THE IMPACT OF HEDGING ON ARTHROPOD PEST POPULATIONS AND RELATED DAMAGE IN PECANS

by

KATE ELIZABETH PHILLIPS

(Under the Direction of William Hudson)

ABSTRACT

Hedging is a canopy management strategy that growers can implement to increase light penetration into the canopy to help increase yield. Studies were conducted at three field sites to observe how hedging and related canopy management strategies impacts arthropod pest populations and related damage in two canopy locations. Canopy management strategies studied include hedging, topping, thinning, and summer and winter hedging. Arthropod pests were individually analyzed at three points in the growing season from the upper and lower canopies of pecan trees. Overall, hedging did not increase arthropod pest populations and did not increase observed damage.

INDEX WORDS: pecan hedging, yellow pecan aphid, blackmargined aphid, black pecan aphid, pecan leaf scorch mite, pecan nut casebearer, hickory shuckworm

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CHAPTER 1

LITERATURE REVIEW

Pecan Production

The pecan, *Carya illinoinensis* (Wangenh.) C. Koch, is native to the south central United States, and is now grown throughout the southern portion of the United States spanning from Virginia to California, and south into Mexico (Thompson and Conner 2012). The southwest United States has a drier climate compared to the humid climate of the southeast United States, with the Midwest being intermediate between the two (Thompson and Conner 2012). This poses various differences in management strategies for growers across the country. Recommended varieties vary by state, depending on climate and disease on insect pressure, but almost half of the planted trees in the US consist of 'Stuart', 'Western Schley', and 'Desirable' (Thompson and Conner 2012). In 2020, there was an estimated 402,000 acres of bearing orchards, both native and improved varieties in the United States, with a total of 302 million pounds of produced nuts for a value of $399 million. Georgia was the highest producer in the United States at 142 million pounds with a crop value of $169 million and a farm gate value of $253 million from 129,000 acres of bearing trees (Stubbs 2020, USDA-NASS 2021). Arthropod pests that feed on the nut can cause damage and loss of crop, but pests of the foliage and tree can cause damage that will impact future growth and production of the trees. Below are common arthropod pests of foliage and nuts in the southeast United States that impact pecan production.

Arthropod Pests of Pecans

The first group of arthropod pests are foliage feeders. While they do not cause damage to the nut itself, they feed on the leaves which can impact overall tree health and affect future production on some levels.

Yellow aphid complex. The yellow aphid complex consists of two species of aphids, the yellow pecan aphid, *Monelliopsis pecanis* Bissell, and the blackmargined aphid, *Monellia caryella* (Fitch). Adults of both species have yellow bodies, but the wings of the blackmargined aphid have a black line on the leading margin of the wing. Nymphs of both species are bullet shaped (Tedders 1978). The first generation of the year hatches from an overwintering egg starting in April. All generations until the fall undergo viviparous reproduction and give birth to live nymphs. In the fall, the last generation lays eggs to overwinter to repeat the cycle. Development into the adult from the first instar nymph takes six to seven days (Tedders 1978). The first aphids normally start to appear in April and by the end of the season, aphids can produce between 21 and 32 generations (Tedders 1978). The season will have two populations peaks, one in the spring and one in the fall (Polles and Mullinix 1977, Tedders 1978). When the population of aphids is smaller, aphids prefer the lower canopy of the trees, but as the population grows, there is no preference and are found spread out throughout the canopy (Polles and Mullinix 1977). Both adults and nymphs are usually found feeding on the underside of the leaves (Paulsen et al. 2013). Blackmargined aphids feed on the primary and secondary veins of the leaves and yellow pecan aphids feed on the tertiary veins (Tedders 1978, Kaakeh and Dutcher 1994). These species of aphids cause damage to the tree by producing a sticky substance called honeydew. Honeydew sticks to the leaves and the sugars in the honeydew provide a substrate for the growth of sooty mold on the leaves blocking photosynthesis (Osburn et al. 1963).

Black pecan aphid. The black pecan aphid, *Melanocallis caryaefoliae* (Davis), is the third species of aphid that feeds on the foliage of pecan trees. These aphids cause damage to the tree by feeding on the leaves causing spots that start out yellow but become necrotic and cause the leaflet to drop, leading to premature defoliation of the trees in severe cases (Tedders 1978). Black pecan aphids can appear as early as May, but populations usually do not reach levels that can cause damage until July (Tedders 1978). Adult black pecan aphids are most often found on the underside of the leaf, but nymphs can also be found on the upper side of the leaf and are attracted to leaves that already have damage from other black aphids (Paulsen et al. 2013).

Pecan leaf scorch mite. The pecan leaf scorch mite (PLSM), *Eotetranychus hicoriae* (McGregor), causes damage to pecan trees by creating brown, scorched looking spots on leaves where feeding occurs. Female mites overwinter in the rough bark of the trees and emerge as early as April, but populations do not grow to large numbers until later in the growing season with hotter weather (Jackson et al. 1983). The eggs of PLSM are white spheres that look like water droplets and the nymph and adult PLSM are a yellow greenish color with two distinctive red dots.

Leaf miners. There are four species of Lepidoptera leaf miners that impact pecans, however only the pecan serpentine leafminer, *Stigmella juglandifoiella* (Clemens), causes enough damage to be economically significant (Payne et al. 1971, Payne et al. 1972). The other three species of leafminers that attack pecan trees but are not economically significant are *Cameraria caryaefoliella* (Clemens), *Phyllonorycter caryaealbella* (Chambers), and *Coptodisca lucifluella* Clemens (Heyerdahl and Dutcher 1985). In heavy infestations of the serpentine leaf miner there can be up to 60 mines on a single leaf, disrupting photosynthesis (Payne et al. 1971). The larva of this leafminer makes winding tunnels in the upper epidermis of the leaf. Young miners are pale green in color and small (less than 1 mm wide) and as they mature, become a larger (5 mm long), darker green larvae due to feeding on the palisade parenchyma (Payne et al. 1971, Payne et al. 1972). This species of leaf miner pupates in the ground, and the emerged adults lay eggs on the upper surface of the leaf (Payne et al. 1972).

Phylloxera. Phylloxera is a genus in the order Hemiptera that damages the tree by creating galls on the feeding locations. The two main species of phylloxera are the pecan leaf phylloxera, *Phylloxera notabilis* Pergande, and the pecan stem phylloxera, *Phylloxera devastatrix* Pergande. The damage caused to the leaves and the stems by the galls is unknown, but leaf galls can serve as a host site for shuckworm early in the season, and because stem phylloxera are not lost in the winter, they can serve as a site for overwintering of the shuckworm (Boethel et al. 1974, Dinkins and Reid 1988). Tissue from the galls of leaf phylloxera had less chlorophyll than normal leaf tissue and higher concentrations of potassium, phosphorus, copper, and sodium (Anderson and Mizell III 1987). Infestations in pecans begin early in the growing season (April-May) when the stem mother hatches from her overwintering egg and feeds on a leaf (Whitehead and Eastep 1937). The puncture where she feeds produces a hard gall that surrounds her as she develops. The galls can be up to 20 mm in diameter on the underside of the leaf (Whitehead and Eastep 1937).

These three insect pests below feed and cause damage to the developing nut.

Pecan nut casebearer. The pecan nut casebearer (PNC), *Acrobasis nuxvorella* Neunzig, causes damage to pecans by tunneling into and feeding on the developing nuts (Bilsing 1924). PNC adults emerge around pollination and lay eggs in the crown of nutlets. The eggs are flat and immediately after laying are white in color but will turn pink after a few hours and remain in this stage for 4 to 5 days until hatching (Knutson and Ree 2005). After hatching, the larvae migrate towards the stem and burrow into the nut to feed. The larvae will use the nutlets in the cluster as their source of food for the time it takes to develop into the pupae, about 25 days, depending on geography and weather (Osburn 1963). The pupa will stay in the nut for 9 to 14 days before emerging as an adult. Adults are gray moths that are 7 to 9 mm long. The adult does not feed on and cause damage to the nuts but can lay more than 50 eggs (Osburn 1963).

Shuckworm. The hickory shuckworm, *Cydia caryana* (Fitch), damages pecan by feeding on the shuck of the developing nut in the later part of the season (Gill 1924). Early in the season, shuckworms will stay in the galls of phylloxera before migrating to the nuts (Boethel et al. 1974, Dinkins and Reid 1988). Shucks impacted by shuckworm will not open correctly causing the nut to not fall to the ground as well as the shuckworms can leave trails and discolorations on the nut (Gill 1924).

Pecan weevil. The pecan weevil, *Curculio caryae* (Horn), is a pest occurring in the later part of the growing season, emerging from the soil beginning as early as July, with peak emergence from the soil occurring in August and September (Swingle 1934, Tedders and Osburn 1971). Adults can reach three-eighths of an inch in length and are brownish in color (Swingle 1934). Adult females use their beaks to chew holes in the nut to lay white, oval eggs (Swingle 1934). Pecan crop is damaged by the feeding on the kernel of the larval stage of the weevil, causing the nut to be unusable. Early stage feeding on the nut by adults can cause nut drop (Swingle 1934).

Knowing the when these pests are present, what they look like, and what damage they cause is important for growers so they can take appropriate steps to control the pests.

Pest Management

Growers have multiple tactics and options they can use to create the best plan of action to manage the pest populations in their orchards. Discussed below are three categories of common management strategies for arthropod pest populations in pecans.

Chemical Control. Growers use a wide variety of pesticides to control the orchard pests. For foliage feeding arthropod pests, the first target in the growing season is phylloxera, and these can be sprayed with insecticides from the neonicotinoid group (Thiamethoxam and imidacloprid). Yellow aphids and blackmargined aphids are targeted throughout the growing season by multiple insecticides including imidacloprid, thiamethoxam, acetamiprid, and amidopyrine, to name a few. Later in the growing season, black pecan aphids are targeted by the same insecticides as the yellow aphid complex as well as chlorpyrifos. The last arthropod pest that growers will spray insecticides for are mites, which generally appear later in the season. Some of the active ingredients that can be sprayed to control mites are abamectin, fenpyroximate, pyridaben, and etoxazole (Acebes et al. 2021).

Biological Control. Biological control is the use of a living organism to manage pest populations. There are multiple predators and parasitoids that feed on pecan aphids. Some of the arthropods that predate on the yellow aphid complex are species of lady beetles (Family: Coccinellidae), two species of green lacewings, *Chyrsoperla comanche* (Banks) and *Chrysopa nigricornis* Burmeister, and spiders (Bumroongsook et al. 1992, Ellington et al. 1995, Petersen and Hunter 2002). One parasitoid of the yellow aphid complex is *Aphelinus perpallidus* Gahan. This species of parasitoid wasp pupates in aphids, turning them black and creates a mummy of the aphid (Bissel 1928, Tedders 1978). Black pecan aphids are predated by the same arthropod predators as the yellow aphid complex, however, generally black pecan aphids are not parasitized by *A.*

perpallidus (Watterson and Stone 1982). The western predatory mite, *Galendromus occidentalis* (Nesbitt), and *Phytoseuilis persimilis* Athias-Henriot are two species of predatory mites that have been shown to control PLSM (Dutcher 2007). PNC has more than 25 species of parasitic wasps that can attack different life stages however the effectiveness of each species is unknown (Nickels et al. 1950, Knutson and Ree 2005). The pecan weevil can be controlled with entomopathogenic nematodes and fungi while the larvae are in the ground (Smith et al. 1993, Shapiro-Ilan et al. 2013).

Cultural Control. When planting a new orchard, growers can choose to plant varieties of pecan trees than are more resistant to arthropod pests. Varieties such as ‘Pawnee’, ‘Navaho’, and ‘Desirable’ are more resistant to aphids while varieties such as ‘Caddo’, ‘Stuart’, and ‘Cheyenne’ are more susceptible to the three species of aphids present in pecans (Thompson and Grauke 1998, Karar et al. 2012, Honaker et al. 2013). The use of cover crops between the rows of trees can increase beneficial insects in the orchard. Crops such as rye and hairy vetch tend to increase the density of lady beetles present in the canopies of the trees compared to trees with no planted cover crops beneath them (Bugg et al. 1991). The cover crops are attractive to beneficial insects because they can host more food sources when populations get low in the canopies of the trees, but this means they can also serve as a host for foliage feeding arthropod pests as well (Bugg 1991, Bugg et al. 1991). Some pest management strategies are not only used in an attempt to control insect pests, but other pests as well, and improve growth of trees. Hedge-pruning of pecan trees is an orchard management strategy that can be used by growers, but little research on the impacts on arthropod pests has been conducted.

Pecan Hedging

Hedge-pruning is a cultural management strategy used by pecan growers to help manage the size of the trees in an orchard. Managing the size of the trees in important because as trees mature, the canopies of the trees can become crowded, reducing light penetration into the lower canopy of the trees by up to 90% when compared to hedge-pruned trees (Lombardini 2006). When hedge-pruning, the sides of trees are cut between 1.5 and 4 meters away from the trunk of the tree (Lombardini 2006, Wells 2018). Also, the tops of the trees can be trimmed down to manage the height of the tree (Wells 2018). One benefit to hedge-pruning the sides and the tops of the trees is improved pesticide coverage into the canopy. Many commercial orchards use air blast sprayers to apply pesticides, but these sprayers become less effective at heights greater than 10 meters when compared to spray coverage at 5 meters (Bock et al. 2015). Pistachios are another tree nut crop that undergo cycles of alternate bearing, where in the 'on' year, there is a heavy crop and in the 'off' year there is a light crop. Pistachio trees that were topped had reduced effects of alternate bearing compared to trees that were not topped (Ferguson et al. 1995). Other benefits of hedge-pruning the canopy in pecans include increased water use efficiency by the trees, increased nut quality, and reduced damage from wind and hurricanes (Wells 2018).

Justification of Research

While multiple studies have targeted the horticultural and disease outcomes of hedge-pruning in pecan trees, there have been no studies on how hedging impacts pest populations. Previous studies on horticultural parameters have looked at how varieties, pruning cycles, and hedge-pruning layouts have impacted factors such as water efficiency, nut quality, and crop load, and studies on diseases in hedge-pruning have shown impacts on scab, but no studies have shown impacts on insect populations. Since climate conditions are different between the southeast and southwest, this study is important to learn how pest populations can be impacted.

Objectives

Objective 1: To determine the relative impact of hedging and thinning on arthropod pest populations and related damage in younger pecan trees.

Objective 2: To determine the relative impact of hedge-pruning on arthropod pest populations and related damage in two cultivars of older pecan trees.

Objective 3: To determine the relative impact of summer hedge-pruning versus winter hedge-pruning on arthropod pest populations and related damage in pecan trees

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CHAPTER 2

IMPACTS OF HEDGING AND THINNING ON ARTHROPOD PESTS AND RELATED DAMAGE IN YOUNGER (30-YEAR-OLD) PRODUCING PECAN TREES[1]

[1] Phillips, K. E., A. Acebes, W. Hudson, J. Schmidt. To be submitted to Economic Entomology

Abstract

Canopy management strategies such as hedging and thinning are used in pecan orchards to reduce crowding of canopy branches. Previous studies have focused on impacts of hedging on horticultural and pathological parameters with no studies observing entomological parameters. To observe the impact of hedging and thinning on arthropod pest populations and damage, leaves and nuts were collected at three points in the growing season from 30-year-old 'Desirable' hedged and non-hedged trees in year one and hedged and thinned trees in year two. Injury created by nut feeding arthropod pests was minimal regardless of canopy management strategy. Observed pests in the leaves were three species of aphids, yellow pecan aphid, *Monelliopsis pecanis* Bissel, blackmargined aphid, *Monellia caryella* (Fitch), and black pecan aphid, *Melanocallis caryaefoliae* (Davis), and pecan leaf scorch mite, *Eotetranychus hicoriae* (McGregor). Damage observed by arthropod pests were black pecan aphid damage, *Phylloxera* galls, and leaf miners. The impact of canopy management on leaf feeding pests varied by pest, however, only yellow aphids complex had a higher population in the hedged trees compared to non-hedged trees, and that was only present in one sample, with the rest of the samples having no significant differences. The results from this study, when combined with previous studies, can help growers make informed decisions on implementing hedging in their orchards.

Introduction

Crowded canopies of pecan trees can experience reduced yield due to the lack of sunlight penetrating the canopy (Wood 2009). Two strategies growers can implement to manage the size of the canopies and increase sunlight are tree thinning and hedging. Tree thinning is the removal of trees once canopies start to crowd, but this occurs once the trees have reached maturity

(Lombardini 2006). Hedging, or hedge-pruning, occurs when growers prune the sides of the canopies to allow more sunlight into the middle of the rows. Previous studies on canopy management have primarily focused on horticultural and pathological parameters with a major interest on hedging impacts in yield (Lombardini 2006, Wells 2018). Studies have also observed how hedging impacts water usage by the trees, wind damage, and scab (Lombardini 2006, Bock et al. 2017, Wells 2018). Few previous studies study pest responses to hedging, with the one exception being scab, a pathogen. Under standard scab management practices for the Southeast, hedging did not increase damage by scab (Bock et al. 2017). Other tree nut systems, including pistachios and macadamia nuts, that also use hedging as a canopy management option are also heavily focused on horticultural parameters of hedging and are lacking in the pest management studies.

Arthropod pests such as leaf feeding and nut feeding arthropods, may be impacted by the changing structure of the pecan canopy with hedging. The primary leaf feeding pests are three species of aphids (yellow pecan aphid, *Monelliopsis pecanis* Bissell, the blackmargined aphid, *Monellia caryella* (Fitch), and the black pecan aphid, *Melanocallis caryaefoliae* (Davis)), pecan leaf scorch mites (PLSM), *Eotetranychus hicoriae* (McGregor), *Phylloxera* sp., and leaf miners. The yellow pecan aphid and the blackmargined aphid are present in the leaves starting in March and April when leaves are first emerging and are tender (Tedders 1978). Black pecan aphids are also present early in the growing season, but do not grow to large enough populations to cause damage until later in the growing season (Tedders 1978). PLSM prefer warmer weather and are not commonly found until later in the growing season. They also prefer the lower canopy of the trees compared to the upper canopy (Jackson et al. 1983). *Phylloxera* and leaf miners both have multiple species present in pecans and the damage is present in the leaves. Pests that feed on the nuts are pecan nut casebearer (PNC), *Acrobasis nuxvorella* Neunzig, and shuckworm, *Cydia caryana* (Fitch). PNC is found early in the nut formation, with the eggs laid at the top of the nutlet and the larvae feed on the developing nutlet (Bilsing 1924). Shuckworms are found later in the growing season once the shell has started to form, and they feed on the developing shuck (Gill 1924).

Previous studies in the Southeastern United States looked into the impacts of hedging on horticultural and pathological parameters, very few studies have looked into how hedging impacts arthropod pest populations, especially in the Southeastern US. The objective of this study was to observe how hedging and thinning impact arthropod pest populations and related damages in younger, 30-year-old 'Desirable' pecan trees in the Southeastern United States. Because each arthropod pest species has a different biology and habitat in the canopy, the hypothesis of this study is that overall, hedging will not make arthropod pest populations and related damage worse, but each species will react differently.

Materials and Methods

Study Site

This study was conducted in Marshallville, GA (32.500209, -83.933302), in a 60-acre commercial pecan orchard that consisted primarily of mature trees (var. Desirable and with var. Sumner as pollinator trees). Trees were about 25 years old standing 12 meters tall. In 2020, all trees were spaced 15 m by 12.5 m, and in 2021, the hedged trees were spaced 15 m by 12.5 m and non-hedged (thinned) trees were spaced 15 m by 25 m due to removing of rows in these blocks. The row middles are mowed regularly and tree row had approximately 6 m herbicide strip centered on the trees. Conventional pecan orchard management for Georgia was practiced in this orchard with standard applications of insecticides and fungicides. The hedging program in this orchard was on a three-year rotation schedule. In 2018, trees were not hedged; in 2019, the west sides of the trees were hedged; and in 2020, the east sides of the trees were hedged.

This study was in a block design with four blocks. Ten rows of trees, with five rows of hedged-pruned trees and five rows of non-hedged trees, were represented in each block (Fig. 2.1). Each treatment has a total of 130 trees for each block. Ten trees from the middle row of each treatment group were selected for leaf and nut sample collection. Samples were taken from both the upper (~9m) and lower (~2m) canopies. The upper canopy samples were obtained by using a hydraulic lift that reaches about 9 meters in height.

Monitoring leaf feeding insect populations

Leaf samples were taken at three points of each season (1 June, 7 July, and 27 August 2020; 3 June, 12 July, and 30 August 2021) to sample for arthropods and arthropod damage. Two compound leaves were collected from both the upper and lower canopies of the trees (ten per replicate). These leaves were stored in bags and kept in coolers to be processed later in the laboratory. To standardize samples, only arthropod and arthropod-related damage on the middle six leaflets of each compound leaf were counted. The number of immature and adult yellow aphids, blackmargined aphids, black aphids and pecan leaf scorch mites were recorded. Arthropod-related injury including necrotic areas caused by black pecan aphids, damage by leaf miners, and *Phylloxera* galls were also recorded.

Monitoring nut feeding insect populations

Nut samples were taken at three points in the season of each year. The first sample of each season was taken 1 June 2020 and 3 June 2021 primarily to assess for pecan nut casebearer (PNC) infestation. The second sample was taken in 7 July 2020 and 12 July 2021 to monitor for PNC and shuckworm infestations. The last sample was taken at harvest on 16 October 2020 and 20 October 2021 to evaluate for shuckworm, stink bug, and nut curculio injuries. One nut cluster (2-6 nuts/cluster) from the upper and lower canopies of each tree was randomly selected, placed in bags and brought back to the laboratory to be processed.

Weather data

Weather data for 2020 and 2021 are listed in Table 2.1. Rainfall and high, low, and average temperature were collected by month using the University of Georgia Weather Monitoring Network.

Statistical analysis

A block design was used to test if hedging has an impact on arthropod communities in pecan trees. Arthropod populations and damage were analyzed using a factorial ANOVA with hedging treatments, canopy locations, and interactions as fixed effects. Before running the ANOVA, all data were examined for normality. If the data did not fit normality, it was transformed using a square root transformation. If there was significant interaction between the two factors (treatment and canopy location), we interpreted the interaction using a Tukey's HSD to separate the means of all possible treatment combinations. If there was no significant interaction between the factors, but one or more main effect was significant, we interpreted the main effects using t-tests. All analyses were performed using in JMP V15 (SAS Institute, 209, Cary, NC) at $\alpha = 0.05$

Results

Yellow pecan aphid (YPA) complex population

2020. In June, no significant interaction was found between hedging treatment and canopy location on YPA populations (Table 2.2: June 2020). The number of YPA's did not differ between the upper and lower canopy but more YPA's were found in the hedged than non-hedged trees (Table 2.2: June 2020). In July, no significant interaction was found between treatment and canopy location (Table 2.2: July 2020). There was no significant difference between hedged trees and non-hedged trees but there were more YPA's in the lower canopy than the upper canopy (Table 2.2: July 2020). In August, there was an interaction between treatment and canopy location, and the upper canopy of the hedged trees had more YPA's than the other three treatment and canopy combinations (Table 2.2: August 2020).

2021. In June, there was a significant interaction between canopy location and treatment. The lower canopy of non-hedged trees had the most aphids and the upper canopy of the non-hedged trees had the least number of aphids (Table 2.2: June 2021). In July and August, there was no significant interaction between canopy location and treatment. There were also no significant differences between canopy locations and between treatments (Table 2.2: July 2021). In August, there was no interaction between canopy location and treatment as well as no significant differences between canopy location or treatment (Table 2.2: August 2021).

Black pecan aphid population

2020. There was no interaction effect between the treatment and canopy location in the black aphid populations (Table 2.3: August 2020). The BPA populations did not differ between hedged and non-hedged trees, however, the upper canopy had significantly more black aphids than the lower canopy (Table 2.3: August 2020).

2021. In August, there was no interaction between variables. Black aphid populations were similar between treatments, but more black aphids were present in the upper canopy than the lower canopy (Table 2.3: August 2021).

Black pecan aphid injury

2020. In August, more leaflets in the lower canopy of both hedged and non-hedged trees had injury from black pecan aphids than the upper canopy, and there was no interaction effect between canopy location and treatment (Table 2.4: August 2020).

2021. In August, there was no interaction between canopy location and treatment for number of leaflets with black aphid injury. There was no significant difference between the upper and lower canopy, but hedged trees had more leaflets with injury than non-hedged trees (Table 2.4: August 2021).

Pecan leaf scorch mite population

2020. In August, no significant interaction was found between canopy location and treatment. When individually analyzing canopy location and treatment, there was no significant difference between hedged trees and non-hedged trees but there were more PLSM in the lower canopy than the upper canopy (Table 2.5: August 2020).

2021. August was the first sample with PLSM present. There was no interaction between treatment and canopy location, and no significant difference between treatments, but the lower canopy had more PLSM than the upper canopy (Table 2.5: August 2021).

Phylloxera galls

2020. In June, there was no significant interaction between the treatment and canopy locations (Table 2.6: June 2020). There was no significant difference between hedged and non-hedged trees and none with canopy location as well (Table 2.6: July 2020). In July, there was no significant interaction between canopy location and treatment (Table 2.6: July 2020). There were significantly more galls located in the non-hedged trees than the hedged trees, but there was no difference between the upper and lower canopies of the trees (Table 2.6: July 2020). In the August sample, there was no interaction between canopy location and hedged or non-hedged, however the lower canopy had more galls than the upper canopy and non-hedged trees had more glass than hedged trees (Table 2.6: August 2020).

2021. In June, there was no significant interaction between canopy location and treatment, and no significant differences between canopy locations and between treatments (Table 2.6: June 2021). July results were similar to June with no significant interaction between canopy location and treatment, and no significant differences between canopy locations and between treatment (Table 2.6: July 2021). In August, there was no interaction between the two variables. Non-hedged trees had more galls present than hedged trees, but there was no significant difference between the upper and lower canopy (Table 2.6: August 2021).

Leaf miners

2020. In July, there was no interaction between the treatment and canopy location. The lower canopy had more leaf miners than the upper canopy but no difference between hedged trees and non-hedged trees (Table 2.7: July 2020). In August, there was an interaction between canopy location and treatment. The lower canopy of non-hedged trees had the greatest number of leaf miners while the upper canopy of both hedged and non-hedged trees had the least (Table 2.7: August 2020).

2021. In August, there was no interaction between the two variables. There was no significant difference between hedged and non-hedged trees, but the lower canopy had more leaf miners than the upper canopy (Table 2.7: August 2021).

Insect-related nut injury before harvest

2020. Nut samples from June and July with insect-related injuries were too low to warrant statistical analysis. In the month of June, 588 nuts were collected and only 15 had pecan nut casebearer damage (~2.6% infestation rate). In the month of July, 478 nuts were collected, and only 6 had pecan nut casebearer damage (1.25 % infestation rate), and no nuts had shuckworm damage.

2021. Similar to 2020, there were not enough nut samples with insect-related injury to warrant analysis for PNC damage. In June, 473 nuts were collected and 12 had evidence of feeding from PNC (~2.5% infestation). In July, 361 nuts were sampled and 12 had evidence of feeding in the nut from PNC (~3.3% infestation). No evidence of shuckworm damage was present in either month.

Evaluation of insect injury on harvested nuts

2020. Overall, insect-related damage on harvested nuts was low. Of the 435 nuts collected, only 23 had shuckworm damage (5.28% infestation rate) and no stink bug or nut curculio damage was found.

2021. Again in 2021, insect-related injury on nuts was low. Of the 312 nuts collected, only 7 had shuckworm damage (2.2%) and no injury from other insect pests was observed.

Discussion

The impacts of hedging and thinning on arthropod pests and their related damage in 30-year-old, 12 m tall pecan trees vary by pest and time of year. Damage by nut feeding pests was minimal in both years of the study, while leaf feeding pest populations and damage varied by pest. The variance in damage in both leaf and nut feeding pests can be attributed to the diverse biology and micro-habitats of each pest.

The impact of hedging and thinning on the yellow aphid complex varied throughout the growing season. Populations of yellow pecan aphids only differed significantly between hedged and non-hedged trees in June 2020, with hedged trees having a significantly larger population. One possible explanation for this difference early in the growing season is that aphids prefer to feed on the softer tissue and smaller veins of the new growth leaves (Tedders 1978) which will be greater in number in hedged trees. It should be noted however, that the yellow complex aphid population throughout the season in both hedged and non-hedged trees (5.7 aphids/2 leaves and 3.42 aphids/2 leaves, respectively) were lower than previous studies (Edelson and Estes 1983), and should not be managed by pesticides if they are the only arthropod pest present (Acebes et al. 2020).

Yellow complex aphids have been found to have two population peaks during the growing season in May-June and August-October (Edelson and Estes 1983, Dutcher et al. 2012), which can explain low populations numbers during our sample dates. The first samples taken in June of both 2020 and 2021 were collected at the tail end of the first population peak, and the final samples taken in August of 2020 and 2021 were collected toward the beginning of the second population peak, which could explain low population numbers in the samples. In 2021 samples, population peaks did not match previous reported studies with the largest population occurring in July. However, yellow aphid complex populations in this study were found to be lower than previous reported studies (Edelson and Estes 1983) which could be attributed to factors including new aphicidal products (Slusher et al. 2021) and weather patterns (Kaakeh and Dutcher 1993).

There was no statistical difference between the observed populations of black pecan aphids in both years, but in 2021 the hedged trees had more leaflets with black pecan aphid damage than the thinned trees.

Larger black pecan aphid populations were observed in the upper canopy compared to the lower canopy in both 2020 and 2021 even though previous studies have shown that in smaller populations, more aphids will be observed in the lower canopy (Polles and Mullinix 1977). One possible explanation for having more aphids in the upper canopy compared to the lower canopy is sampling after insecticide applications to control black aphids. Due to height limitations of air-blast sprayers, the upper canopy of pecan trees will not receive as much insecticide as the lower canopy (Bock et al. 2015).

Pecan leaf scorch mite populations were not impacted by hedging. PLSM were only found in the lower canopy of the trees in August of both years. This is consistent with previous studies have shown that pecan leaf scorch mites prefer lower canopy of trees and warmer temperatures that occur later in the growing season (July-September) (Pierce 1953, Micinski et al. 1979). Trees are hedged in the upper portion of the canopy, so arthropod pests primarily located in the lower canopy will not have the same habitat change as pests in the upper canopy.

Hedging trees reduced numbers of *Phylloxera* galls compared to trees that were not hedged. Early in the growing season, there was no statistical difference between hedged and non-hedged trees, but as the season continued, a significant difference between the treatments was observed, regardless of year. A possible explanation for large differences in population numbers between the 2020 and 2021 growing seasons is pesticide application. Pesticides to control galls were applied in 2020 but were not applied in 2021 (Figure 2.2). Formation of new galls occurs early in the growing season, and numbers of galls present during the growing seasons declines as the season continues due to leaf drop (Whitehead and Eastep 1937). This study shows that regardless of whether pesticides are applied or not to control Phylloxera, hedged trees do have fewer numbers of Phylloxera galls than non-hedged trees.

The incidence of nut injury found in both early season and harvest nut samples was not sufficient to merit statistical analysis. Since the study was done in a commercial orchard, nut-feeding pests were heavily managed to reduce the amount of injury on the crop. This pesticide spray program is common among commercial orchards in South Georgia. Our study shows that under this pest management regime, there is no difference between hedged trees and non-hedged trees.

The impacts of hedging and thinning on younger (30-year-old, 12 m tall) pecan trees varies by pest and phenology and can be important considerations for canopy management decisions. Findings from this study in combination with horticultural and pathological parameters can help growers make informed decisions about canopy management of younger trees. Studies looking at how hedging impacts older pecan trees and when hedging occurs are discussed in the succeeding chapters.

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Table 2.1. Weather data for Marshallville, GA from May to October of 2020 and 2021

	May	June	July	August	September	October
2020						
High (°C)	27.14	30.28	32.61	32.08	28.07	26.11
Average (°C)	20.67	24.38	26.43	25.96	22.86	19.94
Low (°C)	14.47	19.67	21.35	21.70	18.88	14.78
Rainfall	4.93 cm	10.49 cm	21.06 cm	10.49 cm	22.40 cm	3.63 cm
2021						
	May	June	July	August	September	October
High (°C)	27.59	30.71	31.44	31.28	28.94	25.15
Average (°C)	20.79	24.45	25.37	25.43	22.72	18.8
Low (°C)	13.87	19.43	21.13	21.69	17.80	13.96
Rainfall	7.47 cm	12.70 cm	18.75 cm	17.86 cm	8.51 cm	9.14 cm

Table 2.2. Mean number of yellow complex aphids from the upper and lower canopies of hedged and non-hedged 30-year-old 'Desirable' pecan trees.

Treatment	Canopy Location	Mean ± SEM No. Total Yellow aphid complex per two leaves					
		2020			2021		
		June	July	August	June	July	August
Hedged	Upper	2.63 ± 0.52^	3.60 ± 0.84	18.33 ± 3.68 a	1.90 ± 0.47 ab	10.90 ± 2.52	1.55 ± 0.46
	Lower	2.57 ± 0.49^	7.00 ± 1.46*	2.93 ± 0.63 bc	2.13 ± 0.25 ab	14.48 ± 1.71	0.38 ± 0.25
Non-Hedged‡	Upper	1.58 ± 0.32	2.75 ± 0.25	1.00 ± 2.58 b	0.96 ± 0.27 b	9.03 ± 2.04	0.50 ± 0.26
	Lower	1.90 ± 0.32	4.80 ± 1.44*	0.43 ± 0.23 c	4.08 ± 1.41 a	12.68 ± 2.65	0.70 ± 0.47
Interaction Effects (*P* Value)		0.5962	0.5557	0.0017	0.0230	0.9875	0.1623
Non-hedged/Hedged (*P* Value)		0.0324	0.1690	0.0002	0.7698	0.4514	0.8500
Upper/Lower (*P* Value)		0.6965	0.0331	0.0001	0.0073	0.1562	0.1707

Columns with * following the means have a significant higher value between canopy locations using a student t-test
Columns with ^ following the means have a significantly higher value between the treatments using a student t-test
Columns with letters following the means have a significant interaction between canopy location and treatment with a having the highest amount
‡ Non-hedged trees were thinned in 2021

Table 2.3. Mean number of black pecan aphids sampled in August 2020 and 2021 in 30-year old 'Desirable' pecan trees from the upper and lower canopies of hedged and non-hedged trees.

Treatment	Canopy Location	Mean ± SEM No. Total Black Aphids per two leaves	
		2020	2021
		August	August
Hedged	Upper	3.48 ± 1.07*	0.28 ± 0.10*
	Lower	0.63 ± 0.49	0.05 ± 0.03
Non-Hedged‡	Upper	2.58 ± 1.71*	0.70 ± 0.35*
	Lower	0.23 ± 0.10	0.07 ± 0.03
Interaction Effects (*P* Value)		0.6441	0.2944
Non-hedged/Hedged (*P* Value)		0.3538	0.2976
Upper/Lower (*P* Value)		0.0220	0.0487

Columns with * following the means have a significant higher value between canopy locations using a student t-test
‡ Non-hedged trees were thinned in 2021

Table 2.4. Mean number of leaflets with black aphid damage sampled in August 2020 and 2021 in 30-year old 'Desirable' pecan trees from the upper and lower canopies of hedged and non-hedged trees.

Treatment	Canopy Location	Mean ± SEM No. Total leaflets with black aphid injury	
		2020	2021
		August	August
Hedged	Upper	3.10 ± 1.62	6.70 ± 0.45^
	Lower	6.00 ± 1.32*	8.58 ± 0.45^
Non-Hedged‡	Upper	4.05 ± 2.17	2.18 ± 0.95
	Lower	6.70 ± 2.33*	3.53 ± 1.62
Interaction Effects (*P* Value)		0.8817	0.7767
Non-hedged/Hedged (*P* Value)		0.3388	0.0017
Upper/Lower (*P* Value)		0.0079	0.1094

Columns with * following the means have a significant higher value between canopy locations using a student t-test
Columns with ^ following the means have a significantly higher value between the treatments using a student t-test
‡ Non-hedged trees were thinned in 2021

Table 2.5. Mean number of pecan leaf scorch mites sampled in August 2020 and 2021 in 30-year old 'Desirable' pecan trees from the upper and lower canopies of hedged and non-hedged trees.

Treatment	Canopy Location	Mean ± SEM No. Total Pecan leaf scorch mites per two leaves	
		2020	2021
		August	August
Hedged	Upper	2.00 ± 1.44	0 ± 0
	Lower	28.20 ± 11.13*	1.00 ± 0.36*
Non-Hedged‡	Upper	1.13 ± 0.54	0 ± 0
	Lower	12.40 ± 4.89*	2.60 ± 1.35*
Interaction Effects (*P* Value)		0.3132	0.5858
Non-hedged/Hedged (*P* Value)		0.2232	0.4705
Upper/Lower (*P* Value)		0.0019	0.0058

Columns with * following the means have a significant higher value between canopy locations using a student t-test
‡ Non-hedged trees were thinned in 2021

Table 2.6. Mean number of *Phylloxera* galls sampled in 2020 and 2021 from the upper and lower canopies of hedged and non-hedged 30-year-old 'Desirable' pecan trees.

Treatment	Canopy Location	Mean ± SEM No. Total *Phylloxera* galls per two leaves					
		2020			2021		
		June	July	August	June	July	August
Hedged	Upper	0.10 ± 0.07	0.08 ± 0.03	0 ± 0	12.30 ± 4.11	7.10 ± 3.99	2.18 ± 0.88
	Lower	1.15 ± 0.99	0.55 ± 0.46	0.25 ± 0.15*	9.28 ± 3.21	10.73 ± 3.33	3.78 ± 1.94
Non-Hedged‡	Upper	0.53 ± 0.09	0.55 ± 0.20^	0.68 ± 0.36^	26.76 ± 12.68	16.18 ± 7.64	5.23 ± 1.71^
	Lower	1.93 ± 0.49	1.58 ± 0.50^	2.10 ± 1.05*^	17.33 ± 7.61	15.23 ± 3.93	8.93 ± 3.99^
Interaction Effects (*P* Value)		0.8331	0.5250	0.6089	0.9112	0.4818	0.6899
Non-hedged/Hedged (*P* Value)		0.0643	0.0359	0.0076	0.0753	0.0575	0.0109
Upper/Lower (*P* Value)		0.0545	0.1120	0.0328	0.2951	0.6780	0.2550

Columns with * following the means have a significant higher value between canopy locations using a student t-test
Columns with ^ following the means have a significantly higher value between the treatments using a student t-test
‡Non-hedged trees were thinned in 2021

Table 2.7. Mean number of leaf miners from the upper and lower canopies of hedged and non-hedged 30-year-old 'Desirable' pecan trees.

Treatment	Canopy Location	Mean ± SEM No. Total Leaf miners per two leaves			
		2020		2021	
		July	August	July	August
Hedged	Upper	0.45 ± 0.18	0.95 ± 0.31 c	0 ± 0	0.10 ± 0.07
	Lower	0.85 ± 0.18*	7.58 ± 0.37 b	0.15 ± 0.15	0.48 ± 0.25*
Non-Hedged‡	Upper	0.30 ± 0	1.33 ± 0.99 c	0 ± 0	0.07 ± 0.07
	Lower	0.90 ± 0.13*	11.78 ± 1.19 a	0.10 ± 0.04	2.17 ± 1.09*
Interaction Effects (*P* Value)		0.4456	0.0472	NA	0.1195
Non-hedged/Hedged (*P* Value)		0.7366	0.0226	NA	0.1080
Upper/Lower (*P* Value)		0.0019	0.0001	NA	0.0383

Columns with * following the means have a significant higher value between canopy locations using a student t-test
Columns with letters following the means have a significant interaction between canopy location and treatment with a having the highest amount
‡Non-hedged trees were thinned in 2021

Figure 2.1. Map of Marshallville, GA hedging study site. This orchard has four blocks with each block consisting of one hedged and one non-hedged area in 2020 and one hedged and one thinned area in 2021. The trees are about 30 years old and primarily consist of the variety 'Desirable' with 'Sumners' as a pollinator variety.

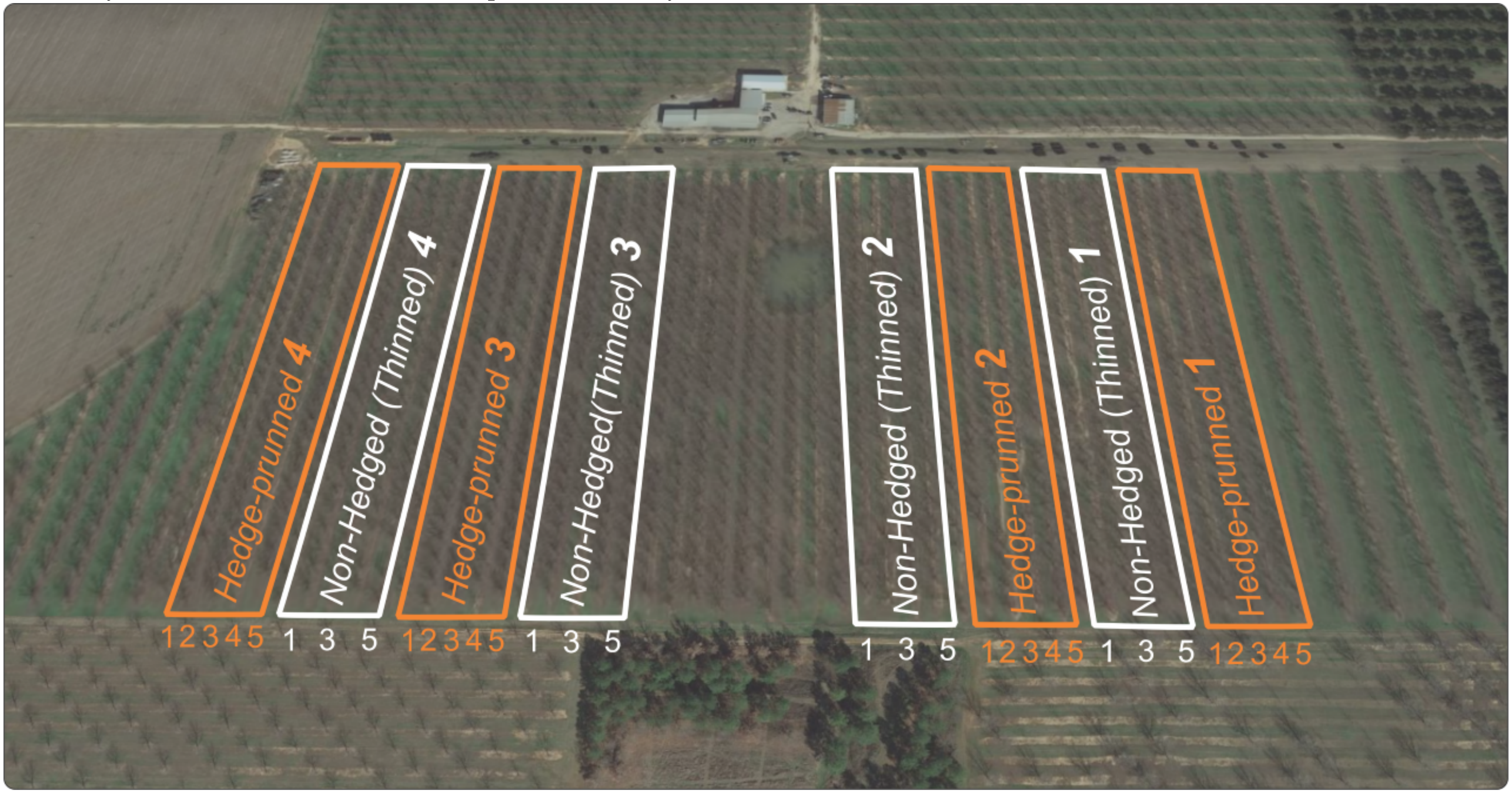

Figure 2.2. Insecticide spray records for 2020 and 2021 for the Marshallville hedging and thinning study.

Date	Product	Rate	Active	IRAC	Pest
5/25/20	Intrepid 2F	6 oz/ acre	methoxyfenozide	18	nuts
6/26/21	Intrepid Edge	4 oz/ acre	methoxyfenozide + spinetorom	5 + 18	Nuts
8/18/21	Abamex	19 oz/ acre	abamax	6	Mites

CHAPTER 3

IMPACTS OF HEDGING ON ARTHROPOD PESTS AND RELATED DAMAGE IN TWO CULTIVARS OF 45-YEAR-OLD PRODUCING PECAN TREES[2]

[2] Phillips, K. E., A. Acebes, W. Hudson, J. Schmidt. To be submitted to Economic Entomology

Abstract

Hedging and topping are two canopy management strategies growers can use to increase light penetration into the canopies and reduce the height of the trees. A previous study observed the impact of hedging on arthropod pest populations and related damage in younger trees, but this study observed the impact of hedging and topping on older trees of two pecan varieties, 'Cape Fear' and 'Stuart'. The cultivars were individually analyzed due to differences in susceptibly to arthropod pests by each cultivar. Leaves and nuts were collected at three points in the growing season from older (45-year-old) pecan trees to observe for arthropod populations and related damage. Leaf feeding pests observed in this study were yellow aphid complex (yellow pecan aphid, *Monelliopsis pecanis* Bissel, and blackmargined aphid, *Monellia caryella* (Fitch)), black pecan aphid, *Melanocallis caryaefoliae* (Davis), pecan leaf scorch mites, *Eotetranychus hicoriae* (McGregor), and leaf miners. No damage from arthropod pests were observed in the collected nuts, but the impacts of hedging and topping on arthropod pest populations that attack leaves varied by pest. No pests had larger populations in hedged trees compared to non-hedged trees at any point during the growing season. Overall, this study showed that in managed orchards, hedged and topped trees did not have larger populations of arthropod pests than the non-hedged and non-topped trees.

Introduction

As pecan trees age and grow, management of the orchard can become more difficult as the height of the tree increases and as the branches begin to crowd. Crowding of tree limbs can reduce light penetration into the canopies of the trees, which reduces yield (McEachern and Stein, 2003). The height of the trees can impact pest management since the coverage of pesticides by an air blast spray decreases as the height in the canopy increases (Bock et al. 2015). By ten years of age, both 'Cape Fear' and 'Stuart' trees can reach over 13 m in height, and the top of the canopy has significantly less pesticide coverage than the lowest branches (Wood 1996, Bock et al. 2015). To control the size of the trees in the orchard, growers can implement hedging and topping as canopy management strategies. Hedging will reduce crowding of the branches, which can increase light penetration into the canopy (Wells 2018) and topping of the trees will reduce the height to allow for better pesticide application into the canopy (Bock et al. 2015).

Multiple studies have shown that the susceptibility of pecans to arthropod pests varies by cultivar (Kaakeh and Dutcher 1994, Wood and Reilly 1998, Karar et al. 2012). Previous studies (Chapter 2), have shown how hedging impacts arthropod pest populations in younger trees of one variety, but no studies have addressed how hedging and topping impacts pest populations in older trees of differing varieties. 'Cape Fear' is a variety that is less susceptible to both yellow and black pecan aphids than 'Stuart' (Kaakeh and Dutcher 1994, Wood and Reilly 1998, Karar et al. 2012).

The objective of this study was to observe how hedging and topping of older (45-year-old) pecan trees impacted arthropod pest populations on two cultivars, 'Cape Fear' and 'Stuart'. Because of differing susceptibilities to pests by the cultivars, each cultivar was independently observed with a hypothesis of each pest being impacted differently by hedging and topping but overall, hedging and topping will not negatively impact arthropod pests of pecans.

Materials and Methods

Study Site

This study was conducted in Montezuma, GA (32.2489, -83.9743) in a 75-acre orchard. This orchard consisted of the varieties 'Cape Fear' and 'Stuart' with trees approximately 45 years old (Figure 3.1). The trees are spaced at 12.5 m by 15 m, and the height of the tree varied by treatment, with hedged trees being about 12 m tall and non-hedged trees were about 15 m tall. Fungicides and insecticides were applied in this orchard according to management practices recommended for the state of Georgia (Figure 3.2). In the winter of 2019, all hedged trees were pruned on the tops and sides. Every other row in this orchard was hedged.

This study was a randomized block design with three blocks for each variety, a total of six blocks. Each block consisted of one hedged row and one non-hedged row as the treatments. A total of ten trees from each row were randomly selected for leaf and nut samples. Samples were taken from the upper (~9 m) and lower (~2-3m) canopies. The samples from the upper canopy were taken using a hydraulic lift that can reach a maximum height of about 9 m. On the hedged trees, the lift reached the top of the canopy, however on the non-hedged trees, the lift only reached to about the middle of the canopy (9 m).

Monitoring leaf feeding insect populations

Leaf samples were taken at three points in the season in 2 June, 16 July, and 25 August 2020 and 1 June, 13 July, and 30 Aug 2021 to sample for arthropods and arthropod damage. Two compound leaves from the upper and lower canopies of each tree were sampled. In July 2020, due to technical difficulties, only samples from the lower canopy were taken. For standardization, only the middle six leaflets were kept. These were stored in bags and taken back to the laboratory to be processed. The total numbers of both immature and adult yellow aphids, blackmargined aphids, and black aphids, and pecan leaf scorch mites were tallied. Damage from leaf miners was also recorded.

Monitoring nut feeding insect populations

Three nut samples were taken during the season. The first batch of samples was taken on 2 June 2020 and 1 June 2021 primarily for monitoring pecan nut casebearer. The second sampling was conducted on 16 July 2020 and 13 July 2021 to monitor for pecan nut casebearer and shuckworm attacks. Due to technical difficulties only samples from the lower canopy were taken for 2020. The last sample was taken at harvest, which was on 16 October 2020 and 20 October 2021. These samples were taken once the shucks had started to split to monitor for shuckworm, stinkbug damage, and nut curculio injuries. One nut cluster (1-7 nuts/cluster) was sampled from the upper and lower canopies, placed in bags, and taken back to the laboratory for subsequent processing.

Weather data

Weather data for 2020 and 2021 is listed in Table 3.1. Monthly rainfall and temperatures were collected from the University of Georgia Weather Monitoring Network.

Statistical analysis

Arthropod populations and damage categories were initially examined for assumptions of parametric tests and square root transformation was conducted to approximate for normality. The data were then subjected to two-factorial ANOVA in JMP V15 (SAS Institute, 2019, Cary, NC) with canopy location and hedging as the fixed effects at $P > 0.05$. If a significant interaction effect was detected, a Tukey's HSD was conducted to compare the means of the different treatment combinations. If no significant interaction was detected, the individual fixed effects were analyzed separately at $\alpha = 0.05$. Since there were only two levels for each fixed effects, a Student's t-test at $\alpha = 0.05$ was conducted to compare the means between each treatment and canopy location. The varieties of trees and sampling dates were analyzed separately to account for extraneous factors including varietal differences of susceptibility to insect infestation and weather.

Results

Yellow aphid complex populations

2020. In the 'Cape Fear' variety, in the month of June, there was no interaction effect between canopy location and treatment (Table 3.2: 'Cape Fear' June 2020). There was also no significant difference in populations for both canopy location and treatment. In July, there was no significant difference between yellow aphid complex populations in hedged trees and non-hedged trees (Table 3.2: 'Cape Fear' July 2020). In August, there was no interaction between canopy location and treatment. Yellow complex aphid numbers were not statistically different between hedged trees and non-hedged trees, but the lower canopy of the trees had significantly more aphids than the upper canopy (Table 3.2: 'Cape Fear' August 2020). For 'Stuart' variety in June, there was no interaction between the canopy location and treatment. Yellow aphid numbers were similar on hedged trees and non-hedged trees, however there were less aphids in the upper canopy than the lower canopy (Table 3.2: 'Stuart' June 2020). In July, there was no significant difference between hedged trees and non-hedged trees (Table 3.2: 'Stuart' July 2020). For August, no significant interaction was found between treatment and canopy location. Yellow complex aphid populations did not differ significantly between hedged trees and non-hedged trees. More aphids were found in the lower canopy than the upper canopy (Table 3.2: 'Stuart' August 2020).

2021. In the 'Cape Fear' variety, for all three months of sampling, there was no interaction between canopy location and treatment for populations of the yellow aphid complex. There were also no significant differences between canopy location and no significant differences between treatments for all three months (Table 3.2: 'Cape Fear'). In June in the 'Stuart' variety, there were not a large enough population to run statistical analysis (Table 3.2: 'Stuart' June 2021). In July, there was no interaction between canopy location and treatment, and no significant difference between canopy location or treatment (Table 3.2: 'Stuart' July 2021). August had no interaction between canopy location and treatment for yellow aphid complex populations, and no significant differences between treatments, but the lower canopy had larger populations than the upper canopy (Table 3.2: 'Stuart' August 2021).

Black pecan aphids

2020. Black pecan aphids were only present in August. For both the 'Cape Fear' and 'Stuart' varieties, there was no significant interaction between the canopy location and treatment. For 'Cape Fear', the lower canopy had more black pecan aphids than the upper canopy, but the number of aphids between the hedged trees and non-hedged trees was similar (Table 3.3: 'Cape Fear' August 2020). For 'Stuart', the upper canopy had fewer aphids than the lower canopy, and the hedged trees had lower number of aphids than the non-hedged trees (Table 3.3: 'Stuart' August 2020).

2021. Populations of black aphids for both varieties of pecans did not appear until August. In the 'Cape Fear' variety, there was not a large enough population to run statistical analysis (Table 3.3: 'Cape Fear' August 2021). For the 'Stuart' variety, there was no interaction between canopy location and treatment, and no statistical differences between canopy location and between treatments (Table 3.3: 'Stuart' August 2021).

Black pecan aphid injury

2020. Black aphid injury was not found in June or July for either variety. In 'Cape Fear' in August, not enough damage was observed to run statistical analysis (Table 3.4: 'Cape Fear' August 2020). In 'Stuart' in August, there was an interaction between canopy location and treatment. The lower canopy of non-hedged trees had the highest number of leaflets with black aphid injury with no statistical difference between the other three treatment combinations (Table 3.4: 'Stuart' August 2020).

2021. Similar to 2020, no black aphid injury was found in June and July for either varieties. For the both varieties, there were not enough leaflets with black pecan damage to run statistical analysis for August (Table 3.4: August 2021).

Pecan leaf scorch mite (PLSM)

2020. Pecan leaf scorch mites were not present until later in the growing season. In July, for both varieties, there was no difference in PLSM numbers between hedged trees and non-hedged trees for either variety (Table 3.5: July 2020). In August, there was no interaction between canopy location and treatment for either variety. The amount of PLSM did not significantly vary between the canopy location or treatment (Table 3.5: August 2020).

2021. The ‘Cape Fear’ variety did not have enough PLSM to run statistical analysis in July (Table 3.5: ‘Cape Fear’ July 2021). In August, there was no interaction between canopy location and treatment, and no statistical difference between hedged and non-hedged trees. PLSM had larger populations in the lower canopy compared to the upper canopy (Table 3.5: ‘Cape Fear’ August 2021). In the ‘Stuart’ variety, in July, there was no interaction between canopy location and treatment and no statistical differences between canopy locations and between treatments (Table 3.5: ‘Stuart’ July 2021). In August, there was no interaction between canopy location and treatment. There was no statistical difference between hedged and non-hedged trees, but the lower canopy had higher populations of PLSM than the upper canopy (Table 3.5: ‘Stuart’ August 2021).

Leaf miners

2020. No leaf miners were found in June or July for either the ‘Cape Fear’ and ‘Stuart’ variety. In August, there was no interaction effect between treatment and canopy location in the ‘Cape Fear’ variety, and similar degree of damage was found between canopy locations and treatments (Table 3.6: ‘Cape Fear’ July 2020). For the ‘Stuart’ variety in August, the canopy location and treatment did not influence the number of leaf miners. The upper canopy had less leaf miner damage than the lower canopy, and but the hedged trees and non-hedged trees had similar amounts of damage (Table 3.6: August 2020).

2021. No leaf miners or leaf miner damage were observed in either variety in June. In July for the ‘Cape Fear’ variety, no interaction between canopy location and treatment was observed as well as no statistical differences between canopy location and treatment (Table 3.6: ‘Cape Fear’ July 2021). In August, no significant interaction was found, and there was no statistical difference between treatments, but the upper canopy had significantly less leaf miners than the lower canopy (Table 3.6: 'Cape Fear' August 2021). For both July and August in the 'Stuart' variety, there was no interaction between canopy location and treatment. There were also no significant differences between canopy location and treatments for either month (Table 3.6: 'Stuart' 2021).

Insect related nut injury before harvest

2020. In June, a total of 682 nuts were sampled. In these nuts, only one had evidence of pecan nut casebearer (PNC) infestation. In the month of July, a total of 240 nuts were sampled from the lower canopy, however no damage from either pecan nutcase bearer or shuckworm was found.

2021. In June, 420 nuts were sampled, and only two had evidence of PNC damage. In July, 376 nuts were sampled and only one had evidence of PNC damage. This orchard had spittlebugs present as well, with a total of 44 present in the samples.

Insect injury on harvested nuts

2020. At harvest, a total of 563 nuts were collect between the 'Cape Fear' and 'Stuart' cultivars. Of the 563 nuts samples, no shuckworms were found, and only four nuts (0.71%) had any damage. No injuries from nut curculio or stink bugs were found on the harvested samples.

2021. At harvest, 398 total nuts were collected from both the 'Cape Fear' and 'Stuart' cultivars. No shuckworms or other damage were observed in the nuts.

Discussion

The impact of hedging on older (45-year-old) pecan trees varies by pest, time of year, and the cultivar of the tree. The two cultivars in this orchard, 'Cape Fear' and 'Stuart', were individually analyzed for each pest population due to differences in susceptibilities to pests for each cultivar (Wood and Reilly 1998, Karar et al. 2012). Arthropod pests observed in this study can be categorized in two ways, leaf feeding and nut feeding. For leaf feeding pests overall, hedging did not make pest populations worse, and for nut feeding pests, due to the low level of injury, no impact of hedging on pest populations and damage was able to be observed.

Regardless of time of year, there were no significant differences in yellow aphid complex populations between hedged and non-hedged trees for either cultivar. The only significant differences present in yellow aphid complex populations were between the upper and lower canopies, with the lower canopy having more aphids present in some of the samples. The canopy-associated yellow aphid complex populations varies throughout the season, with preference in the lower canopy until large populations are present (Polles and Mullinix 1977). The populations in the study are small and below the recommended threshold for treatment (Acebes et al. 2020).

During the population peaks of yellow aphid complex populations in this orchard, 'Stuart' trees had more aphids than 'Cape Fear' trees, which is consistent with previous studies showing 'Stuart' is a more susceptible variety (Karar et al. 2012). In 2020, the largest population of aphids was observed in August, which aligns with the beginning of the second of the two population peaks observed previously for yellow aphid complex populations (Tedders 1978). In 2021, the highest number was observed in July with a smaller number observed in August. One possible explanation for the larger population in July is pesticide application (Fig. 3.2). The July sample was collected before any insecticides were applied to the orchard and the August sample was collected a week after an insecticide to control aphids was applied (Fig. 3.2).

Black pecan aphids are a pest that is usually not present until later in the growing season with population peaks in September and October (Slusher et al. 2021), and this study only had black aphids present in August for both years. Similar to the yellow aphid complex populations, ‘Stuart’ trees are more susceptible to black pecan aphid infestations than ‘Cape Fear’ trees (Wood and Reilly 1998). The populations of black aphids observed in the ‘Cape Fear’ variety for both 2020 and 2021 were below the recommended threshold for pesticide application. For the ‘Stuart’ variety, the 2020 sample was close to the recommended threshold for pesticide application and the 2021 sample was below the threshold. The recommended threshold for pesticide applications to control black pecan aphids is 15% of leaves sampled having black aphids present (Acebes et al. 2020). Multiple factors could be responsible for the low numbers of black aphids observed including collecting samples prior to the population peak (Slusher et al. 2021) and collecting samples after insecticides have been applied (Fig. 3.2).

Observing for injury from black pecan aphids can give insight into what populations looked like prior to pesticide application. In the ‘Cape Fear’ trees in both years and the ‘Stuart’ trees in 2021, there was not enough damage to run statistical analysis, and the ‘Stuart’ leaves in 2020 had low levels of damage present. This shows that the populations of black aphids were small or had not had enough time to create damage on the leaves.

Pecan leaf scorch mites (PLSM) are another leaf feeding pest that is primarily present in the later part of the growing season (Osburn et al. 1963), which is shown by no populations present in June, smaller populations in July, and the largest populations present in August. Regardless of population size and time of year, there were no differences between hedged trees and non-hedged trees in relations to PLSM. The only differences in populations were more PLSM were present in the lower canopy, which is consistent with previous studies (Osburn et al. 1963). Even though no samples were collected from the upper canopy in July 2020, because PLSM is known to be a lower canopy pest, we can assume that the populations in the upper canopy would also be very low.

The populations of leaf miners present in older pecan trees were not impacted by hedging. Four species of leaf miners have been identified as pests to pecans, but only one species is known to cause economic damage (Payne et al. 1972). When observing for injury, all leaf miner species were counted as one category, so it is unknown how many leaf miners belonged to which species.

The primary goal of a commercial orchard is to produce a crop, and because of this, a grower will attempt to control pests that will injure the nut. Because growers are successful in targeting pests that injure the nut, no damage from arthropod pest was found in any nuts from either variety during any sample. When growers use standard management practices to control arthropod pest that feed on the nuts, hedging did not affect the number of nuts with damage by arthropod pests.

Table 3.1. Weather data for Montezuma, Georgia in May to October of 2020 and 2021.

2020						
	May	June	July	August	September	October
High (°C)	27.38	30.76	32.77	32.57	28.00	26.22
Average (°C)	21.14	24.79	26.51	26.23	22.92	20.02
Low (°C)	15.03	20.16	21.94	21.97	19.07	14.93
Rainfall	9.50 cm	5.89 cm	16.10 cm	9.83 cm	14.81 cm	6.40 cm
2021						
	May	June	July	August	September	October
High (°C)	27.65	30.58	31.41	31.44	29.14	25.45
Average (°C)	21.35	24.73	25.52	25.59	22.94	19.16
Low (°C)	14.63	20.27	21.57	21.86	17.88	14.18
Rainfall	8.74 cm	11.25 cm	19.84 cm	18.54 cm	10.59 cm	18.46 cm

Table 3.2. Mean number of yellow complex aphids sampled in 2020 and 2021 from the upper and lower canopies of hedged and non-hedged 45-year-old 'Cape Fear' and 'Stuart' pecan trees.

Variety	Treatment	Canopy Location	Mean ± SEM No. Total Yellow Complex Aphids per Two Leaves					
			2020			2021		
			June	July	August	June	July	August
Cape Fear	Hedged	Upper	0.43 ± 0.08	/	0.57 ± 0.27	1.37 ± 1.32	4.17 ± 0.23	0.40 ± 0.15
		Lower	0.53 ± 0.15	0.37 ± 0.13	5.64 ± 1.98*	0.86 ± 0.38	7.47 ± 2.44	2.23 ± 0.55
	Non-Hedged	Upper	0.20 ± 0.10	/	0.40 ± 0.17	0.96 ± 0.78	3.30 ± 0.56	0.83 ± 0.48
		Lower	0.63 ± 0.19	0.97 ± 0.32	5.10 ± 1.47*	0.13 ± 0.09	3.50 ± 0.38	2.63 ± 1.88
Interaction Effects (*P* Value)			0.3171	/	0.9746	0.3845	0.2716	0.6737
Non-hedged/Hedged (*P* Value)			0.6778	0.1515	0.7384	0.3323	0.1080	0.7865
Upper/Lower (*P* Value)			0.1315	/	0.0017	0.5750	0.2207	0.0636
Stuart	Hedged	Upper	0.37 ± 0.14	/	2.60 ± 1.70	0.17 ± 0.09	8.43 ± 1.85	0.45 ± 0.23
		Lower	0.64 ± 0.23*	0.93 ± 0.35	28.75 ± 10.02*	0.13 ± 0.13	7.56 ± 1.52	3.06 ± 0.67*
	Non-Hedged	Upper	0.11 ± 0.11	/	1.85 ± 0.42	0.17 ± 0.12	13.27 ± 3.20	0.67 ± 0.09
		Lower	0.83 ± 0.34*	0.77 ± 0.15	15.45 ± 6.02*	0.27 ± 0.18	7.60 ± 0.67	3.00 ± 1.47*
Interaction Effects (*P* Value)			0.2303	/	0.3439	NA	0.2504	0.5031
Non-hedged/Hedged (*P* Value)			0.8409	0.6667	0.2819	NA	0.2439	0.9251
Upper/Lower (*P* Value)			0.0250	/	0.0026	NA	0.1336	0.0057

Columns with * following the means have a significant higher value between canopy locations using a student t-test
Columns with / did not have upper canopy samples collected
Columns labelled with NA did not have enough damage to run statistical analysis

Table 3.3. Mean number of black pecan aphid from the upper and lower canopies of hedged and non-hedged 45-year-old ‘Cape Fear’ and ‘Stuart’ pecan trees in August 2020 and 2021.

Variety	Treatment	Canopy Location	Mean ± SEM No. Black pecan Aphids per two leaves	
			2020	2021
			August	August
Cape Fear	Hedged	Upper	0.03 ± 0.03	0 ± 0
		Lower	0.37 ± 0.03*	0 ± 0
	Non-Hedged	Upper	0 ± 0	0.06 ± 0.06
		Lower	0.53 ± 0.43*	0.30 ± 0.21
Interaction Effects (*P* Value)			0.4671	NA
Non-hedged/Hedged (*P* Value)			0.9507	NA
Upper/Lower (*P* Value)			0.0162	NA
Stuart	Hedged	Upper	0 ± 0	0.36 ± 0.03
		Lower	0.28 ± 0.14*	0.31 ± 0.17
	Non-Hedged	Upper	0.11 ± 0.11^	1.47 ± 1.01
		Lower	4.59 ± 2.37*^	1.63 ± 1.25
Interaction Effects (*P* Value)			0.0930	0.7763
Non-hedged/Hedged (*P* Value)			0.0412	0.1821
Upper/Lower (*P* Value)			0.0157	0.8403

Columns with * following the means have a significant higher value between canopy locations using a student t-test
Columns with ^ following the means have a significant higher value between treatments using a student t-test
Columns labelled with NA did not have enough damage to run statistical analysis

Table 3.4. Mean number of leaflets with black aphid damage from the upper and lower canopies of hedged and non-hedged 45-year-old ‘Cape Fear’ and ‘Stuart’ pecan trees in August 2020 and 2021.

Variety	Treatment	Canopy Location	Mean ± SEM No. Black pecan Aphid injury per two leaves	
			2020	2021
			August	August
Cape Fear	Hedged	Upper	0.27 ± 0.27	0 ± 0
		Lower	0.17 ± 0.09	0 ± 0
	Non-Hedged	Upper	0 ± 0	0 ± 0
		Lower	0.07 ± 0.07	0.13 ± 0.13
Interaction Effects (*P* Value)			NA	NA
Non-hedged/Hedged (*P* Value)			NA	NA
Upper/Lower (*P* Value)			NA	NA
Stuart	Hedged	Upper	0.53 ± 0.27 b	0 ± 0
		Lower	0.39 ± 0.22 b	0 ± 0
	Non-Hedged	Upper	0.50 ± 0.29 b	1.87 ± 0.96
		Lower	2.05 ± 0.79 a	0.70 ± 0.56
Interaction Effects (*P* Value)			0.0036	NA
Non-hedged/Hedged (*P* Value)			0.0047	NA
Upper/Lower (*P* Value)			0.0100	NA

Columns with letters following the means have a significant difference between each canopy and treatment combination with a having the most and b having the least
Columns labelled with NA did not have enough damage to run statistical analysis

Table 3.5. Mean number of pecan leaf scorch mites in 2020 and 2021 from the upper and lower canopies of hedged and non-hedged 45-year-old 'Cape Fear' and 'Stuart' pecan trees.

Variety	Treatment	Canopy Location	Mean ± SEM No. total scorch mites per two leaves			
			2020		2021	
			July	August	July	August
Cape Fear	Hedged	Upper	/	0.07 ± 0.07	0 ± 0	0.47 ± 0.17
		Lower	1.67 ± 0.84	0.30 ± 0.30	0 ± 0	9.53 ± 6.49*
	Non-Hedged	Upper	/	0 ± 0	0 ± 0	0.20 ± 0.20
		Lower	0.80 ± 0.21	0.03 ± 0.03	0.03 ± 0.03	12.60 ± 7.57*
Interaction Effects (*P* Value)			/	NA	NA	0.6009
Non-hedged/Hedged (*P* Value)			0.6211	NA	NA	0.9507
Upper/Lower (*P* Value)			/	NA	NA	0.0099
Stuart	Hedged	Upper	/	2.84 ± 1.11	0.43 ± 0.30	12.23 ± 11.49
		Lower	0.76 ± 0.62	7.23 ± 5.33	0.73 ± 0.73	86.63 ± 62.99*
	Non-Hedged	Upper	/	0.20 ± 0.15	0.60 ± 0.35	18.60 ± 5.38
		Lower	0.27 ± 0.03	5.85 ± 4.42	1.27 ± 0.66	92.80 ± 32.25*
Interaction Effects (*P* Value)			/	0.4864	0.7263	0.8993
Non-hedged/Hedged (*P* Value)			0.7650	0.3315	0.5593	0.4206
Upper/Lower (*P* Value)			/	0.1567	0.7622	0.0190

Columns with * following the means have a significant higher value between canopy locations using a student t-test
Columns with / did not have upper canopy samples collected
Columns labelled with NA did not have enough damage to run statistical analysis

Table 3.6. Mean number of leaf miners in 2020 and 2021 from the upper and lower canopies of hedged and non-hedged 45-year-old 'Cape Fear' and 'Stuart' pecan trees.

Variety	Treatment	Canopy Location	Mean ± SEM No. Total Leaf miners per two leaves		
			2020	2021	
			August	July	August
Cape Fear	Hedged	Upper	0.20 ± 0.12	0.37 ± 0.21	0.67 ± 0.07
		Lower	0.49 ± 0.06	0.17 ± 0.09	3.90 ± 1.39*
	Non-Hedged	Upper	0.10 ± 0.10	0.07 ± 0.07	0.67 ± 0.15
		Lower	0.50 ± 0.26	0.20 ± 0.12	2.73 ± 0.79*
Interaction Effects (*P* Value)			0.7548	0.2798	0.6021
Non-hedged/Hedged (*P* Value)			0.7913	0.3417	0.5800
Upper/Lower (*P* Value)			0.8019	0.9786	0.0085
Stuart	Hedged	Upper	0.21 ± 0.11	0.33 ± 0.12	1.79 ± 1.22
		Lower	0.53 ± 0.17	0.57 ± 0.27	3.27 ± 1.83
	Non-Hedged	Upper	0.21 ± 0.11	0.20 ± 0.10	1.80 ± 0.81
		Lower	0.59 ± 0.15	0.50 ± 0.30	3.90 ± 1.69
Interaction Effects (*P* Value)			0.8384	0.8414	0.8194
Non-hedged/Hedged (*P* Value)			0.8384	0.5152	0.8194
Upper/Lower (*P* Value)			0.0576	0.2247	0.2186

Columns with * following the means have a significant higher value between canopy locations using a student t-test

Figure 3.1. Map of Montezuma, GA hedging study site. This orchard has three blocks with each block consisting of one hedged and one non-hedged row of 'Cape Fear' and 'Stuart' trees. The trees are about 45 years old

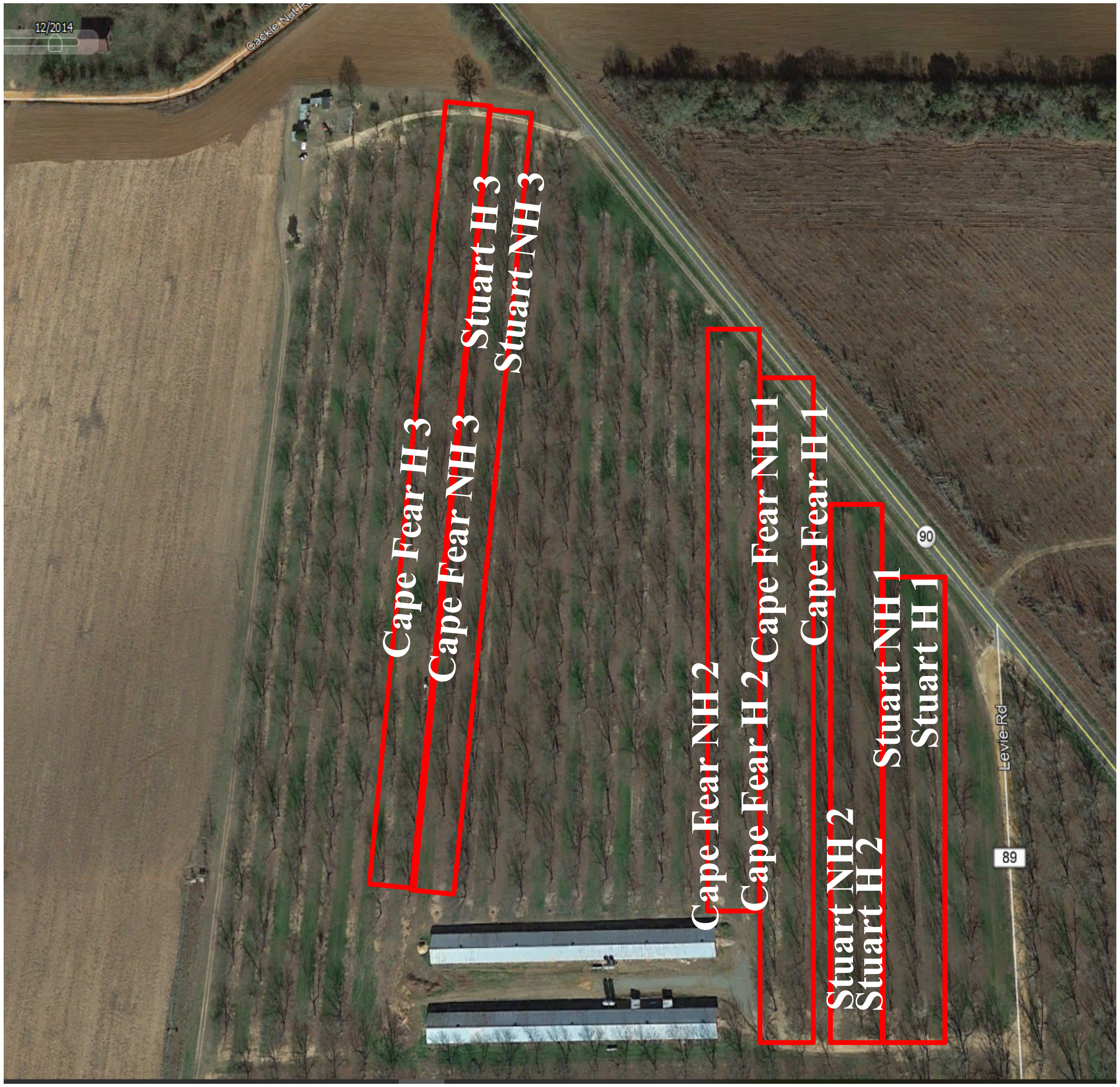

Figure 3.2. Insecticide spray record for 2020 and 2021 for Montezuma field site.

Date	Product	Rate	Active	IRAC	Pest
5/19/20	Intrepid Edge	5 oz/ acre	methoxyfenozide + spinetorom	5 + 18	Nut
8/12/20	Upside	6.5 oz/ acre	cypermethrin	3A	Nut
	NA	6.5 oz/ acre	bifinthren	3A	All
Spray 9	Upside	6.5 oz/ acre	cypermethrin	3A	Nut
	NA	6.5 oz/ acre	bifinthren	3A	All
	Transform	2 oz/ acre	sulfoxaflor	4C	Aphids
Spray 10	Upside	6.5 oz/ acre	cypermethrin	3A	Nut
8/9/21	Upcyde	6.5 oz/ acre	cypermethrin	3A	Nut
8/23/21	Bifenture	6.5 oz/ acre	bifentrin	3A	All
9/3/21	Bifenture	6.5 oz/ acre	bifentrin	3A	All
	Transform	2 oz/ acre	sulfoxaflor	4C	Aphids
9/10/21	Transform	2 oz/ acre	sulfoxaflor	4C	Aphids
	Bifenture	6.5 oz/ acre	bifentrin	3A	All
	ABBA Ultra	12.5 oz/ acre	abamectin	6	Mites

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CHAPTER 4

IMPACTS OF SUMMER HEDGING VERSUS WINTER HEDGING ON ARTHROPOD PESTS AND RELATED DAMAGE IN 25-YEAR-OLD PROUCING PECAN ORCHARDS[3]

[3] Phillips, K. E., A. Acebes, W. Hudson, J. Schmidt. To be submitted to Economic Entomology

Abstract

Standard practices for hedging in the Southeastern United States occur during the winter, or dormant season, with few studies addressing how hedging in the summer compares to hedging in the winter. Prior studies on this topic have only observed horticultural parameters and no entomological parameters. Leaves and nuts from 25-year-old pecan trees of the varieties 'Creek' and 'Caddo' were collected at three points in the growing season to monitor pest populations. Leaf-feeding pests observed include the yellow aphid complex (yellow pecan aphid, *Monelliopsis pecanis* Bissell, and the blackmargined aphid, *Monellia caryella* (Fitch), black pecan aphids, *Melanocallis caryaefoliae* (Davis), pecan leaf scorch mites, *Eotetranychus hicoriae* (McGregor), and leaf miners. The only nut-feeding pest observed was pecan nut casebearer, *Acrobasis nuxvorella* Neunzig. No pest populations observed had statistical differences between summer and winter hedged trees, but more injury caused by black pecan aphids were observed in the summer hedged trees than the winter hedged trees for one sample date. The amount of injury observed in sampled nuts was minimal and no statistical analysis was run. This study shows that in managed orchards, there is no difference in pest population size between summer and winter hedged trees but damage by arthropod pests varies by species.

Introduction

Hedging, or hedge-pruning, can allow growers to increase light penetration into the canopies of pecan trees. Studies on hedging in the Southeastern United States have shown an increase in nut quality, yield, water efficiency, and wind resistance (Lombardini 2006, Wells 2018). Previous studies (Chapter 2 and Chapter 3) looked at how hedging impacts pest populations, but these studies observed orchards which were hedged in the winter. One previous study found that summer hedging did not have any advantages in horticultural parameters compared to winter hedging (Wood 2009), but no entomological parameters were observed.

Arthropod pests located in the canopies of pecan trees are divided into two categories, leaf-feeding pests and nut-feeding pests. Leaf feeding arthropod pests can consist of aphids, mites, and leaf miners, and nut-feeding pests are pecan nut casebearer and hickory shuckworm.

The objective of this study was to observe impact of summer hedging versus winter hedging on arthropod pest populations and the related damages in two varieties of pecan trees, 'Creek' and 'Caddo'.

Materials and Methods

Study Site

This study was conducted on a 40-acre commercial 'Creek' and 'Caddo' cultivar pecan orchard located in Ray City, GA (31.024633, -83.243171). These trees are about 9 meter tall, 25 years-old and in rows spaced about 15 meters by 15 meters (Figure 4.l). This orchard was managed using standard conventional practices for Georgia (Acebes et al. 2020) with the middle of the rows being regularly mowed as well as regular applications of insecticides and fungicides. The summer hedged trees were pruned in summer of 2019 and the winter hedged trees were pruned in Winter of 2020.

This study was designed using a randomized block design with three blocks. Each block consisted of a summer hedged treatment and a winter hedged treatment of both cultivars. Ten trees from each replicate were randomly selected for leaf and nut samples. Lower canopy samples were collected from a height of ~2m and upper canopy samples were collected at a height of ~9m using a hydraulic lift.

Monitoring leaf-feeding arthropod populations

Leaf samples were taken at three points in the season to monitor for arthropod populations and related damages. Two leaves from the lower and upper canopies of each randomly selected tree was sampled and standardized to keep the middle six leaflets, then stored in bags to be processed in the laboratory. In 2020, samples were taken on 2 June, 8 July, and 28 August, and in 2021, samples were taken on 2 June, 13 July, and 1 Sep. Mature and immature yellow aphids, blackmargined aphids, black pecan aphids and pecan leaf scorch mites were counted as well as arthropod related injury caused by black pecan aphids, leaf miners, and *Phylloxera*.

Monitoring nut feeding insect populations

Nuts were sampled at three points in the season to check for nut feeding insects and related damage. The first sample of both the 2020 and 2021 seasons were taken on 2 June of the respective year with the primary goal of assessing for pecan nut casebearer (PNC) eggs and injury. The second sample was taken on 8 July 2020 and 13 July 2021 to evaluate for PNC and shuckworm populations and damage. The last sample was taken right before harvest to monitor for shuckworm, stink bug, and nut curculio damage. On the last sample date, the ‘Creek’ cultivar trees had already been shaken to prepare for harvest, so only lower canopy samples were taken, however, ‘Caddo’ trees had not been shaken yet, so both canopy locations were sampled.

Weather data

Rainfall and temperature data for the 2020 and 2021 is listed in Table 4.1. Monthly data was collected from the University of Georgia Weather Monitoring Network.

Statistical analysis

To test if there is a difference between the impacts of summer hedging and winter hedging on pecan trees, a randomized block design was used in the orchard. Arthropod populations and damage were analyzed using a two-factorial ANOVA in JMP V15 (SAS Institute, 209, Cary, NC) using α=0.05. The hedging treatments (summer and winter) and canopy location (upper and lower) were the fixed effects. Each arthropod and damage category were individually tested by tree cultivar to check for normality. If the population did not fit normality, a square root transformation was used. Interaction between the fixed effects were checked. If significant interaction occurred, a Tukey HSD was used. If no interaction occurred, each fixed effect was analyzed using a student's t-test to observe for significant differences.

Results

Yellow aphid complex

2020. In the 'Creek' cultivar, for all three sample dates, there was no interaction between the canopy location and treatment. There was also no significant difference between treatments and canopy locations in any sample date (Table 4.2: 'Creek' 2020). In the 'Caddo' cultivar, the same results as the 'Creek' cultivar were found for all three sample dates (Table 4.2: 'Caddo' 2020).

2021. In June, for the 'Creek' cultivar, there was interaction between canopy location and treatment, and there was no significant difference between canopy locations and between treatments for populations of the yellow aphid complex (Table 4.2: 'Creek' June 2021). In July and August, the populations were not large enough to run statistical analysis (Table 4.2: 'Creek' 2021). For the 'Caddo' cultivar, results are the same as 'Creek' for each sample date (Table 4.2: 2021).

Black pecan aphids

2020. No black pecan aphids were found in samples collected in June and July for both the 'Creek' and 'Caddo' cultivars. For the 'Creek' cultivar in August, there were not enough aphids present to run statistical analysis (Table 4.3: 'Creek' August 2020). For the 'Caddo' cultivar, there was no significant interaction between canopy location and treatment, and no significant differences between canopy locations and treatments (Table 4.3: 'Caddo' August 2020).

2021. For both the 'Creek' and 'Caddo' cultivars, no black pecan aphids were found in June, and populations were not large enough to run statistical analysis in July and August (Table 4.3: 2021).

Black pecan aphid injury

2020. In August, for the 'Creek' cultivar, there was no interaction effect between canopy location and hedging treatment, and no significant difference between the treatments, but the lower canopy had more leaflets with black pecan aphid injury than the upper canopy (Table 4.4: 'Creek' August 2020). For the 'Caddo' cultivar, there was no interaction effect between canopy location and treatment but there were significant differences between the canopy location and between treatments. The summer hedged trees had more leaflets with injury compared to winter hedged trees, and the lower canopy had more leaflets with injury than the upper canopy (Table 4.4: 'Caddo' August 2020)

2021. In the 'Creek' cultivar in July, there was no interaction between canopy location and treatment. There was no statistical difference between summer and winter hedged trees, but the lower canopy had greater amounts of black pecan aphid damage than the upper canopy (Table 4.4: 'Creek' July 2021). In August, there was no interaction between canopy location and treatment as well as no statistical difference between treatments and canopy locations (Table 4.4: ‘Creek’ August 2021). For the ‘Caddo’ cultivar in July, there was no interaction between canopy location and treatment. There was also no statistical difference between treatment, but the upper canopy had lower amounts of damage than the lower canopy (Table 4.4: ‘Caddo’ July 2021). In August, results were similar to July (Table 4.4: ‘Caddo’ August 2021).

Pecan leaf scorch mites

2020. For both the ‘Creek’ and ‘Caddo’ cultivars, no pecan leaf scorch mites (PLSM) were found in June. In July for the ‘Creek’ cultivar, there was no significant interaction between the treatment and canopy location. The trees hedged in the summer had similar amounts of PLSM as the trees hedged in the winter, but the lower canopies of the trees had more PLSM than the upper canopy (Table 4.5: ‘Creek’ July 2020). In August, there was no significant interaction between the canopy location and treatment, and similar to July, the lower canopy had more PLSM than the upper canopy but no significant difference between treatments (Table 4.5: ‘Creek’ August 2020). For the ‘Caddo’ cultivar in July, results were similar to the ‘Creek’ cultivar with no significant interaction between canopy location and treatment, and the only significant difference being between canopy locations (Table 4.5: ‘Caddo’ July 2020). There was significant interaction between the treatment and canopy location in the August sample. The lower canopy of winter hedged trees had the most PLSM of all the treatment and location combinations while the upper canopies of both summer and winter hedged trees had the least (Table 4.5: ‘Caddo’ August 2020).

2021. No PLSM were observed in June for either cultivar. For the ‘Creek’ cultivar in July, there was no interaction between the canopy location and treatment, and no statistical difference between treatments, but there were more PLSM in the lower canopy than the upper canopy (Table 4.5: ‘Creek’ July 2021). In August, there was no significant interaction between canopy location and treatment and no significant difference in the variables as well (Table 4.5: ‘Creek’ August 2021). In ‘Caddo’ in July, there was no interaction between the variable and no significant differences (Table 4.5: ‘Caddo’ July 2021). In August, there was no interaction between canopy location and treatment and no significant difference between the treatments. The lower canopy had significantly more PLSM than the upper canopy (Table 4.5: ‘Caddo August 2021).

Leaf miners

2020. In June, leaf miners and the associated damage were only counted in the ‘Creek’ cultivar. No significant interaction between the canopy location and hedging treatment was observed, and both canopies had similar populations of leaf miners as well as both hedging treatments (Table 4.6: ‘Creek’ June 2020). The lower canopy of both had more leaf miner damage in July than the upper canopies, however there was no difference between the treatments as well as no significant interactions (Table 4.6: ‘Creek’ July 2020). In August, there was no significant interaction between the treatment and canopy location, and similar to July, only canopy location was significantly different with the lower canopy having more (Table 4.6: ‘Creek’ August 2020). In the ‘Caddo’ cultivar, results for July were similar to results in ‘Creek’ cultivar for July (Table 4.6: ‘Caddo’ July 2020). A significant interaction was observed in August. The lower canopy of summer hedged trees had the highest numbers of leaf miner damage, while the upper canopies of both the summer hedged and winter hedged trees had the least amount of damage (Table 4.6: ‘Caddo’ August 2020).

2021. For the ‘Creek’ cultivar in June and July, the lower canopy had more leaf miners than the upper canopy regardless of treatment, and there were no significant differences between treatments and no interaction between canopy location and treatment (Table 4.6: ‘Creek’ June and July 2021). In August, there was no interaction or significant differences between canopy location and treatment (Table 4.6: ‘Creek’ August 2021). For the ‘Caddo’ cultivar in June, there was not enough damage to run statistical analysis (Table 4.6: ‘Caddo’ June 2021). In July and August, there was no statistical differences between canopy location and treatment as well as no interaction (Table 4.6: ‘Caddo’ July and August 2021).

Early season nut injury

2020. In June, 990 nuts were sampled, and in July, 980 nuts were sampled. In both months, no pecan nut casebearer or shuckworm injury was recorded.

2021. In June, 973 nuts were collected, and eight PNC larvae were observed (0.8% infestation). In July, 661 nuts were collected, and no nuts had any insect related damage.

Harvest

2020. At harvest, 540 nuts were collected. In all the nuts collected, none had any injury related to nut feeding insects.

2021. At harvest, 508 nuts were collected, and none had injury related to nut-feeding insects.

Discussion

The impact of summer and winter hedging varied by category of pest (leaf and nut feeding) and varied throughout the growing season. Varying results were observed in leaf feeding pests, but nut feeding pests had no differences between summer and winter hedged trees due to the low population counts. Some cultivars of pecan trees are more susceptible to arthropod pest infestations than others (Wood and Reilly 1998), so each cultivar was individually analyzed.

Regardless of cultivar or month the samples were collected, there were no significant differences in yellow aphid complex populations between trees hedged in the summer and winter. In both cultivars, populations of yellow complex aphids were low throughout the growing season, with the largest populations present in June. Untreated yellow aphid complex populations have two peaks during the growing season, with the first early in the season (May to June) and the second later in the growing season (late August to harvest) (Polles and Mullinix 1977, Dutcher 1985). The August samples for both years should line up with the second population peak however, the populations were minimal. One possible explanation for why the populations were so small is the samples were collected after the grower had already applied pesticides to control aphid populations (Fig. 4.2).

Black pecan aphids can begin to appear in orchards as early as April, however, most populations do not appear until later in the growing season (Tedders 1978), which correlates with the only populations found in this study to be in August of 2020 and July and August of 2021. The populations that were observed in this study were minimal, and only one sample (‘Caddo’ August 2020) had enough black pecan aphids present to run statistical analysis. All samples with black pecan aphids present were collected after pesticides had been applied to the orchard, which could reduce the number of aphids present (Fig. 4.2).

While the populations of black aphids present in the samples were low, injury caused by black pecan aphids was observed in the samples. Leaflets with black pecan aphid injury present can show what the aphid populations looked like prior to pesticides application. The July 2021 samples for both cultivars had less injury present than the August samples, which can be caused by multiple factors.

Pecan leaf scorch mites were only observed in July and August of both years, which is consistent with previous studies that have shown that PLSM are usually not present until the later part of the growing season (Jackson et al. 1983). Populations were larger in the lower canopy compared to the upper canopy, which is also consistent with previous studies (Osburn et al. 1963).

Pesticide spray records for this orchard (Fig. 4.2) show this orchard was heavily managed to reduce injury by arthropod pests to nuts. This explains the lack of any arthropod pests observed in the nut samples from any collection during the two years. What this study shows is that summer hedging versus winter hedging has no difference on arthropod pest populations that attack the pecan nut when using this pest management strategy.

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Table 4.1. Weather data for Ray City, Georgia from May to October of 2020 and 2021

	May	June	July	August	September	October
2020						
High (°C)	29.08	31.74	33.7	33.27	30.14	28.52
Average (°C)	21.84	25.16	26.66	26.44	23.98	21.46
Low (°C)	15.11	19.67	20.26	21.72	19.78	15.11
Rainfall	5.59 cm	17.63 cm	14.07 cm	20.96 cm	10.41 cm	8.97 cm
2021						
	May	June	July	August	September	October
High (°C)	29.06	31.93	32.62	32.93	31.20	27.67
Average (°C)	21.53	24.91	25.76	26.14	23.66	19.79
Low (°C)	13.68	19.44	21.16	22.08	18.57	13.95
Rainfall	1.73 cm	17.32 cm	30.59 cm	13.46 cm	18.80 cm	10.69 cm

Table 4.2. Mean number of yellow aphid complex immatures and adults in the upper and lower canopies of summer and winter hedged 25-year-old ‘Creek’ and ‘Caddo’ pecan trees

Variety	Treatment	Canopy Location	Mean ± SEM No. Total Yellow Complex Aphids per two leaves					
			2020			2021		
			June	July	August	June	July	August
Creek	Summer	Upper	4.16 ± 2.26	0.30 ± 0.20	0.23 ± 0.19	2.30 ± 1.81	0.10 ± 0.10	0.17 ± 0.17
		Lower	4.03 ± 0.73	0.27 ± 0.09	0.40 ± 0.06	3.73 ± 1.03	0 ± 0	0 ± 0
	Winter	Upper	2.70 ± 1.26	0.27 ± 0.12	0.30 ± 0.12	3.04 ± 0.51	0 ± 0	0.07 ± 0.07
		Lower	2.40 ± 1.10	1.07 ±0.38	0.47 ± 0.09	5.30 ± 1.22	0 ± 0	0.07 ± 0.07
Interaction Effects (*P* Value)			0.9432	0.1677	1.0000	0.7597	NA	NA
Summer/Winter (*P* Value)			0.2163	0.1670	0.5628	0.4056	NA	NA
Upper/Lower (*P* Value)			0.8532	0.1550	0.1767	0.2024	NA	NA
Caddo	Summer	Upper	3.93 ± 1.64	0.37 ± 0.13	0.37 ± 0.22	1.20 ± 0.57	0.03 ± 0.03	0.10 ± 0.10
		Lower	5.10 ± 0.56	0.47 ± 0.32	0.27 ± 0.15	1.77 ± 0.15	0.07 ± 0.07	0.03 ± 0.03
	Winter	Upper	4.90 ± 1.93	0.20 ± 0.20	0.13 ± 0.09	1.67 ± 0.68	0.07 ± 0.03	0 ± 0
		Lower	2.93 ± 1.13	0.20 ± 0.12	0.27 ± 0.14	2.23 ± 0.58	0.03 ± 0.03	0 ± 0
Interaction Effects (*P* Value)			0.0616	0.8321	0.4010	0.6784	NA	NA
Summer/Winter (*P* Value)			0.4133	0.1450	0.4010	0.7230	NA	NA
Upper/Lower (*P* Value)			0.5793	0.7144	0.9015	0.2084	NA	NA

Columns labelled with NA did not have enough aphids to run statistical analysis

Table 4.3. Mean number of black pecan aphids in the upper and lower canopies of summer and winter hedged 25-year-old ‘Creek’ and ‘Caddo’ pecan trees.

Variety	Treatment	Canopy Location	Mean ± SEM No. Total black pecan aphids per two leaves		
			2020	2021	
			August	July	August
Creek	Summer	Upper	0 ± 0	0 ± 0	0 ± 0
		Lower	0.13 ± 0.13	0.10 ± 0.06	0 ± 0
	Winter	Upper	0.03 ± 0.03	0 ± 0	0 ± 0
		Lower	0.03 ± 0.03	0.03 ± 0.03	0.03 ± 0.03
Interaction Effects (*P* Value)			NA	NA	NA
Summer/Winter (*P* Value)			NA	NA	NA
Upper/Lower (*P* Value)			NA	NA	NA
Caddo	Summer	Upper	0 ± 0	0 ± 0	0 ± 0
		Lower	0.47 ± 0.32	0.10 ± 0.10	0 ± 0
	Winter	Upper	0.03 ± 0.03	0 ± 0	0 ± 0
		Lower	0.07 ± 0.03	0.07 ± 0.07	0 ± 0
Interaction Effects (*P* Value)			0.1571	NA	NA
Summer/Winter (*P* Value)			0.3867	NA	NA
Upper/Lower (*P* Value)			0.0611	NA	NA

Columns labelled with NA did not have enough aphids to run statistical analysis

Table 4.4. Mean number of leaflets with black pecan aphid injury in the upper and lower canopies of summer and winter hedged 25-year-old 'Creek' and 'Caddo' pecan trees.

Variety	Treatment	Canopy Location	Mean ± SEM No. Total leaflets with black aphid injury		
			2020	2021	
			August	July	August
Creek	Summer	Upper	0.23 ± 0.23	0 ± 0	0.63 ± 0.43
		Lower	2.30 ± 0.50*	0.77 ± 0.54*	4.20 ± 1.86
	Winter	Upper	0.23 ± 0.03	0 ± 0	1.53 ± 0.52
		Lower	4.10 ± 1.17*	0.80 ± 0.21*	4.23 ± 1.57
Interaction Effects (*P* Value)			0.4559	0.6775	0.1524
Summer/Winter (*P* Value)			0.0976	0.6775	0.4315
Upper/Lower (*P* Value)			0.0002	0.0126	0.0823
Caddo	Summer	Upper	1.63 ± 0.38^	0 ± 0	0.73 ± 0.38
		Lower	6.30 ± 0.75*^	1.70 ± 0.72*	4.63 ± 1.10*
	Winter	Upper	1.13 ± 0.34	0.20 ± 0.12	1.57 ± 1.37
		Lower	3.47 ± 0.82*	1.27 ± 0.41*	2.03 ± 0.82*
Interaction Effects (*P* Value)			0.0969	0.2132	0.2885
Summer/Winter (*P* Value)			0.0308	0.5900	0.2179
Upper/Lower (*P* Value)			0.0011	0.0017	0.0017

Columns with * following the means have a significant higher value between canopy locations using a student t-test
Columns with ^ following the means have a significant higher value between treatments using a student t-test

Table 4.5. Mean number of pecan leaf scorch mites in the upper and lower canopies of summer and winter hedged 25-year-old ‘Creek’ and ‘Caddo’ pecan trees.

Variety	Treatment	Canopy Location	Mean ± SEM No. total scorch mites per two leaves			
			2020		2021	
			July	August	July	August
Creek	Summer	Upper	0 ± 0	0.23 ± 0.23	0.17 ± 0.17	0.03 ± 0.03
		Lower	30.37 ± 26.51*	1.70 ± 1.23*	9.77 ± 9.37*	2.37 ± 1.89
	Winter	Upper	1.50 ± 1.31	0.33 ± 0.24	0.27 ± 0.27	0.80 ± 0.80
		Lower	23.73 ± 6.83*	7.57 ± 3.71*	6.23 ± 1.62*	0.37 ± 0.27
Interaction Effects (*P* Value)			0.5237	0.2425	0.6150	0.1994
Summer/Winter (*P* Value)			0.9626	0.1573	0.1292	0.5441
Upper/Lower (*P* Value)			0.0184	0.0366	0.0058	0.3603
Caddo	Summer	Upper	0.96 ± 0.82	0.17 ± 0.17 c	0 ± 0	0 ± 0
		Lower	140.7 ± 50.64*	3.70 ± 0.25 b	1.93 ± 1.25	0.93 ± 0.26*
	Winter	Upper	0 ± 0	0 ± 0 c	0.03 ± 0.03	0.27 ± 0.27
		Lower	87.6 ± 28.59*	11.26 ± 2.89 a	1.26 ± 0.82	0.43 ± 0.23*
Interaction Effects (*P* Value)			0.2645	0.0170	0.9409	0.0531
Summer/Winter (*P* Value)			0.5352	0.0600	0.5217	0.4923
Upper/Lower (*P* Value)			0.0002	0.0001	0.2561	0.0137

Columns with * following the means have a significant higher value between canopy locations using a student t-test

Columns with letters following the means have a significant interaction between canopy location and treatment with a having the most mites and c having the least

Table 4.6. Mean number of leaf miners in the upper and lower canopies of summer and winter hedged 25-year-old 'Creek' and 'Caddo' pecan trees.

Variety	Treatment	Canopy Location	Mean ± SEM No. Total leaf miners per two leaves					
			2020			2021		
			June	July	August	June	July	August
Creek	Summer	Upper	0.40 ± 0.21	1.73 ± 1.01	2.23 ± 0.84	0.10 ± 0.06	0.13 ± 0.09	0.60 ± 0.32
		Lower	0.10 ± 0.06	5.63 ± 1.30*	9.03 ± 1.24*	0.83 ± 0.15*	0.83 ± 0.33*	1.43 ± 0.43
	Winter	Upper	0.07 ± 0.03	1.43 ± 0.13	2.46 ± 0.42	0 ± 0	0.20 ± 0.10	0.33 ± 0.24
		Lower	0.30 ± 0.15	4.57 ± 1.03*	8.30 ± 1.24*	0.47 ± 0.24*	0.47 ± 0.18*	1.03 ± 0.27
	Interaction Effects (*P* Value)		0.0927	0.5893	0.6587	0.3403	0.2720	0.8400
	Non-hedged/Hedged (*P* Value)		0.8766	0.3488	0.8182	0.1199	0.7747	0.3324
	Upper/Lower (*P* Value)		0.8869	0.0020	0.0009	0.0035	0.0304	0.0516
Caddo	Summer	Upper	-	2.00 ± 0.17	2.80 ± 0.15 c	0.10 ± 0.10	0.23 ± 0.12	0.77 ± 0.50
		Lower	-	5.63 ± 0.98*	11.67 ± 0.94 a	0.13 ± 0.09	0.33 ± 0.15	1.40 ± 0.65
	Winter	Upper	-	1.37 ± 0.47	3.23 ± 0.20 c	0 ± 0	0.03 ± 0.03	0.30 ± 0.10
		Lower	-	3.77 ± 0.87*	7.50 ± 1.38 b	0.13 ± 0.07	0.27 ± 0.07	0.27 ± 0.18
	Interaction Effects (*P* Value)		/	0.3388	0.0185	NA	0.4319	0.4389
	Summer/Winter (*P* Value)		/	0.0798	0.0672	NA	0.3166	0.0938
	Upper/Lower (*P* Value)		/	0.0023	0.0001	NA	0.1109	0.4839

Columns with * following the means have a significant higher value between canopy locations using a student t-test
Columns with letters following the means have a significant interaction between canopy location and treatment with *a* having the most leaf miners and *c* having the least
Columns labelled with NA did not have enough aphids to run statistical analysis
Columns with – and / did not have recorded data

Figure 4.1. Map of Ray City, GA hedging site. The site is comprised of three blocks with each block consisting of two rows of summer hedged trees and two rows of winter hedged trees for each cultivar, 'Creek' and 'Caddo'.

Figure 4.2. Insecticide spray records for 2020 and 2021 for Ray City, GA field site

Date	Product	Rate	Active	IRAC	Pests
3/26/20		3 oz/ acre	Imidacloprid	4A	Nuts
5/1/20		16 oz/ acre	Imidacloprid	4A	Nuts
5/4/20	Intrepid Edge	4 oz/ acre	methoxyfenozide + spinetorom	5 + 18	Nuts
6/15/20	Dimilin 2F	8 oz/ acre	diflubenzuron	15	Nuts
	Sefina	3 oz/ acre	afidopyropen	9D	Aphids
7/16/20	Dimilin 2F	8 oz/ acre	diflubenzuron	15	Nuts
	Abamex	18 oz/ acre	abamectin	6	Mites
7/26/20	Sefina	3 oz/ acre	afidopyropen	9D	Aphids
	Dimilin 2F	8 oz/ acre	diflubenzuron	15	Nuts
8/5/20	Intrepid Edge	4 oz/ acre	methoxyfenozide + spinetorom	5 + 18	Nuts
9/7/20	Transform	1.2 oz/ acre	sulfoxaflor	4C	Aphids
Date	Product	Rate	Active	IRAC	Pests
4/10/21		3 oz/ acre	Imidacloprid	4A	Nuts
4/25/21	Durant	8 oz/ acre	diflubenzuron	15	Nuts
5/13/21	Intrepid Edge	4 oz/ acre	methoxyfenozide + spinetorom	5 + 18	Nuts
6/14/21	Durant	8 oz/ acre	diflubenzuron	15	Nuts
7/9/21		3 oz/ acre	Imidacloprid	4A	Nuts
	0.7 ABBA	4.3 oz/ acre	abamectin	6	Mites
7/25/21	Durant	8 oz/ acre	diflubenzuron	15	Nuts
7/30/21	Intrepid Edge	4 oz/ acre	methoxyfenozide + spinetorom	5 + 18	Nuts
	Transform	1.2 oz/ acre	sulfoxaflor	4C	Aphids
8/9/21	Intrepid Edge	4 oz/ acre	methoxyfenozide + spinetorom	5 + 18	Nuts
8/18/21	0.7 ABBA	4.3 oz/ acre	abamectin	6	Mites
	Sefina	3 oz/ acre	afidopyropen	9D	Aphids