming susceptible to aphid attack. Summer crops conversely harbor abundant prey while pecan aphids are active and might be expected to divert beneficial insects that would otherwise attack the target pests by providing alternate prey at inopportune times (Bugg and Dutcher, 1989; Tedders, 1983). Also certain legumes, especially later senescing legumes may harbor harmful insects such as stink bugs (Hemiptera: Coreidae), and plant bugs (Hemiptera: Miridae) (Dutcher and Todd, 1983; Bugg et al., 1990a,b; Wood et al., 1983; Carroll and Smith, 1993). Studies indicate that a mixture of cool season plant species might provide a seasonal sequence of foods to lady beetles that might otherwise disperse from pecan orchards (Bugg et al., 1990a; Bugg et al., 1991a). Complexes of legumes may be more difficult to seed, harder to manage and more difficult to study, but be less risky under variable weather, soil and sunlight conditions (Kretschmer, 1974). Cool season cover crops, such as hairy vetch and crimson clover, are being used in the understoreys of pecan trees in an attempt to provide alternative prey such as aphids and thrips that are not themselves pests of pecan but that ensure retention of lady beetles and other predators until pecan aphids become available in early May (Tedders, 1983; Bugg et al., 1990a; Bugg et al., 1991a).

Generalist predators may be important in the biological control of insects (Bugg & Wilson, 1989). Such predators can reproduce or at least subsist on nectar, pollen, spider mites (Acari: Tetranychidae), thrips (Thysanoptera: Thripidae), or aphids (Homoptera: Aphididae), and thus be in place before the arrival of pests (Ehler and Miller, 1978; Bisabri-Ershadi and Ehler, 1981; Tamaki, 1981; Gonzalez et al., 1982). Legume ground covers can harbor large aphid populations, attracting beneficial arthropods which can control pecan aphids (Tedders, 1986). Aphids commonly found on legumes in the southern U.S. are blue alfalfa aphid, *Acyrthosiphon kondoi* Shinji, pea aphid *Acyrthosiphon pisum* (Harris), cowpea aphid, *Aphis craccivora* Koch and yellow clover aphid (*Therioaphis trifolii* Monell)(Bugg et al., 1990a). These legume aphids are not pests of pecan trees. The predators and parasitoids that feed on the legume aphids may attack pecan aphids and other pests in pecan trees.

Predators and parasites associated with aphids include generalists and those that are aphid-specific (Brown, 1989). Lady beetles (Coleoptera: Coccinellidae) are one of the most important groups of beneficial insects being predacious in larval as well as adult form. They feed upon small insects such as aphids and scales, and upon eggs of larger insects (Tedders, 1976) and can eat as many as 62 aphids/day (Goff et al., 1989; Liao et al., 1985). Chrysopid larvae (Neuroptera: Chrysopidae) feed mainly on aphids but may also feed upon other small insects and insect eggs (Tedders, 1976). Lacewing larvae can consume 25-30 aphids/day (Goff et al., 1989; Liao et al., 1985).

Flower fly or syrphid fly adults (Diptera: Syrphidae) feed on pollen and nectar of flowers but syrphid larvae feed upon aphids. Assassin bugs (Hemiptera: Reduviidae) feed upon a large variety of plant feeding insects (Tedders, 1976). Beneficial stink bugs (Hemiptera: Pentatomidae) such as the spined soldier bug, *Podisus maculiventris* (Say) are predators of many insects both in adult and immature stages and are one of the most voracious predators, feeding on numerous phytophagous pest species (Tedders, 1976; McPherson, 1982). *Euthyrhynchus floridanus* and *Stiretrus anchorago* (Fabr) are similar to the spined soldier bug and are predatory upon soft bodied injurious insects. These beneficial stink bugs are separated from harmful stinkbugs by their mouth part structure (Tedders, 1976). The most abundant generalists according to Brown (1989) are spiders (Araneae).

Predators found in pecan trees according to Shepard (1973) in order of abundance were spiders, ladybeetle larvae, ladybeetle adults, *Chrysopa* spp., *Zelus* spp., *Orius* spp., and syrphid larvae. Edelson and Estes (1981) listed 20 predatory and one parasitic sp. of insects plus "numerous species" of spiders that feed on pecan aphids. Larvae of *Chrysopa* spp. and several members of Coccinelidae (*Hippodamia* spp., *Hyperaspis* spp. and *Olla* spp.) were reported as the most abundant predator groups in central Texas (Flores, 1981). Aphidophaga observed by Bugg and Dutcher, (1989) were syrphid flies, coccinellids (*Hippodamia convergens* Guerin-Meneville, *Coccinella septempunctata* L., *Cycloneda* sp. and *Olla v-nigrum* Mulsant. In Georgia, several Coccinellidae are known to attack pecan aphids: *Coccinella septempunctata*, *Hippodamia convergens*, and *Olla v-nigrum* (Gordan, 1985).

The principally arboreal *O. v-nigrum* is thought to be especially important in the biological control of pecan aphids (Mizell and Schiffhauer, 1987a). Adult *O. v-nigrum*, an aphidophagous lady beetle, spend November through January sheltered by crevices in the pecan bark and emerge in February to seek prey and reproduce (Mizell and Schiffhauer, 1987b). Vetch cover crops were shown to increase the levels of beneficial species including *Olla abdominalis* (Say) in pecan orchards until pecan trees leaf out and pecan aphids appear (Tedders, 1983). Bugg et al. (1990a) also found that from February thru May many different species of coccinellids were successively abundant on crimson clover and hairy vetch. One field experiment indicated that during April and early May, tarnished plant bug adults and nymphs (Hemiptera: Miridae), alternative food sources for beneficials, were particularly abundant on the hybrid vetches and intermediate on crimson clover (Bugg et al., 1990b).

In a study by Liao et al., (1984) spiders and lacewing eggs were most commonly associated with population fluctuations of pecan aphids in orchards. Lacewing eggs showed significant positive correlations to black-margined aphid densities and were indicators of oviposition rates that increased as the aphid density increased. The seasonal abundance pattern of spiders appeared to be relativley stable. Overall, the most abundant insect predators were *Adalia bipunctata* L., *Olla v-nigrum*, *Chrysopa quadripunctata* (Burmeister) and *Chrysoperla rufilabris* (Burmeister). Among these species, *Chrysoperla rufilabris* was the most common over the two year study. Population levels of coccinellid larvae also responded positively to the black-margined aphid densities (Liao et al., 1984). Liao et al. (1985)

results showed that the lowest natural enemy densities occurred in mid- season in pecan orchards, with chrysopids the major predators encountered in the early season, and spiders the major predators encountered in the late season.

Edelson and Estes (1987) found about 33 aphidophagous arthropod species in pecan trees. Most abundant predators were *Chrysopa rufilabris*, *Chrysopa quadripunctata*, *Olla abdominalis*, *Coleomegilla maculata* (Mulsant) and *Hippodamia convergens*. Predators were most abundant at times of greatest aphid abundance. Chrysopid abundance was positively correlated with total number of aphids (Edelson and Estes, 1987).

Cool-season cover crops used to enhance densities of entomophagous insects on relay-intercropped spring plantings of cantaloupe significantly affected densities of the predominant predators (Bugg et al., 1991c). In a study in California orchards and vineyards, understory cover crops led to increased densities of predaceous arthropods occurring in the canopies of the beneficiary crops (Altieri & Schmidt, 1985). In another California study of Persian walnut (*Juglans regia* L.), ground covers assisted biological control by harboring aphids from late February through May which were attracting lady beetle populations. *Hippodamia convergens* and *Olla v-nigrum* were the two most abundant Coccinellidae attacking walnut aphid (*Chromaphis juglandicola* [Kaltenbach]). Also in this study it was suggested that if the ground cover was disked too early the lady beetles would migrate before walnut aphid densities become available and this could lead to eruptions of aphid. The retention of lady beetles in close proximity to walnut trees was suggested to be more important than production of large numbers of lady beetles (Sluss, 1967).

A cover crop management system for pecan orchards was proposed by Bugg et al., (1991b) to enhance beneficial arthropods in orchards. Cool season and warm season cover crops were evaluated to increase aphidophagous insects and other entomophaga to enhance biological control in vegetable and pecan agroecosystems (Wood et al., 1983; Bugg and Dutcher, 1989; Bugg and Ellis, 1990; Bugg et al., 1990a, 1991a; Bugg and Dutcher, 1993). Work in 1976 indicated that as many as 353,000 convergent lady beetles/ha were produced by May 15 under normal field conditions on pea aphids feeding on hairy vetch and clover. When the legumes mature the food source of pea aphid disappears causing migration of the lady beetles (Tedders, 1986). The migration of lady beetles from maturing legumes coincides with population increases of pecan aphids in pecan canopies and attracts these lady beetles from the legumes. Normal lady beetle populations on interplanted vetch in the pecan orchard yields about 1.3 adult lady beetles/terminal branch on mature pecan trees. Control of injurious pecan aphids is effective with lady beetle populations of this size (Tedders, 1977; Tedders, 1986).

Blue alfalfa aphids and pea aphids were abundant on crimson clover beginning in February and thru the end of March, with hairy vetch sustaining abundant aphids from April thru the 1st part of May (Bugg et al., 1990a). Important predatory insects, such as insidious flower bug, *Orius insidiosus* (Say) (Hemiptera: Anthocoridae), various lady beetles, *Hippodamia convergens*, *Coccinella* *septempunctata*, *Cycloneda* sp. and *Olla v-nigrum*, and bigeyed bugs, *Geocoris* spp. (Hemiptera: Lygaeidae), were shown to attain relatively high densities in various vetches and clovers. Coccinellids first were found in substantial numbers on crimson clover and later on hairy vetch. Cover crops helped to built up and retain high densities of coccinellids, however, no apparent impact on pecan aphid was found (Bugg et al., 1990a).

Pecan orchard understoreys covered with a cool season mixture of hairy vetch and rye (*Secale cereale* [L.], Poaceae), harbored densities of aphidophagous coccinellids which were six times greater than in unmown resident vegetation and about 87 times greater than in mown grasses (Bugg et al., 1991a). However, only a single increase in convergent lady beetle was observed in cover-cropped plots, and biological control of pecan aphids was not improved. Hairy vetch sustained pea aphid, blue alfalfa aphid and thrips, (*Frankliniella* spp.). Bugg and Ellis (1990) demonstrated that hairy vetch/rye harbored particularly high densities of pea aphids and hairy vetch also harbored relatively high densities of insidious flower bug (*Orius insidiosus*) and tarnished plant bug (*Lygus lineolaris* (Palisot de Beauvois) (Hemiptera:Miridae)). No-tillage approaches may conserve beneficial insects better than conventional tillage (Bugg and Ellis, 1990).

A study with sesbania used as an understory plant had substantial populations of cowpea aphids and bandedwinged whitefly (*Trialeurodes abutilonea* (Haldeman)), as alternative prey for Coccinellidae (Bugg and Dutcher, 1993). Understoreys retained high populations of *Hippodamia convergens* and the principally-arboreal *Olla v-*

nigrum. Highly significant differences were found for season-long mean densities of pooled adult lady beetles; densities were 125 and 48 times greater in cover-cropped understoreys than in control understoreys of resident vegetation. However, no significant differences were found with coccinellid or aphid densities in the associated pecan trees.

According to Smith et al. (1994) 'Dixie' crimson clover consistently had higher early spring aphid densities and attracted more beneficial arthropods than several other cool-season legumes evaluated. Lady beetle densities were positively correlated with those of legume aphids but spider densities were not related with those of legume aphids. Aphid predators can be produced in large quantities on aphids which infest legumes. The major disadvantage of 'Dixie' crimson clover cited was that plants mature and senesce while trees are foliating, at which time there are usually few arthropod pests in the tree canopy. They suggested planting crimson clover with another annual legume, such as hairy vetch, that would begin rapid growth after 'Dixie' crimson clover senescence and thus extend the time that the ground cover would hold beneficial arthropods in the orchard.

Augmentation of existing natural enemies is another possibile strategy to control pecan aphids. Augmentation is releasing beneficial insects purchased from commercial sources for the purpose of pest control. Research has shown that inundative releases of green lacewings, such as *Chrysopa carnea* Stephens, has been effective for control of bollworm, *Heliothis zea* (Boddie), and tobacco budworm, *H. virescens* (F.), on cotton and may have considerable potential as a biological control

(Lingren et al., 1968; Ridgway and Jones, 1968,1969). A *Chrysopa* spp. was first mass reared by Finney (1948,1950) and can be mass cultured (Morrison, 1985). Its wide host and prey range make it an effective predator (Zeleny, 1985).

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CHAPTER II

ASSESSMENT OF LEGUME AND NON-LEGUME GROUND COVERS AND AUGMENTATION OF APHID PREDATORS FOR LOW-INPUT PECAN MANAGEMENT

Natasha R. Rice, Michael W. Smith, Raymond D. Eikenbary and Brian A. Kahn
Department of Horticulture and Landscape Architecture
Oklahoma State University
Stillwater, OK 74078

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Abstract: Annual legume ground covers were evaluated in pecan (*Carya illinoinensis* [Wangenheim] K. Koch) to supply nitrogen and increase beneficial arthropods. Releases of *Chrysopa rufilabris* (Burmeister) (Neuroptera: Chrysopidae) were evaluated as a biological control for late-season pecan aphids. Treatments were 5 ha of a 'Dixie' crimson clover (*Trifolium incarnatum* L.) and hairy vetch (*Vicia villosa* Roth) mixture and 5 ha of grass sod. Nitrogen was applied at 0-168 $kg \cdot ha^{-1}$ in 56 kg increments to grass plots but no nitrogen was applied to the legume plots. The most abundant beneficial arthropods sampled in the legumes were spiders, lady beetles, green lacewings and nabids, respectively. Legume ground covers did not increase the densities of beneficial species in the pecan canopies. The most abundant beneficial

arthropods in the pecan canopies were spiders, green lacewings, brown lacewings and lady beetles, respectively. Predominant lady beetle species in the legumes were *Hippodamia convergens* (Guerin-Meneville), *Coleomegilla maculata lengi* (Mulsant) and *Coccinella septempunctata* (L.) (Coleoptera: Coccinellidae) while the most abundant species in the pecan canopies were *Olla v-nigrum* (Mulsant), *Cycloneda munda* (Say) and *Hippodamia convergens*. Releases of *Chrysopa rufilabris* were not effective as a biological control of pecan aphids. The legume mixture supplied over 100 $kg \cdot ha^{-1}$ N to the pecan trees. Legumes significantly increased soil nitrate concentration compared to soil from grass plots.

Introduction

Intensive agricultural management practices with an emphasis on chemical use have created certain economic, environmental and social problems which have led to greater emphasis on development of low-input management systems. Legumes and mixtures of legumes can be grown as ground covers in pecan orchards and offer certain advantages compared to perennial grass sod, such as supplying nitrogen and increasing beneficial arthropods that may control certain pecan pests (Bugg et al., 1991b). Legumes were once commonly used in pecan orchards as cover or green manure crops before the widespread access to inexpensive synthetic nitrogen fertilizers in the 1940's and 1950's (Allison, 1957; White et al., 1981; Tedders, 1983; Allison and Ott, 1987; Ott, 1987).

Two types of commercial pecan orchards exist in the U.S. One is based on wild trees that have been cleared of competing vegetation, with the trees periodically thinned to the correct tree density for optimum production. These trees and nuts are called natives (Harris, 1983). From 1970 through 1990, native pecans accounted for

38% of the U.S. production, and for 92% of Oklahoma's production (Napper, 1991). The second orchard type is planted to three or four different cultivars.

Pecan cultural practices in both cultivar and native orchards are highly variable; however, current practices in most pecan orchards entail heavy applications of fertilizers and pesticides. Fertilization with nitrogen is conducted annually in the spring, with application rates of 100 kg/ha N or more (Harris, 1983). Understorey cover in pecan orchards has been permanent sods such as bermudagrass (*Cynodon dactylon* [L.] Pers.), but these compete for moisture and nutrients, decreasing growth and yield of pecan trees (Gossard and Hammar, 1957; Ware and Johnson, 1958).

Pecan growers use intense pest control programs with eight to 10 insecticide applications in the southeastern U.S. and five to seven insecticide applications in the southcentral U.S. (Tedders, 1983; Bugg et al., 1991b). The frequent use of certain insecticides has led to development of pesticide resistance in aphids (Dutcher and Htay, 1985), outbreaks of secondary pests (Ball, 1981; Mizell, 1991) and reductions in beneficial arthropod populations that act as a natural control of pecan pests (Dutcher, 1983; Dutcher and Payne, 1983; Tedders, 1983; Mizell, 1991). Since nitrogen and insecticides are applied frequently, and soil water tables are shallow in many pecan producing areas, the potential for groundwater and surface water contamination by nitrate and pesticide is high. Lower inputs of pesticides and nitrogen fertilizer in pecan orchards may be achieved by low-input integrated management using legume ground covers (Blackmon, 1948; Bugg et al., 1991b).

Estimates of nitrogen fixed by legumes range from 57-207 kg/ha N (Allison, 1957; Rogers and Giddens, 1957; Erdman, 1967). Crimson clover (*Trifolium incarnatum* L.) and hairy vetch (*Vicia villosa* Roth) appear to be very suitable in the southern U.S. producing 70-180 kg/ha N (Erdman, 1967; White et al., 1981; Wagger, 1989; Holderbaum et al., 1990; Boquet and Dabney, 1991; King and Buchanan, 1993). In pecan orchards, crimson clover has been shown to add 57-78 kg/ha of N (Hunter, 1960). Wood et al., (1983) reported that 'Amclo' arrowleaf clover (*Trifolium vesiculosum* Savi) added about 112 kg/ha N to a pecan orchard.

A complex of three aphid species (Homoptera: Aphididae) attack pecan: the blackmargined aphid, *Monellia cayella* (Fitch), the yellow pecan aphid, *Monelliopsis pecanis* Bissell, and the black pecan aphid, *Melanocallis caryaefoliae* (Davis) (Homoptera: Aphididae) (Tedders, 1978; Tedders et al., 1982; Tedders, 1983). Blackmargined aphids and yellow pecan aphids, commonly called the yellow aphid complex, are the most common foliar-feeding aphids on pecans (Tedders, 1978; Payne et al., 1979) and are a limiting factor in pecan production (Neel et al., 1985). Yellow aphid complex populations exhibit bimodal season abundance patterns with peak populations during May-June and August-October (Shepard, 1973; Polles and Mullenix, 1977; Tedders, 1978; Leser, 1981; Edelson, 1982; Edelson and Estes, 1983). Yellow pecan aphids and blackmargined aphids adversely affect pecan production by clogging the phloem, inducing chlorosis, and suppressing photosynthesis in pecan leaves (Wood and Tedders, 1982; Wood et al., 1985; Wood et al., 1988) thus depleting carbohydrate reserves (Wood and Tedders, 1982), and reducing nut size, weight and yield (Tedders and Wood, 1985). When pecan aphid densities are below recommended threshold levels, few adverse effects on net photosynthesis have been observed (Wood and Tedders, 1986).

The pecan aphid complex is attacked by predators and parasitoids that reduce aphid densities (Shepard, 1973; Tedders, 1978; Flores, 1981; Leser, 1981; Edelson, 1982; Watterson and Stone, 1982; Liao et al., 1984, 1985; Edelson and Estes, 1987). Cool season cover crops such as hairy vetch and crimson clover are being used in the understoreys of pecan trees in an attempt to provide alternative prey such as aphids and thrips that are not themselves pests of pecans but that ensure retention of lady beetles and other predators until pecan aphids become available in early May (Tedders, 1983; Bugg et al., 1990a; Bugg et al., 1991a). The alternate prey aphids common on crimson clover and hairy vetch are blue alfalfa aphid (*Acyrthosiphon kondoi* Shimji), pea aphid (*Acyrthosiphon pisum* (Harris)), and cowpea aphid (*Aphis craccivora* Koch) (Bugg et al., 1990a; Smith et al., 1994). These legume aphids are not pests of pecan trees. Bugg et al. (1990a) found blue alfalfa and pea aphids were abundant on crimson clover beginning in February through the end of March, with hairy vetch sustaining abundant aphids from April through the first part of May. The predators and parasitoids that feed on the legume aphids may attack pecan aphids and other pecan pests.

Bugg et al. (1991b) proposed a cover crop management system for pecans to enhance beneficial arthropods in the orchard. Several cool-season and warm-season cover crops were evaluated to increase aphidophagous insects and other entomophaga to enhance biological control in vegetable and pecan agroecosystems (Wood et al., 1983; Bugg and Dutcher, 1989; Bugg and Ellis, 1990; Bugg et al., 1990a, 1991a; Bugg and Dutcher, 1993). According to Smith et al. (1994), 'Dixie' crimson clover consistently had higher early spring aphid densities and attracted more beneficial arthropods than several other cool-season legumes evaluated. The disadvantage of 'Dixie' crimson clover was that plants matured and senesced while trees were foliating, at which time there are usually few arthropod pests in the tree canopy. They suggested planting crimson clover with another annual legume, such as hairy vetch, that would begin rapid growth as 'Dixie' crimson clover senesced thus extending the time that the ground cover would hold beneficial arthropods in the orchard. Studies indicate that a mixture of cool season cover crops might provide a seasonal sequence of foods to beneficial arthropods that might otherwise disperse from pecan orchards (Bugg et al., 1990a; Bugg et al., 1991a). Bugg et al. (1990a) found that crimson clover and hairy vetch helped to increase and maintain high densities of coccinellids, however, no apparent impact on pecan aphid densities was found.

Augmentation of existing natural enemies is another possible strategy to control pecan aphids. Research has shown that inundative releases of green lacewing have been effective for control of certain injurious insects on field crops and have potential as a biological control (Lingren et al., 1968; Ridgway and Jones, 1968, 1969). *Chrysopa* spp. wide host and prey range make it an effective predator (Zeleny, 1985).

The purpose of this study was to evaluate a 'Dixie' crimson clover and hairy vetch ground cover mixture for its ability to attract beneficial arthropods into the orchard to provide subsequent control of pecan aphids and to supply nitrogen for the pecans. In addition, *Chrysopa rufilabris* was evaluated as a biological control of pecan aphids.

Materials and Methods

The study was conducted at Knight Creek Farm, a commercial orchard located in central Oklahoma near Sapulpa and at the Noble Foundation Research Ranch located in southern Oklahoma near Burneyville. The soil at Knight Creek Farm is a Port loam (fine-silty, mixed, thermic; Cumulic Haplustoll; Mollisols), and at Noble Foundation Research Ranch, a Teller-Minco association (Yahola fine sandy loam and Norwood clay loam, mixed, thermic; Cumulic Haplustoll; Mollisols). These soils occur on river bottom land, and are typical pecan soils in this region. Tree density at Knight Creek Farm was 36 trees/ha with a cross-sectional trunk area of 4.2 m^2/ha. At Noble Foundation Research Ranch tree density was 25 trees/ha with a cross-sectional trunk area of 10.3 m^2/ha. Both sites were native pecan orchards.

Soil preparation and planting. Preparation for ground cover planting consisted of applying glyphosate in August 1991 to kill existing vegetation. Soil was tilled about 2.5 cm deep each year then planted in September 1991 and 1992 at Knight Creek Farm and in October 1991 and September 1992 at Noble Foundation Research Ranch. Hairy vetch and 'Dixie' crimson clover seed were broadcast at 8 kg/ha and 10 kg/ha, respectively. The soil then was packed with a roller. Seed were inoculated with the appropriate *Rhizobium* before planting. At both sites 5 ha of bermudagrass was left intact as the control plot. The legume and control plot was separated by 0.5 km at Knight's and 1.5 km at Noble Foundation.

Orchard management. Orchard plots with grass ground covers were mowed approximately 5 times throughout the year. The clover/vetch ground covers were mowed when the hairy vetch began to senesce and residues were left on the surface. Trees at the Noble Foundation were not under irrigation but those at Knight Creek Farm were irrigated. In 1992 at Knight Creek Farm, *Bacillus thuringiensis* var. *kurstaki* was applied during June against first generation pecan nut casebearer (*Acrobasis nuxvorella* Neunzig, Lepidoptera: Pyralidae). In 1993 at Knight Creek Farm, chlorpyrifos was applied on April 21 and May 3 against phylloxera (*Phylloxera notabilis* Pergande, *P. russelae* Stoetzal, and *P. devastatrix* Pergande, Homoptera: Phylloxeridae), and on June 17 against pecan nut casebearer. Carbaryl was applied to control pecan weevil (*Curculio caryae* (Horn)), Coleoptera: Curculionidae) on September 15 and October 1, 1992 and on August 28 and September 15, 1993 at Knight Creek Farm. At Noble Foundation April 16, 1992, Lorsban was sprayed against phylloxera and *Bacillus thuringiensis* var. *kurstaki* was sprayed on June 4, 1992 for control of pecan nut casebearer. Sevin was applied for control of pecan weevil on Aug. 23 and Sept. 8, 1992. In 1993 at Noble Foundation, Sevin was applied for control of pecan weevil on Sept. 1 and Sept. 17. No other insecticides were used.

Legume biomass and nitrogen content. Five 1 m^2 legume samples were harvested at Knight Creek Farm April 22, 1992 and May 13, 1993, and at Noble

Foundation Research Ranch April 24, 1992 and May 7, 1993. These harvests coincided with the beginning of crimson clover anthesis, and were separated into crimson clover, hairy vetch and non-legume samples, oven-dried at 70°C, weighed and analyzed for nitrogen using the macro-Kjeldahl method (Horowitz, 1980). Total nitrogen in the legume tops was calculated from the legume dry weight and legume nitrogen concentration.

Pecan leaf analysis. Ammonium nitrate was applied at 0, 56, 112, and 168 kg/ha nitrogen to the grass-sodded areas in March. No nitrogen was applied to the legume plots. Pecan leaf samples (middle leaflet pair from the middle leaf on current season's growth) were collected in July from 10 trees in the legume plots and 50 trees in grass plots with known nitrogen application rates (10 trees/nitrogen rate). Samples were dried, ground to pass a 20-mesh screen and analyzed for nitrogen by the macro-Kjeldahl method. The relationship between leaf nitrogen concentration and nitrogen application rate was determined using regression analysis. The apparent nitrogen supplied by the legumes to the pecan trees was calculated based on this relationship.

Soil analysis. Soil samples were collected during October and analyzed for nitrate utilizing cadmium reduction (Page et al., 1982) and non-nitrate nitrogen utilizing macro-Kjeldahl. Ten samples were collected per treatment at 0-15 cm and 15-30 cm depths from legume and grass nitrogen plots. Samples were bagged, transported to the laboratory and frozen for later analysis.

Arthropod Sampling. Legume arthropods were sampled at seven- to 10-day intervals, April through June, using a 38 cm diameter sweep net. Five replications consisting of 10 sweeps/replication were collected between 10 a.m. and 2 p.m., bagged, transported to the laboratory and frozen for later identification and counting. Arthropods monitored on the legumes were aphids; lady beetles (*Hippodamia convergens*, *Coccinella septempunctata*, *Coleomegilla maculata lengi*, *Cycloneda munda*, *Olla v-nigrum*, *Anatis* sp.); green lacewings (*Chrysoperla* and *Chrysopa* spp.); brown lacewings (Neuroptera: Hemerobiidae); nabids (*Nabis* spp., Hemiptera: Nabidae); hover flies (Diptera: Syrphidae); predaceous stink bugs (Hemiptera: Pentatomidae); phytophagous stink bug (Hemiptera: Pentatomidae); soldier beetles (Coleoptera: Cantharidae); and spiders (Araneida). Aphids were divided into alatae and apterae plus nymphs. Lady beetle adults were identified by species and larvae were pooled across species. Adults and larvae of both green lacewings and brown lacewings, as well as nabid and hover fly adults, were counted. Counts of predaceous stink bugs and and phytophagous stink bugs did not distinguish between adults and nymphs. On April 23, 1993, aphids on the legumes were identified to species.

Tree canopy arthropods were also sampled at seven- to 10-day intervals, May through September, using a vaccuum sampling device (D-Vac Co., Ventura, Ca.). Five 0.1 m^2 areas per tree on five trees each in the legume and the grass plots were sampled on each date between 10 a.m. and 2 p.m. Samples were deposited into plastic bags containing pesticide strips, transported to the laboratory, frozen and later identified and counted. Arthropods monitored in the tree canopy by vaccuum sampling were the same as in the legume arthropod samples with the addition of assassin bugs (Reduviidae). Aphids (*Monelliopsis pecanis*, *Monellia caryella* and

Melanocallis caryaefoliae) and unhatched lacewing eggs were counted on 10 compound leaves per tree on five trees per treatment at 7-10 day intervals. Tree canopy arthropod samples, aphid counts and lacewing egg counts were taken at 3 to 4 meters height.

Yield analysis. Crop load was compared among treatments by counting the number of fruiting shoots at mid-canopy height in two 6 m^2 areas per tree in September. Ten trees were used in legume and nitrogen fertilization treatments. The same trees were used for crop load comparisons each year. Covariant analysis was used to determine the effect of treatment on fruiting shoots in 1993. Treatments were applied nitrogen versus legume nitrogen and the covariant was percentage fruiting shoots in 1992.

Phytophagous stink bug damage was determined by harvesting one 40-nut sample per tree on 10 trees each from legume and grass plots. These pecans were then analyzed for stink bug damage by examining kernels for black spots caused by feeding.

Green lacewing rearing and release. Green lacewing pupae were recieved in units of 500/frame, cut into 100 pupae units and reared in one-half-gallon containers at 72°C. When adults emerged they were fed a 50/50 mixture of sucrose/wheast (a combination of whey and yeast). Adults were fed and provided water daily. When the green lacewings were sexually mature (laying eggs) they were released (500/ha) in legume plots on the target dates of July 15, Aug 1 and Aug 15 to supplement native beneficial insects in controlling late-season aphids. Green lacewing release sites were equally spaced in the 5 ha area with releases positioned beneath the pecan canopies.

Results

Arthropod densities. Aphid densities during 1992 peaked in mid-April at both sites (Table 1 & 2). A second peak in aphids occurred in 1992 at Noble Foundation in mid-May. However, on the next sampling date (May 27) few aphids were collected from the hairy vetch, which was senescing. In 1992, the alatae density never exceeded 10% of the total aphids.

In 1993, aphid densities at Knight Creek Farm were more erratic, with the peak density on April 8 followed by a sharp decline, then an increase on the next sample date (Table 3). Aphid densities at Noble Foundation in 1993 peaked in early April with an extremely high density then decreased to near zero by mid-May (Table 4). Differences in aphid populations on the legumes between 1992 and 1993 can be attributed to rainfall. In 1992 rainfall was heavy reducing legume aphid densities at both sites in April. Aphid densities in 1993 at Knight Creek Farm were low and erratic caused by frequent rainfall, while Noble Foundation aphid densities were high due to low rainfall at that site. In 1993, the alatae density never exceeded 8% of the total aphids. Aphids on the legume ground cover in 1993 were blue alfalfa aphid (0.5%), pea aphid (99%) and cowpea aphid (0.5%).

Lady beetle larval densities in the legumes at Knight Creek Farm peaked April 21, 1992, then declined (Table 5). Adult lady beetle densities followed closely, peaking in early May. The lady beetle species in order of abundance in the legumes were *Hippodamia convergens* (37%), *Coleomegilla maculata lengi* (32%), *Coccinella septempunctata* (25%), and *Cycloneda munda* (6%) (Table 5). Smaller lady beetle densities were found in the tree canopies than on the legumes and differences in species distribution between legume and canopy were also found. In 1992 at Knight Creek Farm, no *Hippodamia convergens*, *Coccinella septempunctata*, or *Coleomegilla maculata lengi* were found in the trees with either the grass or legume ground cover. *Olla v-nigrum* was found in trees with clover/vetch ground cover on May 22 ($0.4/m^2$) and *Cycloneda munda* ($0.4/m^2$) in the control plot on Sept. 28. No significant differences in *Olla v-nigrum* or *Cyloneda munda* densities were found between legume and grass ground covers (data not shown).

At Noble Foundation in 1992 lady beetle larvae were only sampled twice on the legumes at the end of May. Lady beetle adult densities on the legumes peaked in mid-May with the most abundant species being *Hippodamia convergens* (74%) and *Coccinella septempunctata* (22%) followed by small populations of *Coleomegilla maculata lengi* (2%) and *Cycloneda munda* (2%) (Table 6). In 1992 at Noble Foundation, there were no significant differences between ground cover treatments in *Hippodamia convergens*, *Coccinella septempunctata*, *Olla v-nigrum* and *Cycloneda munda* sampled from the tree canopies. No *Coleomegilla maculata lengi* were found in the canopies. Lady beetle densities were highest in May (Table 14). Lady beetle species distribution in the canopies were *Hippodamia convergens* (33%), *Coccinella septempunctata* (25%), *Olla v-nigrum* at (25%) and *Cycloneda munda* at (17%).

In 1993 at Knight Creek Farm, lady beetle larvae collected on the legumes from April 28 through June 1 were stable with a slight population peak on May 20 (Table 7). Lady beetle adult densities were erratic (Table 7) coinciding with the erratic nature of the legume aphid populations (Table 3). *Coleomegilla maculata lengi* (51%) was the most abundant lady beetle species followed by *Hippodamia convergens* (26%), *Coccinella septempunctata* (14%) and *Cycloneda munda* (9%). No *Anatis* sp. or *Olla v-nigrum* were found (Table 7). In 1993 at Knight Creek Farm, lady beetle larval densities sampled from the canopies were not significantly different between grass and legume plots. Adult *Hippodamia convergens*, *Coleomegilla maculata lengi*, *Olla v-nigrum*, *Cycloneda munda* and *Anatis* sp. densities in the tree canopies were not significantly different between grass and legume plots (data not shown). No *Coccinella septempunctata* were found in the trees. The highest densities of lady beetle adults occurred during May through mid-July (Table 15). The most abundant lady beetle species were *Olla v-nigrum* (36%) and *Cycloneda munda* (36%) followed by *Hippodamia convergens* (18%) and *Coleomegilla maculata lengi* (9%).

At the Noble Foundation in 1993, lady beetle larval densities peaked May 7 on legumes. Lady beetle adults on legumes also peaked in early May and again in early June (Table 8). The lady beetle species distribution was *Hippodamia convergens* (41%), *Coleomegilla maculata lengi* (25%), *Coccinella septempunctata* (22%), *Cycloneda munda* (10%) and *Olla v-nigrum* (2%). No *Anatis* sp. were found. Lady beetle larvae were found in the tree canopies at Noble Foundation in 1993 but densities were not significantly different between grass and legume plots (Table 16).

Adult *Hippodamia convergens*, *Coleomegilla maculata lengi*, *Olla v-nigrum*, *Cycloneda munda*, and *Anatis* sp. were found but densities were not significantly different between control and legume plots. No *Coccinella septempunctata* were found in the tree canopies (data not shown). Most of the lady beetle adults were found in May and June in the pecan canopies (Table 16). The lady beetle species in order of magnitude were *Olla v-nigrum* (46%), *Cycloneda munda* (38%), *Hippodamia convergens* (8%), *Coleomegilla maculata lengi* (4%) and *Anatis* sp. (4%).

Lady beetle species distributions in the pecan canopies were different than those in the legumes. At Knight Creek Farm in 1993, 36% of the lady beetles sampled in the trees were *Cycloneda munda* but only 9% *Cycloneda munda* were sampled from the legumes. Thirty-six percent of the lady beetles in the tree canopy were *Olla v-nigrum*, but none were found on the legumes. At Noble Foundation in 1993, 46% of the lady beetles were *Olla v-nigrum* in the trees while in the legumes they accounted for only 2%. *Cycloneda munda* was abundant in the pecan canopies (38%), but scarce in the legumes (10%).

In 1992 at Knight Creek Farm green lacewing adult densities in the clover/vetch peaked twice, first in mid-April, then in late May. Green lacewing larvae in the legumes peaked in early May (Table 9). Green lacewing adult and larval densities in the trees were not affected by the ground cover. Green lacewing larvae in the pecan canopies were present on only one sampling date. Green lacewing adult densities in the trees of both grass and clover/vetch plots were at their highest in late May and throughout June, again increasing towards the end of September (Table 13).

Spider densities on the legumes at Knight Creek Farm peaked in 1992 during mid-April as well as in mid-June (Table 9). Spider densities in the trees were not significantly different between the legume and grass plots; however, higher densities were found in May and mid-August than at other times (Table 13). Hover flies were found only on May 22 and June 12 on the legumes (Table 9). Hover fly densities in the trees were not significantly different between grass and clover/vetch plots (Table 13).

Nabis sp. at Knight Creek Farm in 1992 were erratic (Table 9) and densities in the trees were not significantly different between the grass and clover/vetch plots (Table 13). *Arilus* sp. and *Sinea* sp. assassin bugs were found in the pecan canopies but densities were not significantly different between grass and clover/vetch plots. No *Zelus* sp. were found. Total assassin bugs were also not significantly different between treatments. The highest densities occurred in May and in August (Table 13).

Brown lacewing adults, brown lacewing larvae and predaceous stink bugs were not found in the legumes. Brown lacewing adults in the trees were not signficantly different between grass and clover/vetch plots (data not shown). No brown lacewing larvae were found in the pecan canopies. Phytophagous stink bugs and soldier beetles had negligible densities in the legumes and pecan canopies (data not shown). No predaceous stink bugs were found in the pecan canopies.

In 1992 at the Noble Foundation, there were two peaks in green lacewing adults on the legumes, one towards the end of April and the other during mid-May. Green lacewing larvae in the legumes also peaked in mid-May (Table 10). Green lacewing adult and larval densities in the trees were not significantly different between grass and legume plots. The adult densities were highest during May and into June and then increased again in Sept. The green lacewing larval densities in the trees were low until August (Table 14).

Brown lacewing adults and larvae in the legumes at Noble Foundation in 1992 had negligible densities (data not shown). Brown lacewing adults in the trees were not significantly different between treatment. The highest densities of brown lacewing adults were sampled during June and increased through Sept. and into Oct. (Table 14). No brown lacewing larvae were found in the pecan canopies.

Spider densities in the legumes at Noble Foundation in 1992 peaked in mid-April and again at the end of May (Table 10). Spider densities in the tree canopies were not significantly different between the grass and clover/vetch plots. Spider densities were high in May, lower during June and July, then increased to very high densities in August, September and into October (Table 14). Hover fly densities in the legumes peaked at the end of April and again at the end of May (Table 10). No hover flies were found in the pecan canopies. Densities of *Nabis* sp. were negligible in the legumes at Noble Foundation in 1992 (Table 10). No *Nabis* sp. were found in the pecan canopies. *Arilus* sp. and *Sinea* sp. assassin bugs in the trees were not significantly different between treatments. *Arilus* sp. was the most abundant assassin bug species with a peak density in June. No *Zelus* sp. were found. Total assassin bug densities in the trees were not significantly different between the grass and legume plots (Table 14). Negligible phytophagous and predaceous stink bugs, and soldier beetles were found in the legumes (data not shown). No predaceous stink bugs were found in the trees. Phytophagous stink bugs in the pecan canopies were found in August and September, but were not signficantly different between treatments (Table 14).

At Knight Creek Farm in 1993, green lacewing adult densities in the legumes were highest in April, decreasing to zero by the end of May (Table 11). Green lacewing adults in the canopies were not significantly different between grass and clover/vetch (Table 15). Green lacewing larval densities in the legumes peaked in mid-May (Table 11). Green lacewing larvae sampled in the canopies were most abundant in July (Table 15).

Brown lacewing adults in the legumes were negligible and no brown lacewing larvae were found in the legumes. Brown lacewing adults in the canopies were most abundant at the end of June and early July but were not signficantly different between legume and grass plots (Table 15). Brown lacewing larvae were not found in the canopies.

Spider densities in the legumes at Knight Creek Farm in 1993 showed relatively high densities across most of the sample period (Table 11). Canopy samples showed no significant differences between legume and grass plots but spiders usually were present throughout the sample period in both grass and legume plots (Table 15).

Hover flies found in the legumes at Knight Creek Farm in 1993 were most abundant from the end of May to the beginning of June (data not shown). Hover flies in the canopies were not significant between control and legume plots and were only found on two dates in the clover/vetch plots (data not shown). *Nabis* sp. density in the legumes was erratic throughout the sample season (Table 11), and no nabids were found in the canopies.

No assassin bugs were found in the legume samples at Knight Creek Farm in 1993. In the pecan canopies assassin bug densities were erratic, with most of the assassin bugs found between mid-July and mid-August (Table 15). Negligible densities of predaceous and phytophagous stink bugs were found on the legumes (Table 11) as well as in the pecan canopies (data not shown).

At Noble Foundation in 1993, green lacewing adult densities in the legumes peaked in mid-April and mid-May (Table 12). Green lacewing adults in the pecan canopies were most abundant in May; however, they were not significant between the treatments (Table 16). Green lacewing larvae peaked on the legumes in early May (Table 12) while larvae in the canopies were most abundant in early June and August (Table 16). Negligible densities of brown lacewing adults and no brown lacewing larvae were found on the legumes (data not shown). In the canopies brown lacewing adults were found in May and early June, with none on subsequent sampling dates until Aug. 27 (Table 16). No brown lacewing larvae were found in the canopies.

Spider densities at Noble Foundation in 1993 were very high over the entire sample period (Table 12) with peak densities during mid-April, early May and mid-June (Table 12). Spider densities in the canopies were not significantly different between grass and legume plots. The densities were high in both grass and clover/vetch plots (Table 16).

Hover fly densities were negligible in the legumes as well as in the pecan canopies (data not shown). *Nabis* sp. in the legumes were found over most of the sample period with the major peak on May 21 (Table 12). No *Nabis* sp. were found in the pecan canopies. Assassin bugs in the legumes were negligible while those found in the pecan canopies were mainly *Arilus* sp. with a few *Sinea* sp. Most assassin bugs sampled in the canopies were found in the clover/vetch canopies; however, treatments were not significantly different (Table 16). Predaceous stink bugs sampled on the legumes at Noble Foundation in 1993 were most abundant in June (Table 12) with low densities in the canopies found on 18 June in clover/vetch plots and 12 July in grass plots (data not shown). Phytophagous stink bug densities on the legumes were relatively low from April through June with the highest densities occurring in mid-June (Table 12). Three incidences of phytophagous stink bugs in the canopies were found, the first two in July in the clover/vetch and one in August in the grass plots. There was no significant difference between grass and legume plots (data not shown). Stinkbug damage at both sites over the two year study ranged from 0% to 3% in the clover/vetch plots and 0% to 3% in the grass plots with no significant difference between the grass and clover/vetch plots (Table 21).

<u>Pecan aphid and lacewing egg densities</u>. Pecan aphid densities on June 25 and Sept. 17 at Knight Creek Farm in 1992 were larger on trees with legume ground covers than grass ground covers (Table 17). There were no other significant differences, and pecan aphid densities were usually low. Unhatched lacewing eggs

were not affected by treatments. Lacewing eggs were most abundant during early to mid-July (Table 17).

Sampling at Noble Foundation in 1992 found relatively low densities of pecan aphids in April followed by an increase during mid-May with significantly more aphids in the grass plot than the legume plot on May 13 (Table 18). Densities again decreased and were low until Sept. 8. Significantly more aphids/compound leaf were found on pecans with legume ground covers on Aug. 25 and Sept. 8. Aphid densities were relatively low on Aug. 25 with higher densities on Sept. 8. On Sept. 23 there were significantly more pecan aphids found in the trees with grass as a ground cover than with clover/vetch. On the final sample date the pecan aphid densities were not signficantly different (Table 18). Unhatched lacewing eggs showed no significance between grass and clover/vetch plots until Aug. 25 when trees with clover/vetch ground cover had significantly more lacewing eggs. The remaining sample dates were not significantly different (Table 18).

Knight Creek Farm pecan aphid densities in 1993 had only one date, July 13, with a significant treatment difference, in which trees with clover/vetch ground cover had more aphids than those in the grass plot (Table 19). However, aphid densities were very low on July 13. Aphids peaked in June and July in both plots. Unhatched lacewing eggs in the canopies showed no significance between grass and clover/vetch plots. Aphids were low throughout the growing season at Knight Creek Farm (maximum density 3.9 aphids/leaf).

Pecan aphids at Noble Foundation in 1993 showed significantly different densities on two dates. The first was on May 7, with more aphids on trees with grass as a ground cover. However, the densities were low. The second incidence occurred May 28, in which there were significantly more aphids on trees with clover/vetch as a ground cover. This was the highest density of pecan aphids found on any trees during the two years of this study. However, on the next sample date the densities were again low and stayed low for the rest of the season. The peak on May 28 was the highest peak in densities for both grass and clover/vetch plots at Noble Foundation in 1993. Unhatched lacewing eggs showed no significant differences between grass and legume plots. The highest densities in the grass plots occurred at the end of May while the highest densities in the clover/vetch plots occurred in August (Table 20).

Green lacewing releases. There were no significant differences in green lacewing eggs during both years and both sites, except on one date at Noble Foundation in 1992 (Table 18). No significant differences between grass and legume treatments for green lacewing adult or larval densities in the pecan canopies were found (Table 14, Table 15, Table 16, Table 17). Pecan aphid densities also appeared unaffected by green lacewing releases. Green lacewing releases did not affect late season green lacewing densities or improve control of late-season pecan aphids.

Legume biomass and nitrogen. Legume biomass from a single harvest showed different trends at the two sites. Hairy vetch was the dominant legume species at Noble Foundation in 1992 and crimson clover was the dominant legume species at the Noble Foundation in 1993 and at Knight Creek Farm in 1992 and 1993 (Table 22).

Legume biomass was greater at Knight Creek Farm compared to Noble Foundation in both years even though non-legume biomass was higher at Knight Creek Farm both years.

Legume nitrogen concentration in the tops for both sites over the two years was highest for the hairy vetch, ranging from 3.68% to 3.92%. Crimson clover nitrogen concentration ranged from 2.2% to 2.78% (Table 22). Nitrogen in crimson clover tops ranged from 19 kg/ha to 64 kg/ha N over the two years on both sites. Total nitrogen in hairy vetch ranged from 16 kg/ha to 53 kg/ha N. Total nitrogen for both legumes ranged from 72 kg/ha to 89 kg/ha N (Table 22).

Soil nitrogen. At Knight Creek Farm in 1992 there was no significant difference in Kjeldahl-nitrogen between the legumes versus nitrogen applications at 0-15 cm and 15-30 cm depths (Table 23). In 1993 at Knight Creek Farm there was significantly more Kjeldahl-nitrogen found in the 0-15 cm depth soil planted to clover/vetch when compared to the 0, 56, 112 and 168 kg nitrogen applications. At the 15-30 cm depth there was also significantly more Kjeldahl-nitrogen in the soil planted to clover/vetch than in the soil with 112 kg nitrogen applied.

At Noble Foundation in 1992 at 0-15 cm and 15-30 cm, there was more Kjeldahl-nitrogen in the clover/vetch plots than in the 168 kg nitrogen application plot. This might be due to random error. All other treatments were not significant. At Noble Foundation in 1993, more Kjeldahl-nitrogen was found in the 56 kg/ha N application rate at the 0-15 cm depth compared to using legume ground covers (Table 23).

At Knight Creek Farm in 1992 and in 1993, nitrate-nitrogen was more abundant in the plots with clover/vetch than from all but one of the spring nitrogen applications with grass ground covers. At Noble Foundation in 1992, significantly more nitrate-nitrogen was found in the clover/vetch plots compared to the 0 and 23 kg nitrogen application plots at both depths. At Noble Foundation in 1993, significantly more nitrate-nitrogen at both depths was found in the clover/vetch plots than in all but two of the fertilizer treatments (Table 23).

Yield. No significant effect of treatment was found on the percentage of fruiting shoots/tree at Knight Creek Farm or Noble Foundation (Table 24). The covariant (percent fruiting shoots in 1992) affected the percent of fruiting shoots at Noble Foundation but not at Knight Creek Farm. Crop loads at the Noble Foundation varied more than at Knight Creek Farm; therefore, the covariant affected the percentage of fruiting shoots more at the Noble Foundation than at Knight Creek Farm. Fruiting development has been shown to reduce the subsequent crop (Sparks and Brack, 1972; Sparks, 1983).

Nitrogen supplied by legumes. In 1992 at Knight Creek Farm, the pecan leaf N concentration of the clover and vetch plots was 2.6%, the equivalent of 143 kg/ha N ($\hat{y}=-824+366x$, $r^2=0.38$, $P \leq 0.01$) supplied to the trees while at the Noble Foundation the pecan leaf N concentration of the legume plots was 2.74%, the equivalent of 156 kg/ha N ($\hat{y}=-670+295x$, $r^2=0.45$, $P \leq 0.01$) supplied (Table 25). In 1993 at Knight Creek Farm, the pecan leaf N concentration from the legumes was 2.65% which supplied the equivalent of 159 kg/ha N ($\hat{y}=-683+311x$, $r^2=0.32$,

$P \leq 0.01$) to the trees which was the highest value over the two years of the study. At the Noble Foundation in 1993 the pecan leaf N concentration was 2.62% in the legume plots supplying the equivalent of 101 kg/ha N ($\hat{y}$=-600+263x, r^2=0.31, $P \leq 0.01$) to the pecan trees, the lowest nitrogen value during the study. (Table 27).

Conclusions

A mixture of 'Dixie' crimson clover and hairy vetch had large densities of aphids that attracted beneficial arthropods. The most abundant beneficial arthropods sampled in the legumes were spiders, lady beetles, green lacewings and nabids, respectively. The ground cover type, however, did not affect the densities of beneficial species in the pecan canopies. This could be due to low and erratic pecan aphid densities, which were a food source for the beneficial arthropods, and also differences in habitat preference of certain beneficial species.

The most abundant beneficial arthropods in the pecan canopies were spiders, green lacewings, brown lacewings and lady beetles respectively. Spider densities were usually consistant from spring through the fall. Spiders are general predators and their feeding activity is not necessarily linked to pecan aphid densities. Green lacewings generally showed a bimodal seasonal abundance pattern similar to pecan aphid densities, with higher densities in the spring and early summer, low densities through the summer and then greater densities in the fall. Lady beetles were most abundant in the spring. Lady beetle species distribution in the pecan canopies was different than in the legumes. Predominant lady beetle species in the legumes were

Hippodamia convergens, *Coleomegilla maculata lengi* and *Coccinella septempunctata* while the most abundant species in the pecan canopies were *Olla v-nigrum*, *Cycloneda munda* and *Hippodamia convergens*. Data indicate that certain beneficial insect species differ in habitat preference, either being more arboreal or terrestrial in nature. *Olla v-nigrum* and *Cycloneda munda* have more of an arboreal nature, preferring the habitat of the canopy to that of the legumes. *Hippodamia convergens*, however, can inhabit both the legumes and the pecan canopies.

In 1992 at Knight Creek Farm and 1993 at Noble Foundation, significantly more pecan aphids occasionally were found in the canopies with clover/vetch as a ground cover than in the grass. At other times aphid densities were not affected by treatment. Data from Noble Foundation in 1992 were inconclusive with significantly more pecan aphids in clover/vetch or grass plots on different dates. In 1993 at Knight Creek Farm there appeared to be some suppression of pecan aphids in the canopies with clover/vetch as a ground cover. Overall these data are inconclusive regarding the effects of ground cover on pecan aphid densities. During both years the food source for the beneficial arthropods, pecan aphids, were at relatively low and erratic densities in the canopies. This would necessitate either an extinction or a migration of the beneficial species to areas in which a food source existed.

Total biomass from the legumes ranged from 2867 kg/ha (dry weight) to 5703 kg/ha. The clover/vetch ground cover supplied over 100 kg/ha every year to the pecan trees and did not adversely affect pecan yield. However, soil nitrate levels during the fall using clover/vetch was significantly higher than commercially fertilized grass plots, suggesting that nitrate leaching might be higher using legume ground covers.

Results have shown that crimson clover and hairy vetch supplied over 100 kg/ha N to pecan trees, which under most conditions would meet the nitrogen requirements of the trees. However, data showed using the beneficial arthropods associated with the legumes for control of pecan aphids cannot be currently recommended. The release of *Chrysopa rufilabris* for control of pecan aphids was also unsuccessful. Future research involving higher densities of pecan aphids should be attempted to help in analyzing the effectiveness of beneficial arthropods.

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Table 1. Legume aphid densities in 1992 at Knight Creek Farm.

		Aphids/sweep		
Date	Treatment	Apterae	Alatae	Total aphids
7 April	Clover/vetch	29.2	4.8	34.0
	Std error	±13.4	±1.3	±14.5
14 April	Clover/vetch	67.7	4.0	71.8
	Std error	±22.5	±2.0	±24.1
21 April	Clover/vetch	14.9	3.1	18.0
	Std error	±5.7	±0.8	±6.3
5 May	Clover/vetch	1.0	0.2	1.1
	Std error	±0.3	±0.1	±0.2
22 May	Clover/vetch	1.6	0	1.6
	Std error	±0.5	±0	±0.5
12 June	Clover/vetch	0.6	0	0.6
	Std error	±0.1	±0	±0.1
25 June	Clover/vetch	0.4	0	0.4
	Std error	±0.1	±0	±0.1

Table 2. Legume aphid densities in 1992 at Noble Foundation Research Ranch.

		Aphids/sweep		
Date	Treatment	Apterae	Alatae	Total aphids
16 April	Clover/vetch	46.9	2.4	49.3
	Std error	±11.9	±1.0	±12.8
24 April	Clover/vetch	0.2	2.7	3.0
	Std error	±0.2	±0.8	±0.9
30 April	Clover/vetch	1.5	2.0	3.5
	Std error	±0.4	±0.4	±0.6
13 May	Clover/vetch	23.9	0.9	24.8
	Std error	±7.9	±0.5	±8.4
27 May	Clover/vetch	0.2	0	0.2
	Std error	±0.1	±0	±0.1

Table 3. Legume aphid densities in 1993 at Knight Creek Farm.

		Aphids/sweep		
Date	Treatment	Apterae	Alatae	Total aphids
8 April	Clover/vetch	25.3	0.5	25.8
	Std error	±0.9	±0.1	±1.0
15 April	Clover/vetch	1.6	0	1.7
	Std error	±0.8	±0	±0.8
22 April	Clover/vetch	14.8	0.8	15.6
	Std error	±6.2	±0.3	±6.4
28 April	Clover/vetch	14.3	0.1	14.4
	Std error	±10.6	±0.1	±10.6
5 May	Clover/vetch	2.0	0.7	2.7
	Std error	±0.7	±0.3	±0.8
13 May	Clover/vetch	3.2	1.0	4.2
	Std error	±0.8	±0.2	±0.9
20 May	Clover/vetch	1.2	0	1.2
	Std error	±0.2	±0	±0.2
26 May	Clover/vetch	0.7	0	0.7
	Std error	±0.3	±0	±0.3
1 June	Clover/vetch	0.6	0	0.6
	Std error	±0.3	±0	±0.3
8 June	Clover/vetch	0.1	0	0.1
	Std error	±0.1	±0	±0.1
16 June	Clover/vetch	0	0	0
	Std error	±0	±0	±0

Table 4. Legume aphid densities in 1993 at Noble Foundation Research Ranch.

		Aphids/sweep		
Date	Treatment	Apterae	Alatae	Total aphids
6 April	Clover/vetch	218.3	8.3	226.7
	Std error	±37.0	±4.2	±35.6
16 April	Clover/vetch	181.1	24.4	205.5
	Std error	±24.7	±6.8	±25.6
23 April	Clover/vetch	50.1	5.9	56.0
	Std error	±17.1	±1.5	±18.3
7 May	Clover/vetch	4.9	0.8	5.6
	Std error	±2.2	±0.4	±2.5
14 May	Clover/vetch	0.4	0	0.4
	Std error	±0.3	±0	±0.3
21 May	Clover/vetch	0.3	0	0.4
	Std error	±0.2	±0	±0.2
28 May	Clover/vetch	0.4	0	0.4
	Std error	±0.4	±0	±0.4
4 June	Clover/vetch	0.4	0	0.4
	Std error	±0.2	±0	±0.2
14 June	Clover/vetch	0	0	0
	Std error	±0	±0	±0
18 June	Clover/vetch	0	0	0
	Std error	±0	±0	±0
25 June	Clover/vetch	0	0	0
	Std error	±0	±0	±0

Table 5. Lady beetle densities on legumes in 1992 at Knight Creek Farm.

		Lady beetle adults/sweep					
Date	Treatment	*Hippodamia convergens*	*Coccinella septempunctata*	*Coleomegilla maculata lengi*	*Cycloneda munda*	Total	Lady beetle larvae/sweep
7 April	Clover/vetch	0	0	0.02	0	0.02	0
	Std error	±0	±0	±0.02	±0	±0.02	±0
14 April	Clover/vetch	0.04	0	0.04	0	0.08	0.3
	Std error	±0.02	±0	±0.02	±0	±0.04	±0.18
21 April	Clover/vetch	0.04	0	0.02	0	0.06	0.92
	Std error	±0.02	±0	±0.02	±0	±0.02	±0.56
5 May	Clover/vetch	0.18	0.14	0.12	0.04	0.48	0.24
	Std error	±0.06	±0.07	±0.04	±0.02	±0.09	±0.12
22 May	Clover/vetch	0.14	0.1	0.06	0.04	0.34	0.2
	Std error	±0.02	±0.06	±0.04	±0.04	±0.09	±0.13
12 June	Clover/vetch	0.02	0.02	0.06	0	0.1	0.06
	Std error	±0.02	±0.02	±0.04	±0	±0.06	±0.02
25 June	Clover/vetch	0.06	0.06	0.1	0	0.22	0.12
	Std error	±0.02	±0.04	±0.08	±0	±0.08	±0.05

Table 6. Lady beetle densities on legumes in 1992 at Noble Foundation Research Ranch.

Date	Treatment	Lady beetle adults/sweep					
		Hippodamia convergens	*Coccinella septempunctata*	*Coleomegilla maculata lengi*	*Cycloneda munda*	Total	Lady beetle larvae/sweep
16 April	Clover/vetch	0	0.04	0	0	0.04	0
	Std error	±0	±0.04	±0	±0	±0.04	±0
24 April	Clover/vetch	0.1	0.10	0.02	0	0.22	0
	Std error	±0.06	±0.04	±0.02	±0	±0.04	±0
30 April	Clover/vetch	0.2	0.04	0	0	0.24	0
	Std error	±0.08	±0.02	±0	±0	±0.09	±0
13 May	Clover/vetch	1.0	0.26	0.02	0.02	1.30	0.62
	Std error	±0.47	±0.16	±0.02	±0.02	±0.64	±0.19
27 May	Clover/vetch	0.2	0	0	0.02	0.22	0.06
	Std error	±0.09	±0	±0	±0.02	±0.09	±0.04

Table 7. Lady beetle densities on legumes in 1993 at Knight Creek Farm.

		Lady beetle adults/sweep					
Date	Treatment	*Hippodamia convergens*	*Coccinella septempunctata*	*Coleomegilla maculata lengi*	*Cycloneda munda*	Total	Lady beetle larvae/sweep
8 April	Clover/vetch	0.02	0	0	0.02	0.04	0
	Std error	±0.02	±0	±0	±0.02	±0.04	±0
15 April	Clover/vetch	0.02	0.02	0	0	0.04	0
	Std error	±0.02	±0.02	±0	±0	±0.02	±0
22 April	Clover/vetch	0	0	0.22	0.02	0.24	0
	Std error	±0	±0	±0.1	±0.02	±0.12	±0
28 April	Clover/vetch	0.04	0	0.22	0	0.26	0.04
	Std error	±0.04	±0	±0.22	±0	±0.26	±0.04
5 May	Clover/vetch	0.04	0	0.04	0	0.08	0.02
	Std error	±0.04	±0	±0.02	±0	±0.04	±0.02
13 May	Clover/vetch	0.02	0.02	0.04	0.02	0.1	0.04
	Std error	±0.02	±0.02	±0.04	±0.02	±0.05	±0.02
20 May	Clover/vetch	0.12	0.08	0.28	0.02	0.5	0.3
	Std error	±0.1	±0.06	±0.12	±0.02	±0.21	±0.18
26 May	Clover/vetch	0.08	0.06	0.1	0.02	0.26	0.04
	Std error	±0.04	±0.02	±0.08	±0.02	±0.12	±0.04
1 June	Clover/vetch	0.06	0.08	0.06	0.08	0.28	0.06
	Std error	±0.06	±0.02	±0.04	0.04	±0.1	±0.04
8 June	Clover/vetch	0.22	0.06	0.2	0.02	0.5	0
	Std error	±0.09	±0.04	±0.09	±0.02	±0.2	±0
16 June	Clover/vetch	0	0	0.04	0	0.04	0
	Std error	±0	±0	±0.02	±0	±0.02	±0

Table 7. Lady beetle densities on legumes in 1993 at Knight Creek Farm.

		Lady beetle adults/sweep					
Date	Treatment	*Hippodamia convergens*	*Coccinella septempunctata*	*Coleomegilla maculata lengi*	*Cycloneda munda*	Total	Lady beetle larvae/sweep
8 April	Clover/vetch	0.02	0	0	0.02	0.04	0
	Std error	±0.02	±0	±0	±0.02	±0.04	±0
15 April	Clover/vetch	0.02	0.02	0	0	0.04	0
	Std error	±0.02	±0.02	±0	±0	±0.02	±0
22 April	Clover/vetch	0	0	0.22	0.02	0.24	0
	Std error	±0	±0	±0.1	±0.02	±0.12	±0
28 April	Clover/vetch	0.04	0	0.22	0	0.26	0.04
	Std error	±0.04	±0	±0.22	±0	±0.26	±0.04
5 May	Clover/vetch	0.04	0	0.04	0	0.08	0.02
	Std error	±0.04	±0	±0.02	±0	±0.04	±0.02
13 May	Clover/vetch	0.02	0.02	0.04	0.02	0.1	0.04
	Std error	±0.02	±0.02	±0.04	±0.02	±0.05	±0.02
20 May	Clover/vetch	0.12	0.08	0.28	0.02	0.5	0.3
	Std error	±0.1	±0.06	±0.12	±0.02	±0.21	±0.18
26 May	Clover/vetch	0.08	0.06	0.1	0.02	0.26	0.04
	Std error	±0.04	±0.02	±0.08	±0.02	±0.12	±0.04
1 June	Clover/vetch	0.06	0.08	0.06	0.08	0.28	0.06
	Std error	±0.06	±0.02	±0.04	0.04	±0.1	±0.04
8 June	Clover/vetch	0.22	0.06	0.2	0.02	0.5	0
	Std error	±0.09	±0.04	±0.09	±0.02	±0.2	±0
16 June	Clover/vetch	0	0	0.04	0	0.04	0
	Std error	±0	±0	±0.02	±0	±0.02	±0

Table 8. Lady beetle densities on legumes in 1993 at Noble Foundation Research Ranch.

		Lady beetle adults/sweep					
Date	Treatment	*Hippodamia convergens*	*Coccinella septempunctata*	*Coleomegilla maculata lengi*	*Cycloneda munda*	Total	Lady beetle larvae/sweep
6 April	Clover/vetch	0.1	0	0	0.1	0.2	0
	Std error	±0.03	±0	±0	±0	±0.03	±0
16 April	Clover/vetch	0.12	0	0.12	0	0.28	0.34
	Std error	±0.06	±0	±0.07	±0	±0.07	±0.18
23 April	Clover/vetch	0.1	0.08	0.04	0.02	0.28	1.04
	Std error	±0.04	±0.04	±0.02	±0.02	±0.1	±0.34
7 May	Clover/vetch	0.48	0.34	0.08	0	0.9	3.74
	Std error	±0.24	±0.16	±0.04	±0	±0.37	±0.73
14 May	Clover/vetch	0.42	0.18	0.06	0.04	0.7	1.22
	Std error	±0.12	±0.05	±0.06	±0.02	±0.1	±0.27
21 May	Clover/vetch	0.1	0.06	0.24	0.18	0.58	0.16
	Std error	±0.1	±0.06	±0.09	±0.1	±0.19	±0.07
28 May	Clover/vetch	0.1	0.06	0	0.02	0.18	0
	Std error	±0.03	±0.04	±0	±0.02	±0.07	±0
4 June	Clover/vetch	0.14	0.08	0.2	0	0.42	0.06
	Std error	±0.06	±0.05	±0.2	±0	±0.17	±0.04
14 June	Clover/vetch	0	0.02	0	0.02	0.04	0
	Std error	±0	±0.02	±0	0.02	±0.02	±0
18 June	Clover/vetch	0	0	0.06	0	0.06	0
	Std error	±0	±0	±0.04	±0	±0.04	±0
25 June	Clover/vetch	0	0	0.16	0	0.16	0.02
	Std error	±0	±0	±0.08	±0	±0.08	±0.02

Table 9. Arthropod densities on legumes in 1992 at Knight Creek Farm.

		Arthropods/sweep				
Date	Treatment	Green lacewing adult	Green lacewing larvae	Spider	Hover fly	*Nabis* spp.
7 April	Clover/vetch	0.09	0	0.29	0	0
	Std error	±0.04	±0	±0.03	±0	±0
14 April	Clover/vetch	0.1	0	0.4	0	0.12
	Std error	±0.06	±0	±0.09	±0	±0.05
21 April	Clover/vetch	0.02	0.02	0.32	0	0.02
	Std error	±0.02	±0.02	±0.09	±0	±0.02
5 May	Clover/vetch	0	0.16	0.28	0	0.18
	Std error	±0	±0.02	±0.11	±0	±0.04
22 May	Clover/vetch	0.16	0.12	0.42	0.14	0.28
	Std error	±0.05	±0.04	±0.17	±0.07	±0.09
12 June	Clover/vetch	0.02	0	1.38	0.34	0.1
	Std error	±0.02	±0	±0.33	±0.12	±0.03
25 June	Clover/vetch	0	0.04	0.54	0	0.16
	Std error	±0	±0.04	±0.12	±0	±0.07

Table 10. Arthropod densities on legumes in 1992 at Noble Foundation Research Ranch.

		Arthropods/sweep				
Date	Treatment	Green lacewing adult	Green lacewing larvae	Spider	Hover fly	*Nabis* spp.
16 April	Clover/vetch	0.04	0	0.4	0	0.02
	Std error	±0.02	±0	±0.1	±0	±0.02
24 April	Clover/vetch	0.16	0	0.28	0	0.04
	Std error	±0.07	±0	±0.11	±0	±0.02
30 April	Clover/vetch	0.1	0.04	0.14	0.58	0.02
	Std error	±0.06	±0.02	±0.05	±0.2	±0.02
13 May	Clover/vetch	0.3	0.16	0.22	0.08	0.06
	Std error	±0.05	±0.11	±0.11	±0.05	±0.02
27 May	Clover/vetch	0.08	0.1	0.26	0.14	0.02
	Std error	±0.04	±0.03	±0.04	±0.02	±0.02

Table 11. Arthropod densities on legumes in 1993 at Knight Creek Farm.

		Arthropods/sweep					
Date	Treatment	Green lacewing adult	Green lacewing larvae	Spider	Predaceous stink bug	Phytophagous stink bug	*Nabis* sp.
8 April	Clover/vetch	0.12	0	0.34	0	0.02	0.1
	Std error	±0.02	±0	±0.1	±0	±0.02	±0.06
15 April	Clover/vetch	0.08	0	0.18	0	0.02	0.08
	Std error	±0.04	±0	±0.04	±0	±0.02	±0.06
22 April	Clover/vetch	0.22	0	0.3	0.12	0.02	0.3
	Std error	±0.04	±0	±0.1	±0.1	±0.02	±0.11
28 April	Clover/vetch	0.04	0	0.1	0.1	0.04	0.24
	Std error	±0.04	±0	±0.06	±0.1	±0.02	±0.07
5 May	Clover/vetch	0.04	0	0.6	0.08	0.02	0.08
	Std error	±0.02	±0	±0.15	±0.08	±0.02	±0.04
13 May	Clover/vetch	0.08	0.04	0.66	0	0.02	0.04
	Std error	±0.04	±0.02	±0.11	±0	±0.02	±0.04
20 May	Clover/vetch	0.06	0.22	0.26	0	0	0
	Std error	±0.02	±0.1	±0.11	±0	±0	±0
26 May	Clover/vetch	0.04	0.04	0.14	0	0.02	0.02
	Std error	±0.02	±0.02	±0.05	±0	±0.02	±0.02
1 June	Clover/vetch	0	0	0.34	0	0.04	0.02
	Std error	±0	±0	±0.08	±0	±0.02	±0.02
8 June	Clover/vetch	0	0	0.24	0.04	0	0.34
	Std error	±0	±0	±0.05	±0.02	±0	±0.15
16 June	Clover/vetch	0	0	0.04	0	0.06	0.06
	Std error	±0	±0	±0.02	±0	±0.04	±0.02

Table 12. Arthropod densities on legumes in 1993 Noble Foundation Research Ranch.

		Arthropods/sweep					
Date	Treatment	Green lacewing adult	Green lacewing larvae	Spider	Predaceous stink bug	Phytophagous stink bug	*Nabis* sp.
6 April	Clover/vetch	0.06	0	0.52	0	0.06	0.24
	Std error	±0.04	±0	±0.07	±0	±0.04	±0.1
16 April	Clover/vetch	0.46	0.02	0.74	0	0.08	0.04
	Std error	±0.11	±0.02	±0.17	±0	±0.06	±0.04
23 April	Clover/vetch	0.1	0.02	0.46	0.04	0	0
	Std error	±0.05	±0.02	±0.11	±0.02	±0	±0
7 May	Clover/vetch	0.02	0.56	1.06	0.04	0.14	0.08
	Std error	±0.02	±0.18	±0.09	±0.02	±0.07	±0.04
14 May	Clover/vetch	0.02	0.22	0.78	0	0.06	0.02
	Std error	±0.02	±0.04	±0.06	±0	±0.04	±0.02
21 May	Clover/vetch	0.1	0.2	0.26	0	0.06	0.22
	Std error	±0.06	±0.03	±0.14	±0	±0.04	±0.11
28 May	Clover/vetch	0.14	0	0.56	0	0	0.14
	Std error	±0.04	±0	±0.13	±0	±0	±0.07
4 June	Clover/vetch	0.04	0	0.58	0.04	0	0.06
	Std error	±0.02	±0	±0.15	±0.02	±0	±0.04
14 June	Clover/vetch	0	0	0.76	0.02	0.22	0.1
	Std error	±0	±0	±0.21	±0.02	±0.05	±0.03
18 June	Clover/vetch	0	0	0.44	0.1	0.2	0.1
	Std error	±0	±0	±0.12	±0.08	±0.08	±0.03
25 June	Clover/vetch	0	0	0.58	0.06	0.08	0.16
	Std error	±0	±0	±0.12	±0.04	±0.05	±0.09

Table 13. Arthropod densities on pecan canopies in 1992 at Knight Creek Farm.

		Arthropods/m^2				
Date	Treatment[z]	Green lacewing adult	Spider	Total assassin bugs	Hover fly	*Nabis* spp.
5 May	Clover/vetch	0	1.2	0	0	0
	Grass	0	4.4	0.4	0	0
22 May	Clover/vetch	0	2.8	0.4	0	0
	Grass	0.5	1.5	0.5	0	0
12 June	Clover/vetch	0.4	2.0	0	0	1.2
	Grass	0.5	1.5	0.5	0	0.5
25 June	Clover/vetch	1.2	1.2	0	0	0
	Grass	0.8	0.8	0	0	0
7 July	Clover/vetch	0.4	0.4	0	0.4	0
	Grass	0	2.0	0	1.2	0
23 July	Clover/vetch	0	0	0	0	0
	Grass	0	2.0	0	0.5	0
17 Aug	Clover/vetch	0.4	7.6	0.4	0	0
	Grass	0	8.8	0.8	0	0.8
1 Sept	Clover/vetch	0	2.0	0	0	0
	Grass	0	2.8	0	0	0
17 Sept	Clover/vetch	0	0.4	0	0	0
	Grass	0.4	2.4	0	0	0
28 Sept	Clover/vetch	1.2	0	0	0	0
	Grass	1.2	2.4	0	0	0

[z]Treatments were not significantly different at the 5% level.

Table 14. Arthropod densities on pecan canopies in 1992 at Noble Foundation Research Ranch.

		Arthropods/m^2						
Date	Treatment[Z]	Green lacewing adult	Green lacewing larvae	Brown lacewing adult	Spider	Total assassin bugs	Phytophagous stink bugs	Lady beetle adults
24 April	Clover/vetch	0	0	0	0.8	0	0	0.4
	Grass	0	0	0	0	0	0	0
30 April	Clover/vetch	0.8	0	0	1.2	0	0	0
	Grass	0	0	0	0.8	0	0	0
13 May	Clover/vetch	1.2	0	0	2.0	0	0	0.4
	Grass	1.2	0	0	1.2	0	0	1.6
27 May	Clover/vetch	2.4	0	0.4	0.8	0	0	0.4
	Grass	0.8	0.8	0	0	0	0	0.8
12 June	Clover/vetch	2.8	0	0.8	0	1.2	0	0
	Grass	0.4	0	0	0.8	0	0	0
29 June	Clover/vetch	0.4	0	0	0.4	0.8	0	0
	Grass	0	0	0.4	0	0	0	0.4
21 July	Clover/vetch	0	0	0	0.8	0	0	0
	Grass	0	0	0	0.4	0	0	0
31 July	Clover/vetch	0.4	0	0	2.4	0	0	0
	Grass	0.8	0.4	0	0.4	0	0	0
12 Aug	Clover/vetch	0.4	0.8	0	5.6	0	0.4	0
	Grass	0	1.6	0.4	3.6	0	0	0
25 Aug	Clover/vetch	0	0.4	0	2.0	0	0.4	0
	Grass	0	0	0	0.8	0.8	0	0
8 Sept	Clover/vetch	0.8	0	0	2.0	0	0.4	0
	Grass	0.4	0	0.8	1.2	0	0	0.4
23 Sept	Clover/vetch	0.4	0.8	6.0	6.0	0	0	0
	Grass	0.8	0	1.6	3.2	0	0	0
6 Oct	Clover/vetch	2.4	0	2.0	1.2	0	0	0.4
	Grass	3.2	0	1.2	1.2	0.4	0	0

[Z]Treatments were not significantly different at the 5% level.

Table 15. Arthropod densities on pecan canopies in 1993 at Knight Creek Farm.

		Arthropods/m^2					
Date	Treatment[z]	Green lacewing adult	Green lacewing larvae	Brown lacewing adult	Spider	Assassin bugs	Lady beetle adults
20 May	Clover/vetch	0.4	0	0	1.6	0	0.4
	Grass	0	0	0	0.8	0	0
25 May	Clover/vetch	0	0	0	2.8	0	0.4
	Grass	0	0	0	2.8	0	0
1 June	Clover/vetch	0.8	0.4	0	0.4	0	0
	Grass	0.4	0	0	0.8	0	0
8 June	Clover/vetch	0.4	0	0	2.4	0	0
	Grass	0	0	0	1.2	0.4	0.4
24 June	Clover/vetch	0	0	0.4	0	0	0
	Grass	0	0	0	1.2	0.4	0.4
1 July	Clover/vetch	0.4	0.4	0.4	2.0	0	0.4
	Grass	0.4	0	0	1.6	0	0
8 July	Clover/vetch	1.6	0	0	0.4	0	0.4
	Grass	0	0.4	0.4	0.4	0	0.8
13 July	Clover/vetch	2.0	0.4	0	0	0.8	0.4
	Grass	0	0	0	1.2	0.4	0
18 July	Clover/vetch	0	0	0	1.2	0	0.8
	Grass	0	0.4	0	2.0	0	0
2 Aug	Clover/vetch	0	0	0	4.0	0	0
	Grass	0.4	0	0	1.6	1.2	0
18 Aug	Clover/vetch	0	0	0	3.2	0.4	0
	Grass	1.2	0	0	0.8	0	0

[z]Treatments were not significantly different at the 5% level.

Table 16. Arthropod densities on pecan canopies in 1993 at Noble Foundation Research Ranch.

		Arthropods/m^2						
Date	Treatment[Z]	Green lacewing adult	Green lacewing larvae	Brown lacewing adult	Spider	Assassin bugs	Lady beetle adults	Lady beetle larvae
7 May	Crimson/vetch	0.4	0	0.4	3.2	0	0.4	0
	Grass	0.8	0	0	2.4	0	1.6	0.4
14 May	Crimson/vetch	0	0	3.2	2.8	0.8	0	0
	Grass	0.4	0	0	0.8	0	1.2	0
21 May	Crimson/vetch	0.8	0	0.8	3.2	1.6	0	0
	Grass	0.8	0	0.8	1.6	0	0.4	0
28 May	Crimson/vetch	4.8	0	0.8	1.2	0	1.6	0
	Grass	2.4	0.4	0.8	5.2	0	1.2	0.8
4 June	Crimson/vetch	0.8	0	0.4	0	0	0.4	0.4
	Grass	0	1.2	0	3.6	0	0.4	0
14 June	Crimson/vetch	0	0.4	0	2.8	0	0	0
	Grass	1.2	0	0	1.2	0	1.2	0
18 June	Crimson/vetch	0	0	0	1.2	0.4	0	0
	Grass	0	0	0	2.0	0	0.4	0
25 June	Crimson/vetch	0.8	0	0	3.2	0	0	0
	Grass	0	0.4	0	1.6	0	0.4	0
2 July	Crimson/vetch	0	0	0	4.0	0.4	0	0
	Grass	0	0.8	0	2.8	0	0	0
9 July	Crimson/vetch	0	0	0	1.2	0	0.4	0
	Grass	0	0	0	0.8	0	0	0
12 July	Crimson/vetch	0	0	0	2.0	0	0	0
	Grass	0	0	0	0.8	0	0	0
23 July	Crimson/vetch	0	0	0	2.0	0.4	0	0
	Grass	0	0	0	2.8	0.4	0	0.4
30 July	Crimson/vetch	0	0.4	0	1.2	0	0	0
	Grass	0	0	0	0.4	0	0	0

Table 16. (Continued)

		Arthropods/m^2						
Date	Treatment[Z]	Green lacewing adults	Green lacewing larvae	Brown lacewing adults	Spider	Assassin bugs	Lady beetle adults	Lady beetle larvae
6 Aug	Crimson/vetch	0.4	0.4	0	1.2	0.8	0	0
	Grass	0.8	0	0	1.6	0	0	0
12 Aug	Crimson/vetch	0	0.4	0	3.6	0	0	0
	Grass	0.8	0.8	0	2.0	0	0	0
20 Aug	Crimson/vetch	0.4	0	0	1.2	0	0	0
	Grass	2.0	0	0	0.4	0	0	0
27 Aug	Crimson/vetch	1.6	0	0.4	0.8	0	0	0
	Grass	2.0	0	0	0	0	0	0

[Z]Treatments were not significantly different at the 5% level.

Table 17. Aphids and green lacewing eggs per compound leaf in 1992 at Knight Creek Farm.

Date	Treatment	Aphids/leaf	Green lacewing eggs/leaf
5 May	Clover/vetch	0.1	0
	Grass	0.1	0
		NS[z]	NS
22 May	Clover/vetch	0.1	0
	Grass	0.1	0
		NS	NS
12 June	Clover/vetch	0.2	0.06
	Grass	0.1	0.08
		NS	NS
25 June	Clover/vetch	0.3	0.02
	Grass	0	0
		*	NS
7 July	Clover/vetch	0	0.18
	Grass	0	0.08
		NS	NS
15 July	Clover/vetch	0.1	0.14
	Grass	0.1	0.12
		NS	NS
23 July	Clover/vetch	0.1	0.04
	Grass	0	0
		NS	NS
30 July	Clover/vetch	0.1	0.08
	Grass	0	0.02
		NS	NS
17 Aug	Clover/vetch	0.1	0.04
	Grass	0	0
		NS	NS
1 Sept	Clover/vetch	1.5	0.02
	Grass	0.4	0.02
		NS	NS
17 Sept	Clover/vetch	21.5	0
	Grass	5.3	0
		*	NS

Table 17. (Continued)

Date	Treatment	Aphids/leaf	Green lacewing eggs/leaf
28 Sept	Clover/vetch	49.1	0
	Grass	17.5	0
		NS	NS

[Z]NS, * Non-significant (NS) or significant at 5% (*).

Table 18. Aphids and green lacewing eggs per compound pecan leaf in 1992 at Noble Foundation Research Ranch.

Date	Treatment	Aphids/leaf	Green lacewing eggs/leaf
24 April	Clover/vetch	0.3	0.02
	Grass	0.1	0
		NS[z]	NS
30 April	Clover/vetch	0.2	0.02
	Grass	0.2	0
		NS	NS
13 May	Clover/vetch	17.0	0.02
	Grass	72.0	0.14
		*	NS
27 May	Clover/vetch	0.1	0.24
	Grass	0.1	0.14
		NS	NS
11 June	Clover/vetch	0.1	0.12
	Grass	0.9	0.06
		*	NS
29 June	Clover/vetch	0	0.08
	Grass	0.1	0.02
		NS	NS
17 July	Clover/vetch	0	0
	Grass	0.1	0.02
		NS	NS
21 July	Clover/vetch	0	0.04
	Grass	0	0.08
		NS	NS
31 July	Clover/vetch	0.1	0.18
	Grass	0.1	0.24
		NS	NS
12 Aug	Clover/vetch	0.1	0.24
	Grass	0	0.08
		NS	NS
25 Aug	Clover/vetch	0.2	0.06
	Grass	0	0
		*	*

Table 18. (Continued)

Date	Treatment	Aphids/leaf	Green lacewing eggs/leaf
8 Sept	Clover/vetch	22.0	0.02
	Grass	4.1	0.14
		*	NS
23 Sept	Clover/vetch	3.0	0
	Grass	43.9	0.02
		*	NS
9 Oct	Clover/vetch	7.2	0.6
	Grass	6.8	0
		NS	NS

[z]NS, * Non-significant (NS) or significant at 5% (*).

Table 19. Aphids and green lacewing eggs per compound pecan leaf in 1993 at Knight Creek Farm.

Date	Treatment	Aphids/leaf	Green lacewing eggs/leaf
20 May	Clover/vetch	0.7	0
	Grass	1.2	0
		NS[z]	NS
1 June	Clover/vetch	1.0	0
	Grass	0.3	0
		NS	NS
8 June	Clover/vetch	1.1	0
	Grass	0.3	0
		NS	NS
24 June	Clover/vetch	1.0	0
	Grass	1.8	0
		NS	NS
1 July	Clover/vetch	2.0	0.14
	Grass	3.9	0.08
		NS	NS
8 July	Clover/vetch	1.2	0.08
	Grass	0.4	0.04
		NS	NS
13 July	Clover/vetch	0.5	0.14
	Grass	0	0.02
		*	NS
15 July	Clover/vetch	0.1	0.06
	Grass	0.1	0.06
		NS	NS
21 July	Clover/vetch	0	0.02
	Grass	0	0.02
		NS	NS
3 Aug	Clover/vetch	0	0.02
	Grass	0	0
		NS	NS
10 Aug	Clover/vetch	0	0.10
	Grass	0	0.04
		NS	NS

Table 19. (Continued)

Date	Treatment	Aphids/leaf	Green lacewing eggs/leaf
18 Aug	Clover/vetch	0	0.22
	Grass	0	0.08
		NS	NS

[z]NS, * Non-significant (NS) or significant at 5% (*).

Table 20. Aphids and green lacewing eggs per compound pecan leaf in 1993 at Noble Foundation Research Ranch.

Date	Treatment	Aphids/leaf	Green lacewing eggs/leaf
7 May	Clover/vetch	0.2	0
	Grass	1.1	0
		*[z]	NS
14 May	Clover/vetch	0	0
	Grass	0.4	0
		NS	NS
21 May	Clover/vetch	2.3	0.04
	Grass	1.3	0.02
		NS	NS
28 May	Clover/vetch	294.4	0
	Grass	5.6	0.14
		*	NS
4 June	Clover/vetch	0.8	0.02
	Grass	0.7	0
		NS	NS
14 June	Clover/vetch	0	0
	Grass	0	0.04
		NS	NS
18 June	Clover/vetch	0.3	0
	Grass	0.1	0
		NS	NS
25 June	Clover/vetch	0.1	0.04
	Grass	0.1	0.02
		NS	NS
2 July	Clover/vetch	0.1	0.02
	Grass	0.1	0
		NS	NS
9 July	Clover/vetch	0.1	0.04
	Grass	0.1	0.08
		NS	NS
12 July	Clover/vetch	0.1	0.02
	Grass	0.1	0.06
		NS	NS

Table 20. (Continued)

Date	Treatment	Aphids/leaf	Green lacewing eggs/leaf
23 July	Clover/vetch	0	0.02
	Grass	0	0
		NS	NS
30 July	Clover/vetch	0.1	0.38
	Grass	0	0.04
		NS	NS
6 Aug	Clover/vetch	0.1	0.06
	Grass	0	0.04
		NS	NS
12 Aug	Clover/vetch	0.2	0.04
	Grass	0	0.06
		NS	NS
20 Aug	Clover/vetch	0.2	0.2
	Grass	0	0.08
		NS	NS
27 Aug	Clover/vetch	0.2	0.1
	Grass	0.1	0.02
		NS	NS
9 Sept	Clover/vetch	0.3	0
	Grass	1.5	0.02
		NS	NS

[z]NS, * Non-significant (NS) or significant at 5%(*).

Table 21. Phytophagous stinkbug damage to pecan kernels at Knight Creek Farm and Noble Foundation Research Ranch.

Location	Year	Treatment[z]	Kernels damaged (%)
Knight	1992	Clover/vetch	2.7
		Grass	2.9
	1993	Clover/vetch	0
		Grass	0.3
Noble	1992	Clover/vetch	0.9
		Grass	0.8
	1993	Clover/vetch	0.5
		Grass	0

[z]Treatments were not significantly different at the 5% level.

Table 22. Nitrogen concentration in legume tops, total nitrogen and biomass from ground covers in 1992 and 1993 at Knight Creek Farm and Noble Foundation Research Ranch.

Location	Treatment	N conc. (%)	Total N (kg/ha)	Biomass (kg/ha)
		1992		
Knight	Clover	2.78±0.14[z]	64±17	2362±611
	Vetch	3.83±0.06	20±5	532±143
	Grass	-	-	2809±571
	Total	-	84±22	5703±696
Noble	Clover	2.77±0.12	19±5	709±207
	Vetch	3.91±0.11	53±7	1372±203
	Grass	-	-	785±178
	Total	-	72±17	2867±210
		1993		
Knight	Clover	2.20±0.04	58±8	2650±361
	Vetch	3.68±0.18	16±5	437±149
	Grass	-	-	860±207
	Total	-	74±21	3948±678
Noble	Clover	2.62±0.05	50±11	1881±406
	Vetch	3.92±0.21	39±13	1070±392
	Grass	-	-	571±155
	Total	-	89±5	3522±382

[z]Mean ± standard error.

Table 23. Effect of nitrogen application rate on areas with grass ground covers and legume ground covers on Kjeldahl-N and NO3-N in soil sampled at two depths in October.

			Kjeldahl-N ($\mu g \cdot g^{-1}$)		NO_3-N ($\mu g \cdot g^{-1}$)	
			Sample depth (cm)			
Location	Year	Treatment	0-15	15-30	0-15	15-30
Knight	1992	0	1407	830	4.9 ***	2.0 ***
		56	1405	780	5.2 ***	4.6 **
		112	1474	936	7.1 **	3.7 **
		168	1391	771	5.8 ***	2.8 ***
		Legume	1451	858	14.6	8.7
Significance			NS	C	NS	Q
	1993	0	1115 **	700	1.1 ***	3.3 ***
		56	1206 *	735	2.5 ***	1.5 ***
		112	1155 **	637*	3.9 *	1.3 ***
		168	1283	692	4.8	2.5 ***
		Legume	1426	778	6.3	7.3
Significance			NS	NS	L	L
Noble	1992	0	1977	969	9.0 *	4.1 **
		56	1777	911	7.3 **	4.1 **
		112	1591	999	10.5	7.0
		168	1069 **	480 ***	13.6	12.8
		Legume	1666	1005	15.7	11.5
Significance			L	L Q	L	L
	1993	0	1460	622	8.9 ***	3.2 **
		56	1730 *	710	7.7 ***	2.0 ***
		112	1672	781	8.3 ***	8.2
		168	1402	516	14.9 *	11.7
		Legume	1424	724	22.8	12.1
Significance			Q	Q	L Q	L

*, **, *** significantly different from the legume ground cover at 5% (*), 1% (**), or 0.1% (***).
NS, L, Q, C Non-signficant (NS), or significant linear (L), quadratic (Q) or cubic (C) trends within the four applied N treatments at the 5% level.

Table 24. Covariant analysis of the percent fruiting shoots in 1993 as affected by treatment, ground cover and fruiting shoots in 1992.

	Sums of Squares	
Source	Knight	Noble
Applied-N vs. Legume-N	577	4899
1992 Fruiting Shoots %	35	*3614
Error	21135	27710

* Significant at the 5% (*) level.

Table 25. Apparent nitrogen supplied to the pecan trees by legumes.

	Apparent nitrogen (kg/ha)	
Location	1992	1993
Knight Creek Farm	143±26[z]	159±25
Noble Foundation	156±31	101±19

[z]Mean±90% confidence limit.

CHAPTER III

SUMMARY

A mixture of 'Dixie' crimson clover and hairy vetch had large densities of aphids that attracted beneficial arthropods. The most abundant beneficial arthropods sampled in the legumes were spiders, lady beetles, green lacewings and nabids, respectively. The beneficial arthropods attracted did not affect the densities of beneficial species in the pecan canopies. No significant differences in beneficial arthropod densities were found in pecan canopies with clover/vetch as the ground cover versus pecan canopies with grass as the ground cover.

The most abundant beneficial arthropods in the pecan canopies were spiders, green lacewings, brown lacewings and lady beetles respectively. Spider densities were usually consistant from spring through the fall. Spiders are general predators and their feeding activity is not necessarily linked to pecan aphid densities. Green lacewings generally showed a bimodal seasonal abundance pattern similar to pecan aphid densities, with higher densities in the spring and early summer, low densities through the summer and then greater densities in the fall. Lady beetle were most abundant in the spring. Lady beetle species distribution in the pecan canopies was different than in the legumes. Predominant lady beetle species in the legumes were *Hippodamia convergens*, *Coleomegilla maculata lengi* and *Coccinella septempunctata* while the most abundant species in the pecan canopies were *Olla v-nigrum*, *Cycloneda munda* and *Hippodamia convergens*.

In 1992 at Knight Creek Farm and 1993 at Noble Foundation we had significantly more pecan aphids in the canopies with clover/vetch as a ground cover than in the grass. Data from Noble Foundation in 1992 was inconclusive showing signficantly more pecan aphids in clover/vetch and grass plots at different dates of the year. In 1993 at Knight Creek Farm there appeared to be some suppression of pecan aphids in the canopies with clover/vetch as a ground cover. Overall the data are inconclusive regarding the effects of ground cover on pecan aphid densities.

There were no significant differences, except on one date in 1992, for green lacewing eggs during both years and both sites. No significant differences between grass and legume plot green lacewing adult or larval densities in the pecan canopies were found. Pecan aphid densities also appeared unaffected by green lacewing releases. Green lacewing releases did not affect late season green lacewing densities or improve control of late-season pecan aphids.

Crimson clover and hairy vetch showed high biomass accumulation depending on the site grown. The clover/vetch ground cover supplied over 100 kg/ha every year to the pecan trees and did not adversely effect pecan yield. However, soil nitrate levels during the fall using clover/vetch was significantly higher than commercially fertilized grass plots, suggesting that nitrate leaching might be higher using legume ground covers.

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APPENDIXES

APPENDIX A

LADY BEETLE DENSITIES ON PECAN CANOPIES IN 1992 AT KNIGHT CREEK FARM

Lady beetle densities on pecan canopies in 1992 at Knight Creek Farm.

		Lady beetle adults/m^2	
Date	Treatment[z]	*Olla v-nigrum*	*Cycloneda munda*
5 May	Clover/vetch	0	0
	Grass	0	0
22 May	Clover/vetch	0.4	0
	Grass	0	0
12 June	Clover/vetch	0	0
	Grass	0	0
25 June	Clover/vetch	0	0
	Grass	0	0
7 July	Clover/vetch	0	0
	Grass	0	0
23 July	Clover/vetch	0	0
	Grass	0	0
17 Aug	Clover/vetch	0	0
	Grass	0	0
1 Sept	Clover/vetch	0	0
	Grass	0	0
17 Sept	Clover/vetch	0	0
	Grass	0	0
28 Sept	Clover/vetch	0	0
	Grass	0	0.4

[z]Treatments were not significantly different at the 5% level.

APPENDIX B

LADY BEETLE DENSITIES ON PECAN CANOPIES IN 1992 AT NOBLE FOUNDATION RESEARCH RANCH

Lady beetle densities on pecan canopies in 1992 at Noble Foundation Research Ranch.

		Lady beetle adults/m^2			
Date	Treatment^Z	*Hippodamia convergens*	*Coccinella septempunctata*	*Olla v-nigrum*	*Cycloneda munda*
24 April	Clover/vetch	0.4	0	0	0
	Grass	0	0	0	0
30 April	Clover/vetch	0	0	0	0
	Grass	0	0	0	0
13 May	Clover/vetch	0	0	0.4	0
	Grass	0.4	0	0.8	0.4
27 May	Clover/vetch	0	0.4	0	0
	Grass	0	0.8	0	0
12 June	Clover/vetch	0	0	0	0
	Grass	0	0	0	0
29 June	Clover/vetch	0	0	0	0
	Grass	0.4	0	0	0
21 July	Clover/vetch	0	0	0	0
	Grass	0	0	0	0
31 July	Clover/vetch	0	0	0	0
	Grass	0	0	0	0
12 Aug	Clover/vetch	0	0	0	0
	Grass	0	0	0	0
25 Aug	Clover/vetch	0	0	0	0
	Grass	0	0	0	0
8 Sept	Clover/vetch	0	0	0	0
	Grass	0	0	0	0.4

APPENDIX B (Continued)

		Lady beetle adults/m^2			
Date	Treatment[Z]	*Hippodamia convergens*	*Coccinella septempunctata*	*Olla v-nigrum*	*Cycloneda munda*
6 Oct	Clover/vetch	0.4	0	0	0
	Grass	0	0	0	0
23 Sept	Clover/vetch	0	0	0	0
	Grass	0	0	0	0

[Z]Treatments were not significantly different at the 5% level.

APPENDIX C

LADY BEETLE DENSITIES ON PECAN CANOPIES IN 1993 AT KNIGHT CREEK FARM

Lady beetle densities on pecan canopies in 1993 at Knight Creek Farm.

Date	Treatment[z]	Lady beetle adults/m²				
		Hippodamia convergens	*Coleomegilla maculata lengi*	*Olla v-nigrum*	*Cycloneda munda*	*Anatis* spp.
20 May	Clover/vetch	0	0	0	0	0
	Grass	0	0	0	0	0
25 May	Clover/vetch	0	0	0	0.4	0
	Grass	0	0	0	0	0
1 June	Clover/vetch	0	0	0	0	0
	Grass	0	0	0	0	0
8 June	Clover/vetch	0	0	0	0	0
	Grass	0	0	0	0.4	0
24 June	Clover/vetch	0	0	0	0	0
	Grass	0	0	0	0.4	0
1 July	Clover/vetch	0	0	0	0.4	0
	Grass	0	0	0	0	0
8 July	Clover/vetch	0	0.4	0	0	0
	Grass	0.8	0	0	0	0
13 July	Clover/vetch	0	0	0.4	0	0
	Grass	0	0	0	0	0
18 July	Clover/vetch	0	0	0.8	0	0
	Grass	0	0	0	0	0
2 Aug	Clover/vetch	0	0	0	0	0
	Grass	0	0	0	0.4	0.4
18 Aug	Clover/vetch	0	0	0	0	0
	Grass	0	0	0	0	0

[z]Treatments were not significantly different at the 5% level.

APPENDIX D

LADY BEETLE DENSITIES ON PECAN CANOPIES

IN 1993 AT NOBLE FOUNDATION RESEARCH RANCH

Lady beetle densities on pecan canopies in 1993 at Noble Foundation Research Ranch.

		Lady beetle adults/m^2				
Date	Treatment[Z]	*Hippodamia convergens*	*Coleomegilla maculata lengi*	*Olla v-nigrum*	*Cycloneda munda* spp.	*Anatis*
7 May	Clover/vetch	0.4	0	0	0	0
	Grass	0	0	1.6	0	0
14 May	Clover/vetch	0	0	0	0	0
	Grass	0	0	0.8	0.4	0
21 May	Clover/vetch	0	0	0	0	0
	Grass	0	0	0.4	0	0
28 May	Clover/vetch	0.4	0	0	1.2	0
	Grass	0	0	0.8	0.4	0
4 June	Clover/vetch	0	0	0	0	0.4
	Grass	0	0	0	0.4	0
14 June	Clover/vetch	0	0	0	0	0
	Grass	0	0.4	0	0.8	0
18 June	Clover/vetch	0	0	0	0	0
	Grass	0	0	0.4	0	0
25 June	Clover/vetch	0	0	0	0	0
	Grass	0	0	0	0.4	0
2 July	Clover/vetch	0	0	0	0	0
	Grass	0	0	0	0	0
9 July	Clover/vetch	0	0	0.4	0	0
	Grass	0	0	0	0	0
12 July	Clover/vetch	0	0	0	0	0
	Grass	0	0	0	0	0

APPENDIX D (Continued)

Date	Treatment[z]	Lady beetle adults/m^2				
		Hippodamia convergens	*Coleomegilla maculata lengi*	*Olla v-nigrum*	*Cycloneda munda*	*Anatis* spp.
23 July	Clover/vetch	0	0	0	0	0
	Grass	0	0	0	0	0
30 July	Clover/vetch	0	0	0	0	0
	Grass	0	0	0	0	0
6 Aug	Clover/vetch	0	0	0	0	0
	Grass	0	0	0	0	0
12 Aug	Clover/vetch	0	0	0	0	0
	Grass	0	0	0	0	0
20 Aug	Clover/vetch	0	0	0	0	0
	Grass	0	0	0	0	0
27 Aug	Clover/vetch	0	0	0	0	0
	Grass	0	0	0	0	0

[z]Treatments were not significantly different at the 5% level.

VITA

Natasha R. Rice

Candidate for the Degree of

Master of Science

Thesis: ASSESSMENT OF LEGUME AND NON-LEGUME GROUND COVERS AND AUGMENTATION OF APHID PREDATORS FOR LOW-INPUT PECAN MANAGEMENT

Major field: Horticulture

Biographical:

Personal Data: Born in Ardmore, Oklahoma, December 25, 1968, the daughter of Mike and Marilyn Rice.

Education: Graduated from Ardmore High School, Ardmore, Ok., in May, 1987. Received Bachelor of Science degree in Horticulture from Oklahoma State University in December, 1991. Completed requirements for the Master of Science degree at Oklahoma State University in July, 1994.

Professional Experience: Greenhouse assistant, Quality Plants Inc., Stillwater, Ok., March, 1990 to May, 1991. Research assistant, Department of Horticulture, Oklahoma State University, May 1991 to December 1991. Graduate research assistant and teaching assistant, Department of Horticulture, Oklahoma State University, January 1992 to May 1994.