RECENT ADVANCES IN PECAN PEST MANAGEMENT IN IMPROVED AND SEEDLING PECAN ORCHARDS

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ABSTRACT

The current state of pecan insect pest management in improved and seedling orchards in the southern U.S. is described by a review of the recent literature generated by research and extension programs. New research results are reported on the damage potential of late season insect pests in pecan orchards from controlled field experiments. Controlling the shuckmining injury caused by hickory shuckworm did not increase pecan yield or kernel quality during the current season on 'Desirable' pecan trees in an infestation that developed between two and four weeks after shell-hardening. The combination of injury by a low population of blackmargined aphids and a late season infestation of hickory shuckworm in 'Desirable' pecan trees caused a significant degradation in kernel color; whereas, trees treated with selective chemical control of either the aphids or the hickory shuckworm or both insects had significantly brighter kernel color. Significant linear regression models were found between abundance of adult pecan weevil emerging from the soil beneath tree crown and number of damaged nuts in the tree. The regression models indicated that trees with higher weevil density emerging beneath the canopy tended to have more damaged pecans than trees with lower weevil density in the soil beneath the canopy.

INTRODUCTION

Insects have a significant impact on production in improved and seedling pecan (Juglandaceae: Carya illinoensis (Wangh.) K. Koch) orchards in the southern U.S. and the primary strategy for control is integrated pest management (Harris 1983; Harris et al. 1998; Layton 1993; Dutcher 1997b, 1997c; Ellis 2001). Pecan producers are more successful after they acquire expertise in insect identification, and knowledge of insect bionomics and control. The southern states have effectively trained many pecan producers through interactive applied research and education programs. These growers invest in a high quality crop with preventive herbicide and fungicide applications, comprehensive insect and mite scouting and management programs, irrigation, plant nutrients applied to the foliage and the soil, and sunlight management by thinning and pruning. Seasonal and regional variations in insect and mite pest populations are high and the grower has to have a comprehensive scouting program to assess the status of pests. The fruit and foliage is susceptible to insect and mite damage for 6 to 7 months and insecticide sprays typically control insects for 1-2 weeks so that spray timing is critical to effective control. Costs of control have to be curtailed in many seasons due to the high year-to-year variability in pecan production. Fortunately, growers can rely on a large complex of beneficial insects, spiders, mites and insect diseases to keep pest problems in check. Also, good scouting techniques are in place to determine when a pest outbreak is likely to occur. When an outbreak occurs and a spray
is required to save the fruit or foliage the chemical is selected on the basis of its efficacy against the pest and its effects on beneficial biological control agents as determined by research at the experiment station. We briefly review the current and emerging IPM techniques developed by research and extension programs for improved and seedling pecan orchards. Then, we present new research results on the damage impact of hickory shuckworm, pecan aphids, and pecan weevil on pecan production and quality.

Current Pest Management Techniques. Current insect monitoring and control techniques for pecan orchards with improved and seedling trees are a combination of monitoring, chemical control, classical and conservation biological control, and reliance on natural controls (Ellis and Bertrand 2001; Dutcher 1997b, 1997c, 1998; Harris and Jackman 1996; McVay and Hall 1998; Tedders 1983; M. W. Smith et al. 1996a). Monitoring the fruit and foliage can often identify a potentially damaging insect population in time to apply a chemical or biological control. After budbreak, the orchards ideally are monitored each week for foliage pests. Sampling units for monitoring the tree crown are the compound leaf, the terminal (foliage and stem of the current years stem growth), and whole crown inspection. The sample unit is the compound leaf for measuring the seasonal occurrence of aphids [Homoptera: Aphididae: Monelliiopis pecanis Bissell (yellow pecan aphid), Monellia caryella (Fitch) (blackmargined aphid), Melanocallis caryaeafoliae (Davis) (black pecan aphid)], leafminers [Lepidoptera: Gracillariidae: Phyllonorycter caryaealbella (Chambers), P. trinitata (Chambers), Cameraria caryaeolliella (Clemens); Nepticulidae: Stigmella juglandifoliella (Clemens); and Heliozelid: Coptodisca lucifluella Clemens], pecan leaf casebearer [Lepidoptera: Pyralidae: Acrobasis juglandis (LaBaron)], and pecan leaf scorch mite [Acar: Tetanychidae: Eotetranychus horticitei McGregor]. Growers typically examine five compound leaves from every fourth tree in every fourth row and selecting rows of each pecan variety grown on the farm (Ellis 2001). Seasonal occurrence of insects varies considerably among seedling (grown from seed and not grafted to a known cultivar) trees. Each seedling tree has to be considered as a separate ‘variety’ and trees are sample individually. Leaf samples taken from the periphery of the tree crown at mid-tree height near the nut bearing terminals of the tree offer the best indication of insect activity that will affect pecan production. Predators, parasites and pathogens are monitored by examining entire leaf terminals (foliage on the current years stem growth, usually three to seven compound leaves). The scout has a higher probability of finding predators with this sample unit as the insects are as likely to inhabit the stem and leaf rachis as the leaf blade. Parasitoids and pathogens typically attack a portion of the pest population and are usually less abundant than pests. A larger portion of the plant than the compound leaf is required as a sample unit to detect populations of these biological control agents. The terminal also offers a larger sample unit than the compound leaf for detecting low (less than one aphid/compound leaf) populations of black pecan aphids (Dutcher 1997b). Tree size of bearing pecan trees (12 years old or older) typically ranges 8–20 m, and samples are collected with a pruning pole or from an elevated platform on a modified pickup truck or a hydraulic lift. Infestations of various phyloxxerans [Homoptera: Phylloxeridae: Pflloxxera spp. including P. devastatrix Pergande (pecan phylloxera) and P. notabilis Pergande (pecan leaf phylloxera)], spittlebugs [Homoptera: Cercopidae: Clastoptera achetina (Germar)], and gregarious caterpillars [Lepidoptera: Notodontidae: Datana ministra Grote & Robinson (walnut caterpillar) and Arctiidae: Hyphantria cunea Drury (fall webworm)] can be readily identified by a whole tree inspection from the ground. Control of phyloxxerans requires an insecticide spray at bud break before the galls appear and the whole tree inspection only serves to identify infestations that can be controlled the following season. Whole tree crown inspection effectively identifies trees during the current season that need to be treated for spittlebugs and gregarious caterpillars. Nut pests are monitored with more sophisticated sampling techniques. Pecan nut casebearer [Lepidoptera: Pyralidae: Acrobasis nuxvorella Neunzig] adult flight is monitored with pheromone traps. Oviposition and larval feeding
injury are monitored by examining fruiting terminals on the tree (Knutson and Ree 1999). From fruit set to shell-hardening, nut drop is monitored with gravity traps that collect nuts as they fall out of the tree and tagged nut clusters (Dutcher 2002; Harris et al. 1986). The gravity traps keep the nuts that have dropped out of the tree from being removed by nut-feeding rodents and birds and nuts damaged by hickory shuckworm [Lepidoptera:Tortricidae: *Cydia caryana* (Fitch)], pecan nut casebearer, hickory nut curculio [Coleoptera:Curculionidae: *Conotrachelus hactoriae* (Schoof)], pecan weevil [Coleoptera:Curculionidae: *Curculio caryae* (Horn)], spittlebugs, and hemipterans [Hemiptera: Pentatomidae: *Nezara viridula* (L.), *Euschistus servus* (Say), *E. tristigmus* (Say) and Coreidae: *Leptoglossus oppositus* (Say), *L. phyllopus* (L.)] can readily be identified. Weekly observation of tagged nut clusters identifies the time that the nut drop occurs. Emergence of hickory nut curculio and pecan weevil adults is monitored with pyramid traps (Tedders and Wood 1994) beginning in early summer and continuing through October. The growth and development of the pecans is also monitored in each variety each week by collecting and dissecting a few selected pecans from trees. The important phenological stages of nut development are fruit set, nut expansion, half-shell-hardening, full-shell-hardening and shuck split. The pecan kernel develops through water, gel and dough stages after nut expansion and before shuck-split. Pecan nut losses to pecan nut casebearer damage are most significant between fruit set and early fruit expansion as the larva may need to feed on more than one nut to complete its development when the nutlets are small. Before shell-hardening damage by nut curculio, hickory shuckworm, hemipterans, and pecan weevil cause the nut to drop. After shell-hardening, nut curculio does not cause damage, hickory shuckworm mines the shuck, and pecan weevil and hemipterans cause damage to the kernel. The pecan kernel is more susceptible to pecan weevil kernel damage after gel-stage.

New techniques for monitoring and control have been improved through regional research. Most recently effective control and monitoring systems for pecan nut casebearer, stink bugs and black pecan aphids have been developed, field tested, and implemented in commercial orchards. A highly effective monitoring and control system was developed for pecan nut casebearer by combining a pheromone monitoring system, a sequential sampling plan, a prediction model, and insecticides (Harris 1995; Harris et al. 1994, 1995a, 1995b, 1997; Millar et al. 1996). Important factors in pheromone trap catch were dose, lure age, and trap design (Knutson et al. 1998). Research has found ways of replacing broad spectrum insecticides with tebufenozide (Confirm 2E, Dow AgroSciences, Indianapolis, IN), a biorational pesticide for pecan nut casebearer control. Pecan nut casebearer monitoring has been adjusted to predict first nut entry for different areas of pecan production (Davis 1993; Layton 1993; Mulder 1997; Ree 1995). Biological research continues to improve our understanding of oviposition and nut entry behavior of pecan nut casebearer (Aguirre et al. 1995) and the interaction of pecan nut casebearer, pecan weevil and masting of pecan (Chung et al. 1995; Harris et al. 1996).

Hickory shuckworm pheromone trap catch with the current lures is low (Collins et al. 1995) during the mid-summer even though adults are present and causing significant nut drop (Yonce and McVay 1994) (Fig. 1). Research continues to identify and evaluate additional pheromone components (M. T. Smith et al. 1994; M. T. Smith 1995a), trap design and placement (McVay et al. 1995), emergence patterns and population trends (McVay et al. 1994; Yonce and McVay 1994). In controlled field experiments, male moth response to the new components was mixed (M. T. Smith 1995a). Analysis of trap catch data indicates that the populations have a clumped distribution that becomes more uniform as the population size increases. These results indicate a need for more traps per orchard to measure moth flight accurately. The current recommendation is one trap/ten acres (M. T. Smith 1995a). Biological studies have measured the response of hickory shuckworm larvae and larval parasitoids to cold temperatures (Nava-Camberos et al. 1996; Yonce et al. 1996).
70 nuts infested

% Infestation

% nuts infested

FIC. 1. Seasonal occurrence of Hickory shuckworm moths, nut drop and shuckmulching damage in 1997 in a Georgia pecan orchard at the Ponder Farm, Till Co., Georgia.

nuts collected per trap

nuts collected per trap
Stink bug monitoring was improved with a new trapping technique, where a pyramidal pecan weevil trap was painted yellow and a large malaise trap was affixed to the top (Mizell and Tedders 1995; Mizell et al. 1997). A pheromone, attractive to brown and dusky stink bugs, was discovered and used in pecan orchards to monitor the seasonal activity (Yonce and Mizell 1997). The stink bugs remain in the pecan orchard year around and are low in orchards that maintain a mowed sod with herbicided tree rows. Stink bugs cause damage in pecan in the fall and anytime when droughty conditions surround the orchard area. At these times when alternate host plants in adjacent border crops are harvested or senesce, these areas become less desirable for stink bugs and the stink bugs migrate into the pecan orchard. The influx of stink bugs from harvested peanut fields into pecan can last 30 days (Mizell et al. 1997). Irrigated pecan orchards are highly attractive to stink bugs and feeding before shell hardening can cause the nut to abort within 7 days (Wood and Tedders 1996).

Pecan weevil trapping has been improved with pyramidal cone traps (Tedders and Wood 1994; Tedders et al. 1996) and circle traps (Mulder et al. 1997), and a pheromone trapping system is in development (Hedin et al. 1996, 1997; Collins et al. 1996). The activity of pecan weevil adults after emergence from the soil is better understood from recent research (Cottrell 2001). This research indicates that pecan weevil emergence rate increases at dusk each day to nearly double the rate during the day, night or dawn. When weevils emerge, 60% crawl on the ground to the tree trunk and 40% fly to the trunk before ascending into the tree crown. After ascending into the large (>15-m in height) trees in this study, weevils oviposited in a higher percentage of the pecans in the lower third of the canopy than in the middle or upper thirds. Weevils were also easily intercepted with traps set between trees at 5, 8 and 12 m indicating frequent flight of weevils between trees.

A sampling technique for black pecan aphid was developed to detect low population levels and give the growers an early warning for each infestation. The sample unit was changed from the compound leaf to the terminals and complete enumeration of the aphids is replaced, rating the terminals as having 0, 1 or 2+ aphids and whether nymphs are present. The older sampling technique underestimated small populations and overestimated large populations. By noting the presence of adults and/or nymphs a lag period can be identified between the appearance of the first adults aphids and exponential population growth (Dutcher 1997a).

Research has developed pecan pest management programs for control of pecan weevil, hickory shuckworm, pecan nut casebearer and the aphid complex based on integration of chemical and biological controls. Alternatives to broad spectrum insecticides for pecan pest control were developed. Tebufenozide (Confirm 2F, DowAgrosciences, Indianapolis, IN), for example, effectively controls pecan nut casebearer gregarious caterpillars and hickory shuckworm without destroying predacious insects of aphids and mites (Dutcher 1996). The specific aphicide, imidacloprid (Provado® 1.6E or Admire® 2E, Bayer Chemical Co., Kansas City, MO), effectively controls pecan aphids that tend to increase rapidly after carbaryl is applied for weevil control during the late season (Dutcher 1994b, 1995a, 1996, 1997a, 1997b). Pecan weevil control is still reliant on sprays of carbaryl to the foliage as an adulticide (Tedders and Wood 1995). New biological controls such as a rickettsiella-like organism (Adams et al. 1997) may be a potential biological control agent against pecan weevil.

Reductions in pecan aphid abundance were often associated with techniques such as intercropping with summer crop of sesbania, controlling secondary predation by red imported fire ant and spraying predator attractants that conserved aphidophaga (Bugg and Dutcher 1993; Kaakeh and Dutcher 1992, 1993c; Dutcher 1993, 1994a, 1995b, 1998). Reductions in the frequency of fungicide sprays were shown to conserve entomophagous fungi that regulate pecan aphid populations (Pickering et al. 1990). Pecan arthropods were influenced by cool season intercrops (M.W. Smith et al. 1994, 1996a), and methods were
developed for screening potential intercrop plants (M.W. Smith et al. 1996b). Native pecan production was found to be profitable with limited insect control (Reid 1993). Organosilicone surfactants were found to control pecan aphids for a short time (Wood et al. 1997). Blackmargined aphids and associated honeydew attracts aphid predators to the pecan foliage and may ameliorate biological control of aphids (Harris and Li 1996). Red imported fire ant commonly occurs in pecan orchards and is an important predator of pecan weevil (Dutcher and Sheppard 1981) as well as certain aphidophagous insects (Tedders et al. 1990; Dutcher et al. 1999). The environmental factors effecting pecan aphid population dynamics were determined (Kaakeh and Dutcher 1993a, 1993b), and the aphids were found to have a wide range of tolerance to high temperature and are temporarily reduced by rainfall. An excellent resource that integrates and updates information on new biologically oriented management methods for pecan production is the National Center for Appropriate Technology (Diver and Ames 2000).

Significant advances have been accomplished in host plant resistance of pecan insects on pecan cultivars. Resistance of “Pawnee” and “Navajo” cultivars to blackmargined aphid has been demonstrated in greenhouse and field evaluations (Thompson and Grauke 1998). These cultivars are not immune to aphid infestation, but resistance would enhance current recommended control techniques. These results are consistent with lab and field research in Georgia (Kaakeh and Dutcher 1994) where blackmargined, black pecan and yellow pecan aphids were found to have lower reproductive rates and altered probing behavior and lower infestation levels on “Pawnee” and “Cape Fear” cultivars. Black walnut, butternut, pecan and several hickory species were investigated as potential sources of resistance factors to aphids (M. T. Smith et al. 1993, M. T. Smith 1995b). Blackmargined aphid adults lived longer and had higher reproductive rates on pecan, water, scrub, shellbark hickory, and hican than on black walnut, butternut, and several other hickory spp. Percentage survival of blackmargined aphid nymphs to the adult stage was lower on most hickory and walnut species than on pecan, hican or water hickory. Yellow pecan aphid adults lived longer and had higher nymph survival on pecan than on hickory or walnut. Black pecan aphid had similar adult longevity over all tree species but reproduced and developed from nymph to adult only on pecan. Pecan cultivars have variable susceptibility to black pecan aphid feeding damage as measured by the amount of chlorosis. Certain cultivars have a water-soluble antibiotic factor on the leaf surface that suppresses black pecan aphid populations (Wood and Reilly 1998). Two new cultivars - “Kanza” and “Creek” - have some resistance to hickory shuckworm and “Kanza” is highly resistant to phylloxera species (Thompson et al. 1996a, 1996b). A leaf disc bioassay was developed to evaluate pecan cultivars for host plant resistance to black pecan aphid (Estes 1995). Pecan cultivars differed significantly in susceptibility to hemipteran kernel damage in a recent evaluation over four seasons (Dutcher et al. 2001). The majority of the cultivars in the experiment that had consistently low levels of kernel spot also had highly desirable horticultural characteristics, and these cultivars were recommended for planting. Most cultivars with consistently high levels of kernel spot were also not recommended for planting (Worley and Mullinix 1997; Thompson et al. 1996a, 1996b).

Research in the area of trap cropping in pecan is a major initiative. Trap cropping effectively controlled the complex of kernel feeding hemipterans on pecan with consistent 50% reductions in kernel damage with trap crops (M. T. Smith 1996, 1999). Differences in the seasonal occurrence of brown (E. servus) and dusky (E. tristigmus) stink bugs may be important to the effectiveness of trap crops. Brown stink bugs are trapped more readily on the ground than dusky stink bugs that are more abundant in the tree canopy (Cottrell et al. 2000).

Pecan aphids were found to develop insecticide resistance in the field within two seasons of the introduction of use of pyrethroids or organophosphates. Combinations of insecticides were also losing efficacy over time (Dutcher 1997d). Black pecan aphids have
developed for screening potential intercrop plants (M.W. Smith et al. 1996b). Native pecan production was found to be profitable with limited insect control (Reid 1993). Organosilicone surfactants were found to control pecan aphids for a short time (Wood et al. 1997). Blackmargined aphids and associated honeydew attracts aphid predators to the pecan foliage and may ameliorate biological control of aphids (Harris and Li 1996). Red imported fire ant commonly occurs in pecan orchards and is an important predator of pecan weevil (Dutcher and Sheppard 1981) as well as certain aphidophagous insects (T Tedders et al. 1990; Dutcher et al. 1999). The environmental factors effecting pecan aphid population dynamics were determined (Kaakeh and Dutcher 1993a, 1993b), and the aphids were found to have a wide range of tolerance to high temperature and are temporarily reduced by rainfall. An excellent resource that integrates and updates information on new biologically oriented management methods for pecan production is the National Center for Appropriate Technology (Diver and Ames 2000).

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METHODS AND MATERIALS

Pecan nut quality and quantity were compared in insecticide-treated and untreated pecan trees in two field experiments. The first experiment measured the impact of hickory shuckworm infestations on kernel quality and nut yield. The second experiment measured the combined effects of hickory shuckworm and blackmargined aphid infestations on kernel quality and nut yield. A third experiment measured the amount of pecan weevil kernel damage in untreated pecan trees and correlated weevil damage to the number of pecan weevils emerging beneath each tree to the number of pecans damaged in each tree during the season.

The first experiment was set out in 1997 to measure the impact of the time of hickory shuckworm mining on kernel quality. The experiment was set out in a 4.8-ha block of pecans planted to the cultivar 'Desirable' in 1986-87. Five untreated pecan trees in the orchard were monitored each week from 6 June to 8 October for nut drop caused by hickory shuckworm oviposition by collecting dropped pecans from gravity traps and examining them for oviposition sites. Each gravity trap was a square (1.3X1.3m) net held off the ground on a plastic frame hung on each of the five untreated trees. The trap frame was made from plastic (PVC) irrigation pipe (1.3-cm diameter) and the net was made from army surplus, nylon mosquito netting. The trap was positioned below the canopy halfway between the trunk and the dripline. The trap was held in place by a plastic bag filled with sand placed in the center of the net. From 7 August to 8 October, 100 fresh nuts were picked each week from untreated trees and dissected to determine the percentage with shuckmining damage. Hickory shuckworm moth flight was monitored from 6 June to 8 October with pheromone (Pherocon® cap code: HSW, Trece Inc., Salinas, CA) baited traps (Pherocon® IC, Trece Inc., Salinas, CA). Trap catch was recorded every week and lures (one cap per trap) were changed every 2 weeks. The treatments were three timing schedules of late season applications of cypermethrin (Ammo® 3E, FMC Corp., Philadelphia, PA) at a concentration of 0.06 g active ingredient/liter of spray solution. The first treatment was a single application at shell-hardening on 21 August. The second treatment was a single application at two weeks after shell-hardening on 10 September. The third treatment was two applications at two and four weeks after shell-hardening on 10 September and 24 September. All insecticide treatments were applied with a 1,200-liter capacity, PTO-driven, airblast, orchard sprayer (Durand-Waylon, LaGrange, GA) at a ground speed of 3.2 km/hr, a pump pressure of 5.55 kg/cm², and a spray volume of 25-30-liter per tree depending on the tree size. These treatments were compared to a fourth treatment, an untreated control treatment for hickory shuckworm infestation level, nut yield and quality. Treatments were applied in a randomized complete block design with three replications per treatment (df=treatment, block, tree, error = 3,2,1,17). Each treatment was applied to 12 trees in three, four-tree linear plots, and the center two trees were observed for treatment effects. Hickory shuckworm infestation level was measured on 8 October by sampling 50 pecans from each observation tree and dissecting the shucks. Shucks with either one or more larvae and/or feeding sites were counted as infested, and the result was used to calculate the proportion of the nut sample infested. Yield of each observation tree was measured directly on 7 November by mechanically shaking each tree and collecting nuts from the ground. Percentage of the nut weight in the kernel and nut weight were measured from a 50-nut sample collected from each observation tree after drying the sample in an oven at 55° C for 48 hrs. The kernels were then graded as fancy, standard and amber based on color (Worley and Mullinix 1997). The kernels in each group were weighed and compared to the total sample weight to determine the percentage of the sample weight in each group. Data were analyzed for differences between treatments with analysis of variance and least significant difference test (Snedecor and Cochran 1967). Correlation coefficients were calculated.
(Snedecor and Cochran 1967) in tree by tree comparisons over all treatments between percentage hickory shuckworm infestation and nut yield and quality variables. Summary statistics (mean, standard deviation, 95% confidence interval) were also calculated (Snedecor and Cochran 1967) for each variable.

The second experiment, in 1998, measured the interaction between aphid feeding damage and hickory shuckworm shuck mining by controlling neither, each, and both aphids and shuckworms with selective insecticides. Imidacloprid (Provado® 1.6E, Bayer Chemical CO., Kansas City, MO) was applied at a concentration of 20 g active ingredient/liter on 30 August for aphid control, and spinosad (Success® 480 SC, Dow AgroSciences, Indianapolis, IN) was applied at a concentration of 0.033 g active ingredient/liter on 30 August and 13 September for hickory shuckworm control. Treatments were arranged in a complete random block design (df_{treatment,block, error} = 3,4,12) with five single tree replications in five blocks with one of the following treatments: 1=no insecticide; 2=spinosad; 3=imidacloprid; and 4=spinosad plus imidacloprid. All insecticide treatments were applied with a 1,200-liter capacity, PTO-driven, airblast, orchard sprayer (Durand-Waylon, LaGrange, GA) at a ground speed of 3.2 km/hr, a pump pressure of 5.55 kg/cm², and a spray volume of 25-30 liter per tree depending on the tree size. Aphids were monitored on the foliage of five terminals (current years stem growth) per tree each week from 30 August to 6 October. Hickory shuckworm infestation level was measured on 6 October. Yield and kernel quality was measured on each tree on 5 November. Data were collected and analysed by the same methods as in the first experiment.

The third experiment, in 1986, measured the correlation between trap catch and pecan weevil damage in pecan trees that were not treated with insecticides. Pecan weevil adult emergence was monitored in 33 large 'Stuart' pecan trees in a 1.5-ha plot in Peach County, GA, at the U.S.D.A. Southeastern Fruit and Tree Nut Laboratory. The trees were treated with fungicides, herbicides and fertilizer following the recommendations of the Georgia Cooperative Extension Service (Ellis and Bertrand 1986). The trees were not treated for control of pecan weevil for ten seasons prior to the experiment. Adult emergence was monitored from 15 July to 15 October by placing 12 cone emergence traps over the weevil infested soil within the drip line of each tree. Traps were 0.96 m in diameter at the base and 0.96 m in height. Each trap had a closed collection top that only collected weevils that emerged directly under the cone trap. Weevils were collected from the traps two or three times per week and adults were sorted by sex and counted. The trees were harvested during November and December and the total yield, nut and kernel weights, and percentage weevil damage were measured in each tree. Data were analyzed by correlation and regression analysis and analysis of variance to determine if there were any significant relationships between the emergence of weevils and the yield, quality and damage estimates (Snedecor and Cochran 1967). Twelve closed cone pecan weevil emergence traps were placed under the drip line of each tree, during summer and fall of 1986. Four traps were 1.3 m, four traps were 2.6 m and four traps were 3.9 m from the trunk base. The traps were monitored from 1 July to 1 November on three days per week by collecting and sorting by sex the emerging pecan weevils. The traps only collected weevils that emerged directly below the trap (2.89 m²), and each trap covered 0.0000964 ha. At harvest, the yield of each tree was measured by shaking the pecans from the tree and onto the ground with a mechanical shaker, sweeping the pecans up, putting the pecans through a mechanical cleaner that removed all the trash leaving only the whole pecans, and weighing the pecans. Nut weight and percentage weevil damage was estimated from a 100-pecan sample that was collected from each tree (before the pecans were cleaned in the mechanical cleaner), hand cleaned, weighed and examined for damage. The number of pecans per tree was estimated by measuring number of nuts per kg and multiplying by the yield. The number of damaged pecans was estimated by multiplying the number of pecans per tree by the proportion damaged. Yield and nut weight were measured on freshly harvested pecans. Summary
statistics (mean, standard deviation, 95% confidence interval) were calculated (Snedecor and Cochran 1967) for each variable. Correlation and regression analysis (Snedecor and Cochran 1967) were used to determine the significance of relations between the trap catch and the production and damage variables.

RESULTS

In the first experiment, weekly nut drop and shuck-mining monitoring indicated that hickory shuckworm damaged pecans dropped from the tree between 13 June and 30 July and shuck-mining began on 14 August and continued to increase until 8 October (Fig. 1). The pheromone traps did not collect any moths during the time when shuckworms were causing nut drop. The treatments of the first experiment resulted in a range of hickory shuckworm infestation levels that indicated that spraying significantly (P<0.05, ANOVA, LSD=3.8%) reduced the percentage infestation (Table 1). The control treatment had the highest infestation at 23%, the trees receiving one spray at shell-hardening had a significantly lower infestation at 6.4%. The trees receiving either one spray at two weeks after shell-hardening or two sprays at two and four weeks after shell-hardening had significantly lower infestations at 1.3 and 0.8%, respectively. The reduction in the shuck-mining did not result in a significant (P<0.05, ANOVA) change in the following variables (mean ± 95% CI): yield (13.6 ± 7.7 kg/tree), percentage of the nut weight in the kernel (49 ± 3.2%), and whole nut weight (9.1 ± 1.8 g/nut). The percentage of the kernel weight in the fancy grade was significantly higher in the trees treated with two sprays than in the control or the trees treated with one spray. Yield, percentage kernel, percentage fancy grade and nut weight were not significantly correlated to hickory shuckworm infestation in tree-by-tree comparisons overall treatments.

TABLE 1. Effects of the Spray Timing of the Application of Cypermethrin to Pecan Trees on Percent Infestation by Hickory Shuckworm, and the Effects on Kernel Quality.

<table>
<thead>
<tr>
<th>Treatment a</th>
<th>% infestation</th>
<th>% fancy</th>
<th>% kernel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>23 a</td>
<td>11 b</td>
<td>51 a</td>
</tr>
<tr>
<td>Spray 1</td>
<td>6.4 b</td>
<td>12 b</td>
<td>54 a</td>
</tr>
<tr>
<td>Spray 2</td>
<td>1.3 c</td>
<td>12 b</td>
<td>49 a</td>
</tr>
<tr>
<td>Sprays 2 and 3</td>
<td>0.8 c</td>
<td>15 a</td>
<td>52 a</td>
</tr>
</tbody>
</table>

Spray dates correspond to shell-hardening on 21 August (Spray 1), and two and four weeks after shell-hardening (Spray 2 and 3, respectively). Means in the same column and followed by the same letter are not significantly different (P<0.05, ANOVA, LSD Test).

In the second experiment, hickory shuckworm shuckmining damage was significantly (P<0.01, F-test, LSD Test) reduced by the spinosad and spinosad plus imidacloprid treatments and not by the control and imidacloprid treatments. Blackmargined aphids were the only aphids that were found in the samples and populations were lower than is usually found in a commercial orchard. These aphids reached a mean peak population density of 15-17 aphids/compound leaf in the last week of September in trees that were not treated with imidacloprid, and this was significantly higher (P<0.01, ANOVA, LSD = 3.6 aphids/compound leaf) than blackmargined aphid populations (0.0 aphids/compound leaf) in the trees treated with imidacloprid on the same sampling date. Blackmargined aphid
populations were not affected by the spinosad treatments. There were no significant differences (P<0.05, ANOVA) between treatments in the percentage kernel or yield. The percentage of the kernel weight in the fancy grade was significantly lower (P<0.01, ANOVA, LSD = 6.8 %) in the untreated control than in the spinosad, imidacloprid, and spinosad plus imidacloprid (Table 2.).

**TABLE 2. Interaction of Pest-Specific Insecticides on Hickory Shuckworm and Blackmargined Aphid Control, Kernel Quality and Yield.**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>% infestation</th>
<th>peak # aphids/ft</th>
<th>% fancy</th>
<th>% kernel</th>
<th>yield (kg/tree)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Success + Admire</td>
<td>2 b</td>
<td>0 b</td>
<td>13 a</td>
<td>53 a</td>
<td>18 a</td>
</tr>
<tr>
<td>Admire Alone</td>
<td>14 a</td>
<td>0 b</td>
<td>19 a</td>
<td>51 a</td>
<td>21 a</td>
</tr>
<tr>
<td>Success Alone</td>
<td>2 b</td>
<td>17 a</td>
<td>15 a</td>
<td>52 a</td>
<td>17 a</td>
</tr>
<tr>
<td>Control</td>
<td>16 a</td>
<td>15 a</td>
<td>1 b</td>
<td>52 a</td>
<td>20 a</td>
</tr>
</tbody>
</table>

*The active ingredient in Success® (DowAgroSciences) is spinosad. The active ingredient in Admire® (Bayer Chemical Co.) is imidacloprid.

*Means in the same column and followed by the same letter are not significantly different (P<0.01, F-test, Least Significant Difference Test). Means in the same column and followed by the letter are not significantly different (P<0.05, F-test.).

In the third experiment, pecan weevil percentage kernel damage ranged from 21.8 to 80.5% with a mean (±95% CI) of 40.2±5.0%. The cumulative number of weevils emerging in the traps under each tree over the entire season ranged from 6 to 155 weevils/season-tree with a mean (±95% CI) of 68.4±13.9 weevils/season-tree. The weevil density was 23,674 females/ha, 35,432 males/ha and 59,106 weevils/ha. The cumulative number of female weevils emerging in the traps under each tree over the entire season ranged from 3 to 68 weevils/season-tree with a mean (±95% CI) of 27.4±5.8 weevils/season-tree. The cumulative number of male weevils emerging in the traps under each tree over the entire season ranged from 4 to 97 weevils/season-tree with a mean (±95% CI) of 41.0±8.9 weevils/season-tree. The number of damaged pecans/tree ranged from 149 to 7,125 nuts/tree with a mean (±95% CI) of 2,721±647 nuts/tree. Tree by tree analysis found significant correlations (r_critical, df=31, p<0.05 = 0.344, and r_critical, df=31, p<0.01 = 0.442) between the number of weevils caught per season and the number of nuts damaged (r = 0.4607); the number of females caught per season per tree and the number of nuts damaged (r = 0.4123); and, the number of males caught per season per tree and the number of nuts damaged (r = 0.4517). Proportion of the nuts with weevil damage was not related to yield (r = -0.3046). These correlations indicate that the total number of damaged nuts in any given tree is related to the number of weevils emerging beneath the tree and the proportion of the crop with weevil damage is not related to the yield or the number of weevils emerging beneath the tree. The proportion of the nuts damaged in each tree had the lowest (36.3%) coefficient of variation. Yield (71.3%), number of weevils caught per tree (59.4%) number of females caught per tree (61.6%), number of males caught per tree (63.4%), and number of damaged nuts per tree (69.7%) had higher coefficients of variation. Significant linear regression models were found between trap catch and number of damaged nuts (Table 3).
TABLE 3. Linear Regression Models of Pecan Weevil Trap Catch (Dependent Variable) and Number of Damaged Nuts (Independent Variable) in a Block of 33 'Stuart' Pecan Trees Not Treated for Pecan Weevil in Ten Previous Seasons. Byron, Georgia, 1986.

<table>
<thead>
<tr>
<th>dependent variable</th>
<th>( b_0 )</th>
<th>( b_1 )</th>
<th>( R^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td># weevils/season</td>
<td>1249.2</td>
<td>21.53</td>
<td>0.2122</td>
</tr>
<tr>
<td># females/season</td>
<td>1451.8</td>
<td>46.35</td>
<td>0.1700</td>
</tr>
<tr>
<td># males/season</td>
<td>1370.8</td>
<td>32.94</td>
<td>0.2040</td>
</tr>
</tbody>
</table>

\( ^a \) Significant at the p<0.05 level, t-test or \( b_0 \) and \( b_1 \), F-test for \( R^2 \).
\( ^b \) Significant at the p<0.01 level, t-test or \( b_0 \) and \( b_1 \), F-test for \( R^2 \).

The regression models indicated that trees with higher weevil density emerging beneath the canopy tended to have more damaged pecans than trees with lower weevil density in the soil beneath the canopy. The regression equation relating number of females caught per tree to number of damaged nuts per tree was not highly significant; whereas, the regression equations relating number of total weevils and males caught per tree to number of damaged nuts per tree were both highly significant. Since relative variation is equal for all variables, one remotely possible reason for the higher probability that males are a predictor of damage is that males may play a role in the location and nuts and attraction of females to the nuts.

**DISCUSSION**

Effective decision tools for applying insect controls rely on understanding the relationship between pest abundance and damage impact. The size of pecan trees and the variable nature of insect pest abundance between seasons and orchards make it difficult to isolate the damage of a particular insect pest and measure its impact on yield or quality. Another confounding factor is the high variability between years in pecan nut yield. Most pecan insect pests are indigenous to hickory and pecan and the qualitative consequences of a lack of insect control are the damage caused by feeding and the reinestation of the orchard. These factors contribute to the low number of research papers that quantify the damage impact of pecan pests. Foliage feeding insects have an accumulative and additive detrimental effect on pecan nut quality and production. Aphids extract a large amount of energy from the pecan tree (Wood and Tedders 1983), and poor or even moderately good aphid control has been shown to result in a significant and progressively worsening reduction in the trees' ability to produce pistillate flowers and a crop in subsequent seasons (Dutcher et al. 1984, Dutcher 1985). Interactions between leaf nitrogen concentration, leaf water status or crop load and feeding damage by black pecan aphids and mites produce side effects. Improving leaf N and leaf water status and a lower crop load reduced black pecan aphid damage; whereas, improving leaf N and leaf water status made pecan leaf scorch mite damage more severe (Wood and Reilly 2000). Nut feeding insects cause a direct reduction in pecan production and quality. Gall formation by *P. devastatrix* in the spring on the pecan stems and nut clusters reduces nut cluster size and nut weight of affected terminals at harvest (Neel and Hedin 1985). Pecan nut casebearer losses in the spring are carried through to harvest in the fall (Dutcher 2002). Nut drop caused by insects is far less than nut drop caused by natural abortion of nuts by the tree (Dutcher 2002, Harris et al. 1986). At harvest in a commercial orchard, typically 20% of the nuts have shriveled kernels and are blown over the mechanical harvester or are rejected on the conveyer belt due to cracked shells or pecan weevil emergence holes (Eikenbary et al. 1983). Pecan weevil damage can be
significant even when chemical controls are applied (Hall et al. 1981, Hall and Eikenbary 1983). Our results indicate that control of hickory shuckworm infestations can increase kernel color slightly if they are controlled late in the season during the current season. When infestations of hickory shuckworm and blackmargined aphid are low, the combined effect of both insects was associated with a highly significant reduction in kernel color. The reductions in kernel color by either aphids alone or hickory shuckworm alone was not significant. Our results also show that pecan weevil kernel damage is related to trap catch of adults emerging from the soil beneath the tree. Pecan weevil can cause a direct loss of up to 80% of the kernels. Lack of control of pecan weevil, hickory shuckworm and blackmargined aphid also contributes to the reinfestation of the orchards during the following season since all three pests complete their life cycles in the pecan orchard.

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