DEVELOPING LOW-INPUT MANAGEMENT STRATEGIES FOR NATIVE PECANS

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PREFACE

The production of pecans from native (seedling) trees represents approximately one third of the nation's pecan crop. Yet the native pecan production system is rarely the focus of scientific investigation. The study of native pecan trees in their native habitat can offer all producers greater insight into the response of pecan trees to both biotic and environmental stress. With this knowledge, production systems can be designed for each pecan bio-region that optimizes seed production while minimizing production costs.

This study is an attempt to define and develop a low-input management system for native pecan producers in Northeast Oklahoma, Southeast Kansas, and Southwest Missouri. Reduction in pesticide use in these groves requires an increased level of awareness of both crop load and insect populations. The studies presented in this work are an attempt to broaden the knowledge base needed to create a total management system that relies on minimum inputs.

The first chapter of this manuscript describes a low-input management system for native pecans and why the low-input approach is vital to the continued profitability of native pecans. Chapters II and III discuss the practical aspects of deploying hickory shuckworm pheromone traps in a native pecan orchard for the monitoring of moth activity. In the final chapter, the influence of time of nut removal on return bloom is explored. Each chapter of this manuscript has been prepared in publication format. The first chapter was prepared in the format of a review article while chapters II, III, and IV were written for publication in scientific journals.

Although this work represents the conclusion of my formal training at Oklahoma State University, the future holds exciting opportunities for many cooperative research projects on native pecans. I extend special thanks to my major advisor, Dr. Raymond D. Eikenbary, who encouraged me to return to the halls of academia and inspired me to pursue study in low-input management systems. I look forward to working with Dr. Eikenbary in the future and hope we can continue our frequent philosophical discussions.

I would like to express my gratitude to the other members of my advisory committee; Dr. John R. Sauer, Dr. Michael W. Smith, Dr. Robert D. Morrison, and Dr. David L. Weeks. Each of these men have given freely of their time and talents to critically review my work and to offer words of encouragement.

I would like to thank Dr. Walter A. Woods, former Dean of Agriculture, and Dr. Paul H. Jennings, former head of the Department of Horticulture, both of Kansas State

University, for their encouragement and support during my sabbatic leave from Kansas State University. I would not have been able to pursue this advanced degree without the extended leave they granted.

I express deepest appreciation to my wife, Brenda, and children, Cathy, Sarah, and Michael, who have stood by me throughout the course of this study and provided the support I needed to complete this work. Finally, I would like to dedicate this manuscript to my late father, Roger A. Reid.

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DEVELOPING LOW-INPUT MANAGEMENT STRATEGIES FOR NATIVE PECAN ORCHARDS

Introduction

An average of 40,000 MT of pecans are produced annually from seedling trees growing in natural stands throughout Kansas, Louisiana, Missouri, Oklahoma, and Texas (USDA/ERS, 1992). Pecans produced from "native" trees represent more than one third of the total US production. In Kansas, Oklahoma, and Missouri, native pecans account for over 90% of the pecan acreage (Figure 1)(Thompson, 1984).

Several economic factors have lead to a decrease in profits earned from managing native pecans. Until 1990, the prices growers received for native pecans remained almost constant, while the price of improved pecans (nuts from large, thin-shelled cultivars) increased slightly (USDA/ERS, 1992)(Figure 2). Adjusted for inflation, grower prices for both native and improved nuts actually decreased until 1990 (Figure 3). However, a series of weather related problems during the early 1990's caused serious crop losses reducing pecan supplies. This supply reduction drove prices to record highs in 1993 but growers actually received no

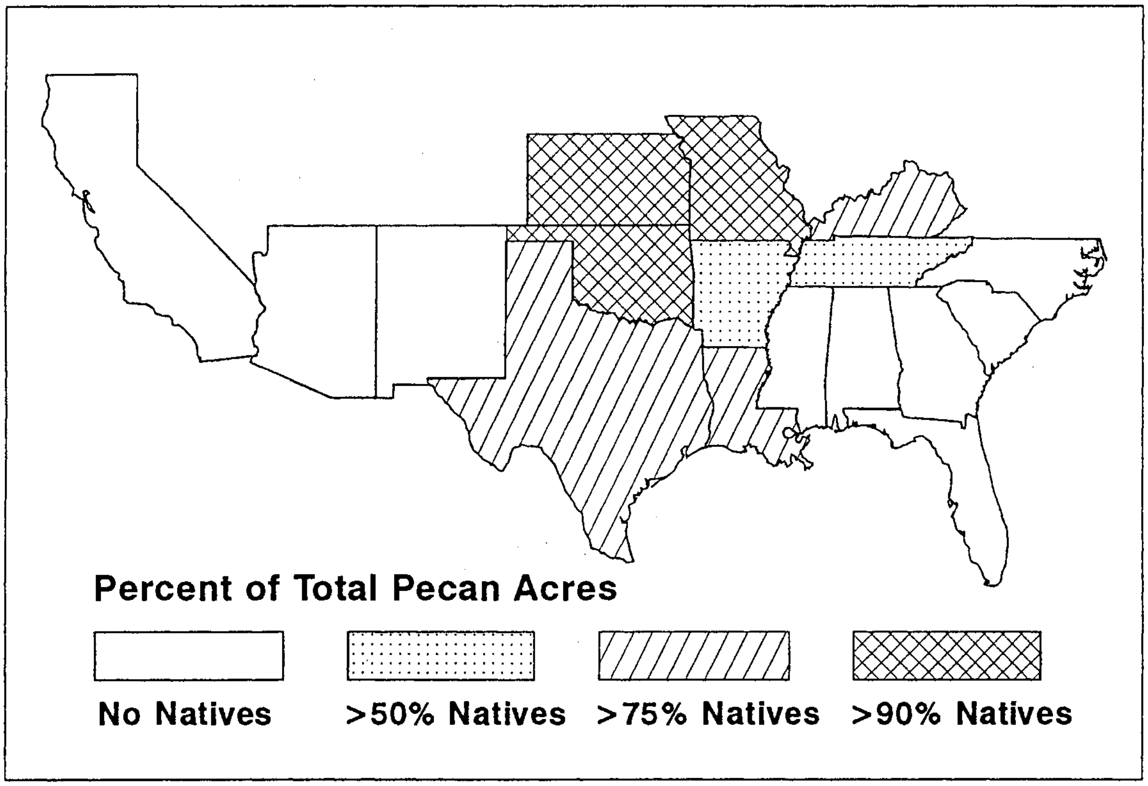

Figure 1. The Importance of Native Pecans in Pecan Producing States.

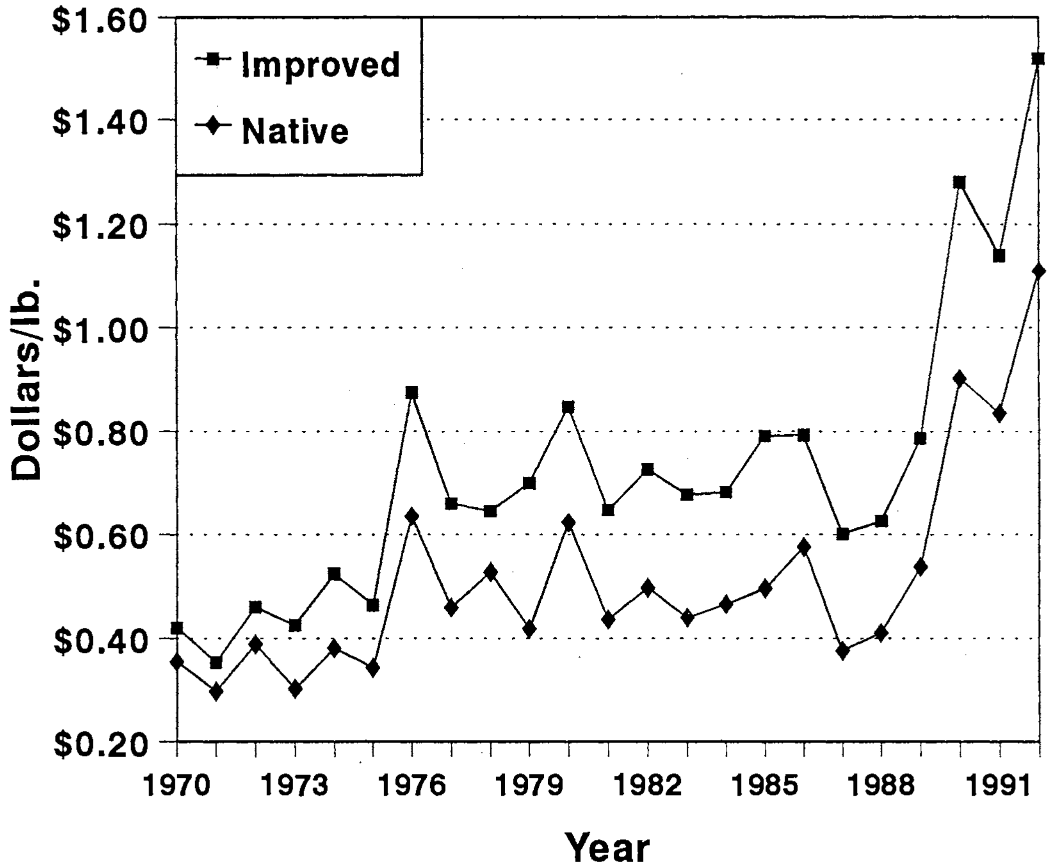

Figure 2. In-shell Pecan Prices Received By Growers of Native and Improved Pecans in the U.S. for the Years 1970 Through 1992.

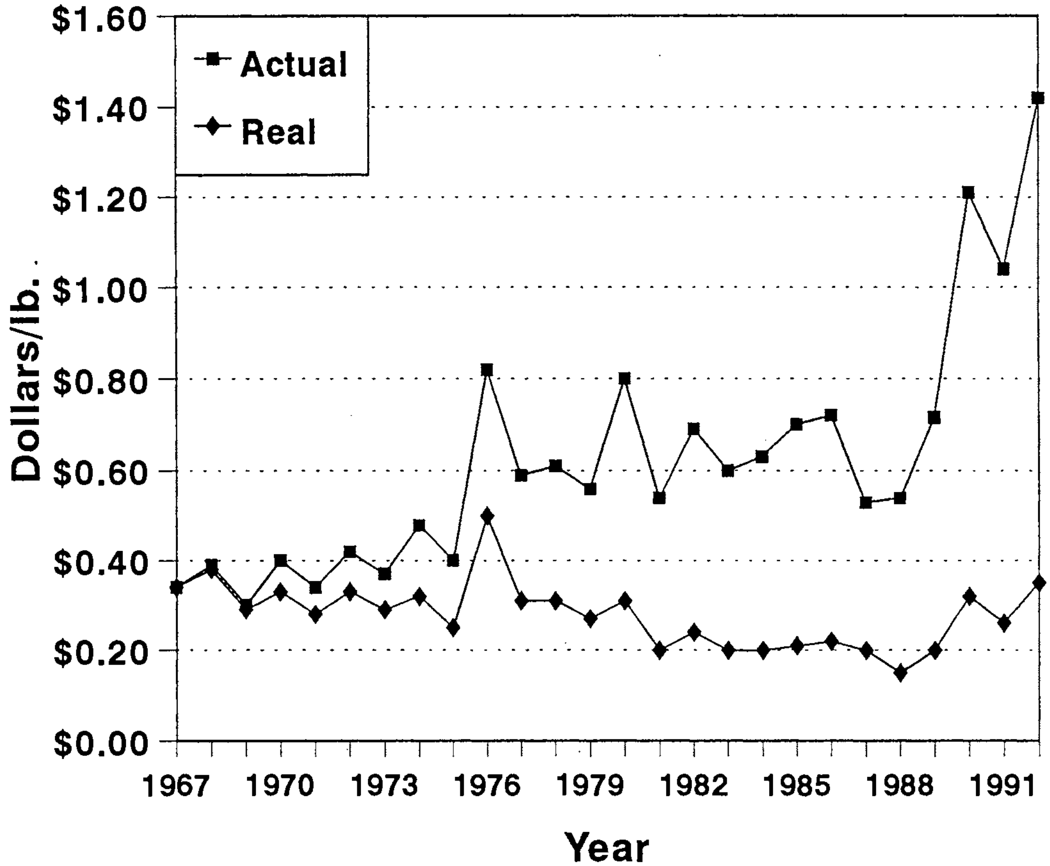

Figure 3. Grower Prices for All Pecans in Actual and Real Dollars. The price paid to growers are expressed in actual dollars. The price paid to growers after adjustment for inflation are shown in real dollars.

greater compensation for their product in 1993 than they received in the early 1970's after adjusting these prices for inflation. In sharp contrast, costs of production inputs have risen dramatically over the same time period (Table I). With input costs out-pacing increases in nut prices, native pecan producers have three avenues for maintaining profitability: increasing yields per acre, adopting new technologies, or reducing production costs.

Yield of Native Pecans

On an industry wide basis, pecan yield per acre has increased over the last 20 years as orchards of improved cultivars have taken a larger share of the U.S. production. Limited by the genetic potential of a seedling population, native pecan yield per acre peaks at around 1000 kg/ha (Reid and Olcott-Reid, 1985). Currently, this yield is obtained using an intensive management program that requires large investments in fossil fuels, fertilizer, and pesticides.

Adopting New Technology

The labor and equipment needed for harvesting and cleaning pecans in Texas accounted for 25% of total production costs in 1987 (Pena, 1987). Several mechanical harvesters were introduced in the mid 1960's for use in native pecan groves. These machines have enabled producers to harvest large acreages, while reducing labor costs.

TABLE I

1970 AND 1992 PRODUCER PRICE INDEXES FOR SELECTED EQUIPMENT AND SUPPLIES USED IN NATIVE PECAN PRODUCTION

Commodity	1970	1992
Farm Implements	115.3	348.0
Oil Products	103.1	408.1
Nitrogen Fertilizer	65.1	163.4
Pesticides	108.5	455.4

Source: U.S. Dept. of Labor, Bureau of Statistics. 1967=100.

Harvesting technology has been refined since that time, but significant changes to allow additional reductions in harvesting costs have not occurred since the mid 1970's.

Reducing Production Costs.

The leading variable costs associated with the production of native pecans include fuel, fertilizer, pesticides, equipment maintenance, and labor. Pest control alone accounted for as much as 50% of all variable costs in a Texas study (Pena, 1987).

In the absence of yield increases or technological breakthroughs, reducing the cost of production remains the only viable approach native pecan producers have to improve profitability. Reducing production costs by substituting biological and managerial inputs for chemical and fossil fuel inputs has been the focus of 'Low-input' agricultural research. Much of the biological information needed to develop a low-input approach to native pecan management is available. Integrating that information into low-input management systems tailored to specific bio-regions offers an exciting challenge for pecan researchers in the 1990's.

Low-Input Agriculture and Native Pecans

The expressions, 'low-input agriculture' and 'low-input sustainable agriculture' are often used but are poorly defined. Low-input sustainable agriculture has been defined as a philosophy and system of farming based on a set of values that reflect heightened levels of ecological awareness (MacRae et al., 1989). In practice, low-input sustainable systems avoid the use of synthetically manufactured fertilizers, pesticides, and growth regulators (Pimentel et al., 1989). Crop rotation, green manures, animal manures, cultivation, and mineral-bearing rocks are used to maintain soil fertility. Cultural and biological control measures are employed to check insects, diseases, and weeds. What sets low-input sustainable agriculture apart from low-input agriculture is that management decisions in the sustainable system are made within the narrow confines of what is philosophically defined as organic (all inputs are naturally occurring compounds).

Low-input agricultural systems employ many of the same biological and cultural techniques used in sustainable systems but are not limited to purely organic methods. Management decisions in low-input systems are economically based rather than philosophically based. The principles that govern low-input agricultural systems are: (1) adapting crop production techniques to the environment of the bio-region, (2) preserving and enhancing naturally available biological and soil resources, and (3) substituting management skill for routine scheduling of cultural practices.

Northern Native Pecans:

Ideal for the Low-Input Approach.

Native pecans thrive in the riparian environments of N.E. Oklahoma, S.E. Kansas, and S.W. Missouri. Commercial orchards, carved from riverbottom forests in this area, are located on the northern edge of the native pecan belt. The growing season in this region is relatively short for pecan, ranging from 190 to 210 days. Heavy, loamy-clay soils dominate most pecan sites in the three state area. Soils are deep, fertile, slightly-acid (pH 6.0-6.7), and subject to seasonal flooding. Production problems and practices are quite similar throughout this area, where native pecans dominate the industry (Figure 1).

The native pecan agro-ecosystem in N.E. Oklahoma, S.E. Kansas, and S.W. Missouri is ideally suited for the low-input management approach. Five factors contribute to this ideal suitability:

1. Low economic returns for native pecans provide financial incentive for growers to avoid making expenditures for production inputs of questionable value.
2. Lepidopterous insects that attack pecan fruit and foliage have fewer generations per year. Thus, control measures may be applied less frequently or not at all.
3. Northern native pecans grow under conditions of limited disease pressure. Fungicide applications are often unnecessary in the area.

4. A permanent ground cover, high soil organic matter content, and slightly acid soil pH ensure an adequate supply of zinc in northern native orchards. Foliar zinc applications, commonly recommended for Texas native pecans (Johnson et al., 1987), are unnecessary in this three state area.
5. Pecans adapted to fruiting in regions of a short growing season produce seeds that grow, fill, and dehisce in fewer than 150 days from pollination (Reid, 1985). This rapid fruit development shrinks windows of opportunity through which fruit feeding insects attack or injure the fruits.

Keeping these five factors in mind, a low-input management system for northern native pecans may be devised by using current knowledge of pecan tree physiology, integrated pest management, and agricultural economics.

The Native Pecan Agroecosystem: A Review

Pecan [*Carya illinoinensis* (Wangenh.) K. Koch] is the largest of the North American hickories. This tree is native throughout much of the central United States, thriving in the flood plains of major rivers in the Mississippi river drainage system (Little, 1971). In areas where pecan is endemic, it is often the dominate forest species comprising more than 50% of the native forest biomass (Spencer et al., 1981). Many landowners have taken advantage of this natural resource by developing pecan orchards from the native trees.

Converting a bottomland forest into a productive native pecan grove is a five-step process (Reid and Olcott-Reid, 1985). First, all species of trees other than pecan are removed, and the understory is cleared. A permanent ground cover is then established under the trees to facilitate harvest and to prevent soil erosion. After the initial forest thinning process, most native pecan areas are often too crowded for optimum nut production. Old, weak, or diseased trees are removed to allow adequate space for younger, more productive trees. Nut production in the native grove is further stimulated by the annual application of nitrogen fertilizer. And finally, an insect management program is initiated to prevent serious yield losses from nut feeding insects.

All cultural practices applied to native pecan groves are to promote high annual nut production. Even with superior management, native pecan orchards have a strong tendency towards irregular bearing (Figure 4). The unreliable annual supply of seedling pecans inhibits food processors from developing additional products that utilize seedling pecans. This absence of new product development contributes to depressed grower prices for native pecans.

Several internal and external factors influence seed production in pecan. An understanding of how these factors

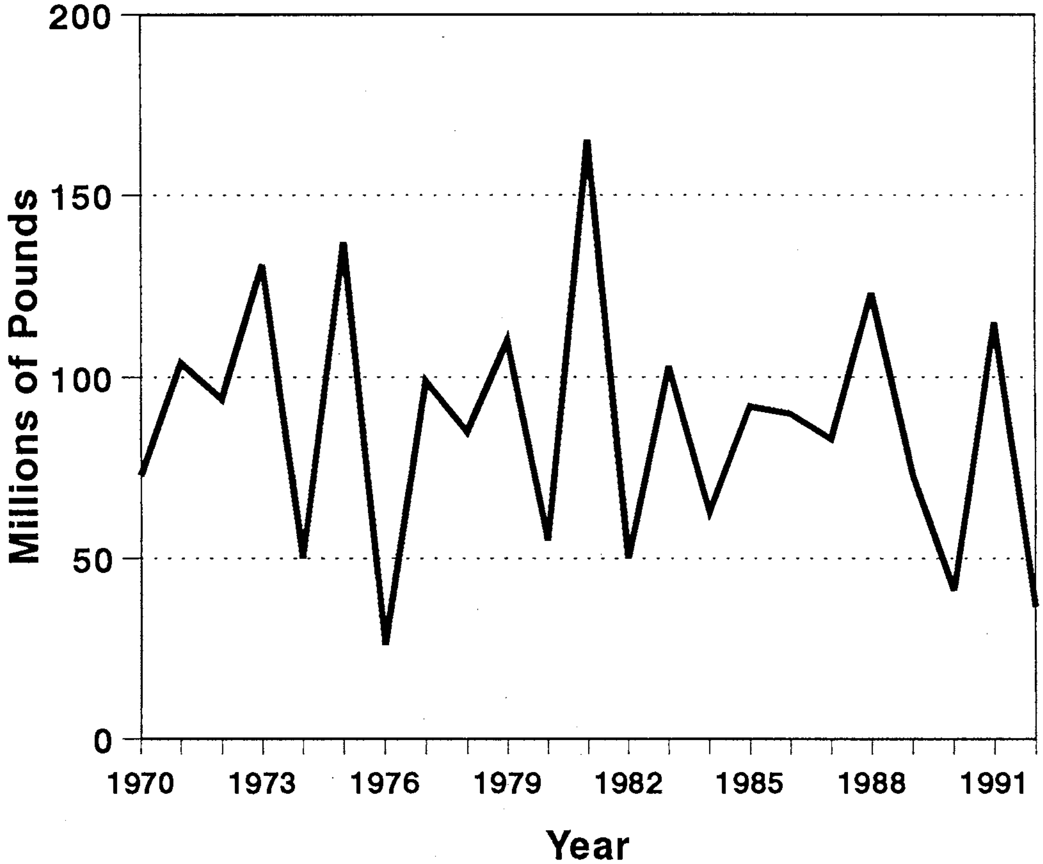

Figure 4. Total U.S. Native Pecan Production for the Years 1970 Through 1992.

interrelate is needed before new cultural practices, including low input strategies, can be developed to reduce irregular bearing and improve grower profitability.

Internal Factors: The Cropping Cycle. Pistillate flowers of pecan trees are borne on terminals of the current season's new growth (Brison, 1974). Although no morphological evidence of pistillate flower initiation can be found until after growth commences in the spring (Wetzstein and Sparks, 1984), flowering intensity is determined during the previous growing season through the influence of seed production on tree physiology (Smith et al., 1986)(Figure 5). During growth and development, pecan seeds pull large amounts of carbohydrates from surrounding plant tissues (Davis and Sparks, 1974). This reduction in carbohydrate level coupled with a shift in balance of endogenous phytohormones may limit pistillate flower initiation the following year (Wood, 1991).

External Factors Affecting Pecan Yield. Native pecan yield is influenced by weather, tree spacing, weed competition, soil fertility, diseases, and insects. These factors influence pecan yield at two points in the cropping cycle (Figure 6). Drought and early-season, nut-feeding insects can cause significant nut abortion, thus influencing yield directly. Tree overcrowding, weed competition, low soil fertility, foliar diseases, and foliage-feeding insects influence yield indirectly by reducing tree vigor and photosynthetic efficiency.

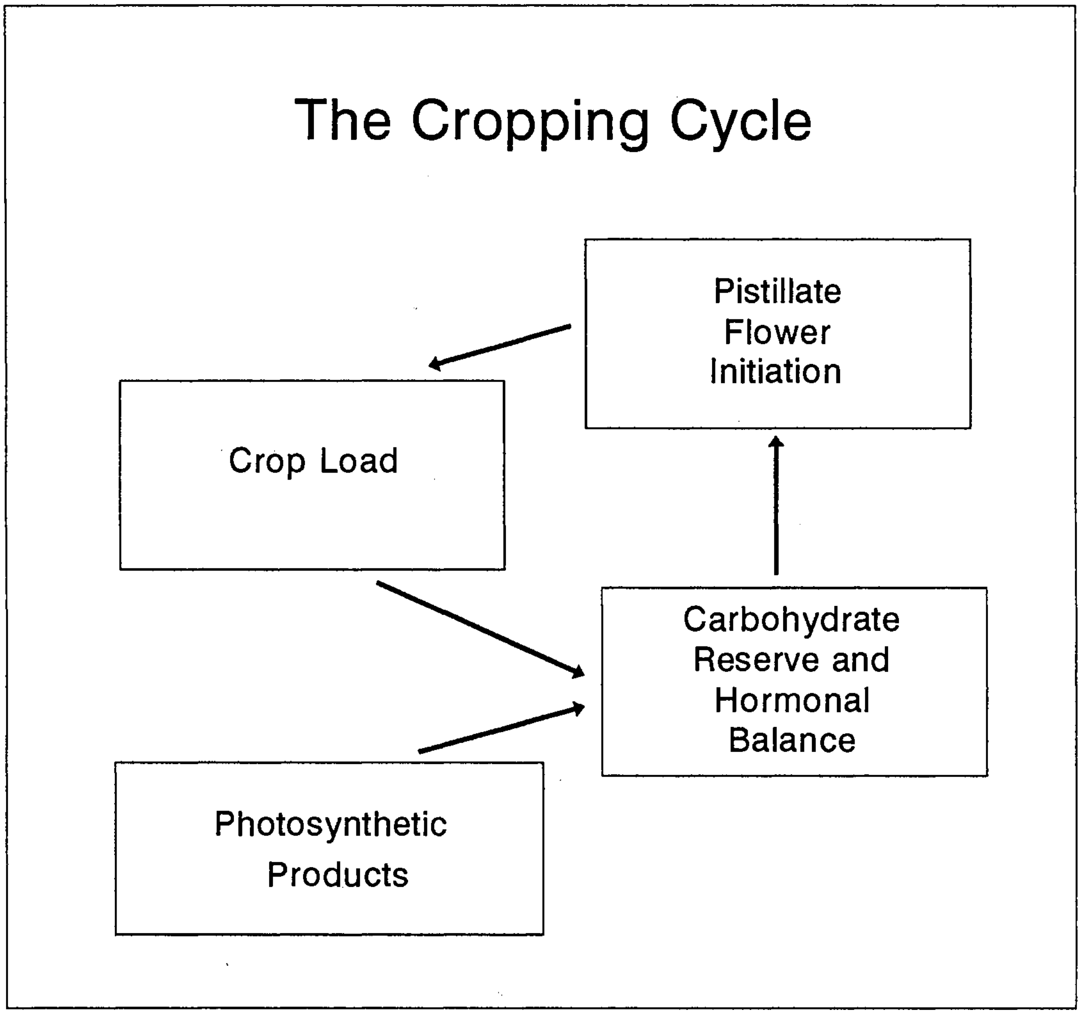

Figure 5. A Schematic Representation of the Pecan Cropping Cycle.

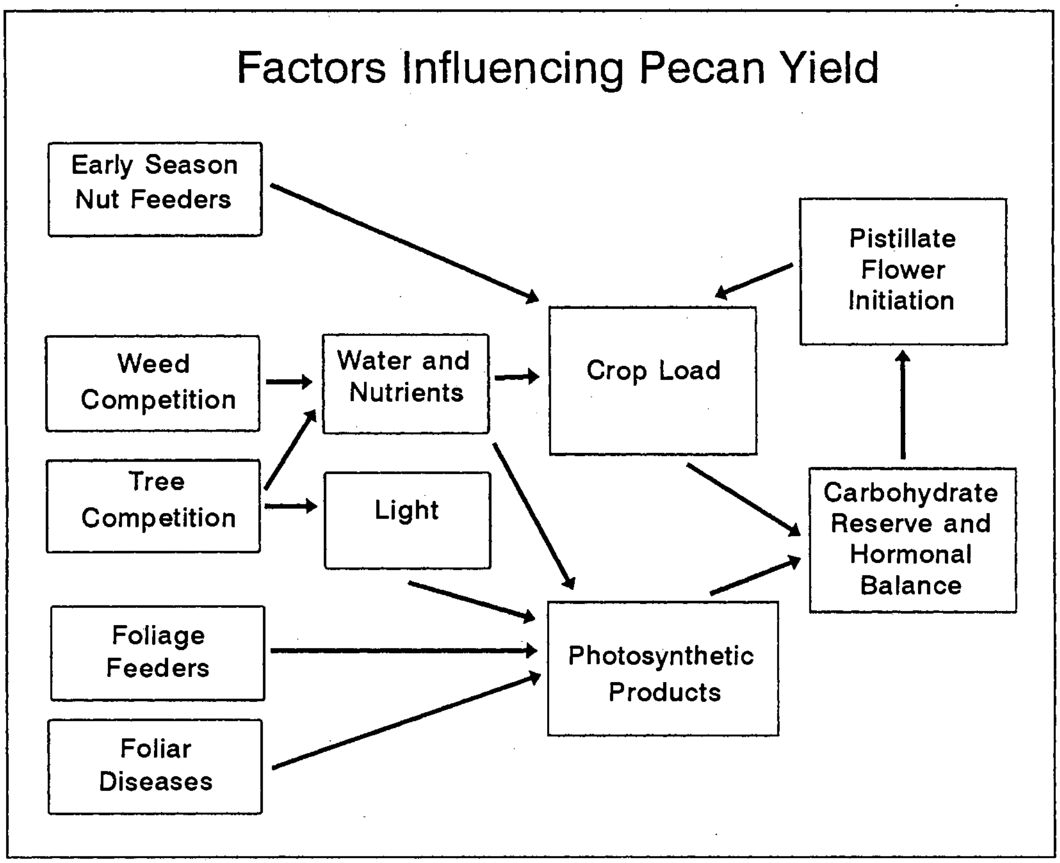

Figure 6. The External Factors That Affect the Pecan Cropping Cycle.

As discussed earlier, the primary focus of native pecan management has been to minimize the impact of all external crop-reducing factors. This approach has been only moderately successful in reducing alternate bearing (Sparks, 1983). Further advances in pecan yield regulation will be made only after cost effective methods for thinning heavy crop loads are developed.

Nut-Feeding Insects. Pest control efforts in native pecan groves are aimed at three major nut-feeding insects; pecan nut casebearer (*Acrobasis nuxvorella* Neunzig), hickory shuckworm (*Cydia caryana* (Fitch)), and pecan weevil (*Curculio caryae* (Horn)). Although pecan weevil is the most serious pest native pecan producers face (Payne et al., 1979), this insect attacks nuts after seed development is largely completed (Harris, 1985) and has little impact on the pecan cropping cycle. Pecan nut casebearer and hickory shuckworm cause nuts to abort before seed development is complete (Payne et al., 1979). This nut thinning directly affects the pecan cropping cycle and may offer a possible biological solution to overproduction problems.

Making A Low-Input Program Work

In developing a low-input management program for native pecan orchards, an analysis of current inputs is necessary to identify potential areas for input reductions. Production costs for the typical pecan grower include nut harvest, nitrogen fertilization, and insect control.

As mentioned previously, nut harvest consumes 25% of all variable costs. In the absence of new technologies, harvest costs must increase with increases in costs for machinery, fuel, and labor. Reductions in harvests costs are not on the horizon for any management system.

Nitrogen Fertilization. Native pecan orchards respond to nitrogen fertilization with yield increases (Reid, 1990a). Trees in well spaced groves will respond within 2 years of the initial nitrogen application. Nitrogen application may be the most profitable cultural practice used to increase native pecan yield. If the cost of urea (45% N) is $170.00/ton (1990 price) and a grower applies 225 lbs urea/acre (100 lbs. N/Acre), he will spend $19.13/acre on fertilization. The application of 100 lbs. N/acre to native pecans increases yield by an average of 200 lbs/acre. If native pecans are sold for $0.50/lb., fertilization will return $100.00/acre in increased nut production and $80.87/acre in profit.

As long as the price for manufactured nitrogen remains relatively low, there is little incentive to develop alternative soil-fertility management systems. Increasing prices for fossil fuel used in the manufacture of chemical nitrogen and growing public concern for nitrogen contamination of ground water resources may alter this situation. If future events precipitate large increases in the cost for applying chemical nitrogen, native pecan growers will be among the first to turn to nitrogen-fixing cover crops as a low-input alternative. The nitrogen-fixing capacity of forage legume crops is well known (Brady, 1974). The ability of orchard-grown legumes to provide all the nitrogen needed to sustain high yields is a question that needs further study.

The incorporation of legume cover crops in the pecan agroecosystem also has important pest management ramifications. Legumes provide a nursery for the *in situ* proliferation of beneficial insects that can be manipulated for the control of pecan aphids (Tedders, 1983). Successful aphid biological control programs using legume cover crops have been employed in south Georgia (Bugg and Dutcher, 1989; Tedders, 1983). In northern pecan states, pecan aphids are only an occasional pest and are rarely the target of chemical control measures. Naturally occurring beneficial insects keep aphids in check during most years in Kansas (Dinkins and Reid, 1985). For legumes to become part of a soil fertility program for northern low-input orchards, the influence of this cover crop on insect populations (both harmful and beneficial) must be studied carefully to ensure that total inputs for nitrogen fertilization and insect control are reduced.

Insect Control. With pesticide prices increasing fourfold from 1970 to 1992 (Table I), limiting their use on native pecans could significantly reduce production costs. The primary targets of the insecticides applied to native pecans in the north are pecan nut casebearer, hickory shuckworm, and pecan weevil. Because these insects have tremendous destructive potential, insecticides are applied 4 to 5 times a year under the assumption that economically damaging populations occur every year (Gallott et al., 1988; Morrison et al., 1982). For native pecan orchards that have had a high level of management for many years, this assumption may be invalid. During years of overproduction, pecan nut casebearer and hickory shuckworm may actually play the much needed role of nut thinning agents. Late in the late season, pecan weevil populations may be driven so low by years of pesticide application that further applications are not economically justified.

Scouting procedures have been developed for all the major insect pests of pecan (Reid, 1988). Unfortunately, too many native pecan managers still apply insecticides without prior information on pest population levels. Low-input strategies can work only after growers learn to substitute investments in management effort for investments in routine pesticide applications of questionable benefit. Intelligent decision making about pest management requires an intimate knowledge of insect and host plant biology and accurate scouting methods for determining economic injury levels.

<u>Insect and Crop Load Monitoring</u>. The success of a low-input, pecan-management program hinges on our ability to weigh insect control costs (both economic and biological) against potential income loss. In spite of

recent advances in pecan pest management, native pecan growers are often faced with making pest control decisions without the benefit of accurate economic injury information. A brief look at the management of two nut feeding insects points out weaknesses in current IPM practices.

Pecan Nut Casebearer. A growing-degree day model (Ring et al., 1983) and sequential sampling plan (Ring et al., 1989) have been proposed for pecan nut casebearer. The growing-degree day model has had some success in estimating a best 'spray date' for control of this insect, whereas the sequential sampling plan attempts to determine the need for control. Both techniques are based on determinations of percent nut clusters infested with pecan nut casebearer. The expression of damage in percent infested clusters may accurately reflect insect behavior but is not easily converted to nut loss estimates. The discrepancy between percent infested clusters and percent nut loss can be seen in Table II. Regardless of how percent damage is expressed, lack of accurate estimates for nut load renders percent damage information useless for determining economic injury levels. Percent nut loss to pecan nut casebearer was similar in 1986 and 1987 (16.7% and 16.9% respectively), yet nut yield per acre was three times greater in 1987 than in 1986 (Reid, 1990a). In 1987, 16 percent nut loss would have provided a beneficial level of nut thinning to reduce overproduction. In a low crop year such as 1986, 16 percent

TABLE II

PECAN NUT CASEBEARER DAMAGE EXPRESSED AS PERCENT INFESTED CLUSTERS AND PERCENT OF NUTS DAMAGED[1]

Year	Percent Infested Nut Clusters	Percent of Nuts Damaged
1981	11.5	9.1
1982	28.5	19.8
1983	7.0	3.3
1984	32.5	22.0
1985	34.0	26.4
1986	25.5	16.7
1987	27.5	16.9

1. Data collected annually by sampling 20 nut clusters on each of 10 native pecan trees growing in S.E. Kansas in the years 1981 through 1987.

nut removal by casebearer represents a significant economic loss.

Precise estimation of pecan yield potential will be crucial to the future of biological control of seed overproduction (i.e., allowing pecan nut casebearer to thin pecan fruit). A recent attempt to estimate yield (Wright et al., 1990) has limited application to native pecan systems. The authors found statistically significant differences between yield estimation models for different cultivars, years, and sites. Because of the genetic diversity in a native pecan grove, yield estimation models must be developed from large scale data bases. The management decisions native pecan managers make are for large acreages (40 to 400 ha). Methods to estimate the yield potential of a 40 ha native pecan grove (or larger) are needed to determine economic thresholds and make pest control decisions.

Hickory Shuckworm. The current pest management approach to controlling hickory shuckworm can best be described as the "also" approach. Native pecan producers rarely apply a pesticide with the exclusive objective of controlling shuckworm. In Kansas and Oklahoma, native pecan growers often make a insecticide application in early July to control insect pests such as walnut caterpillar, fall webworm, hickory nut curculio, and also hickory shuckworm (Gallot et al., 1988, Morrison et al., 1982). In August, insecticides applied to control pecan weevil also control hickory shuckworm.

As low-input strategies are adopted and pesticide applications are reduced, will hickory shuckworm become a more prominent pest? The hickory shuckworm has three generations per season in Kansas (Dinkins and Reid, 1988). The overwintering generation emerges before nut set and does not injure pecan. The first summer generation is usually so small that nut drop caused by this insect is negligible. Larvae from the second summer generation mine nut shucks and have been shown to inhibit nut fill. In a survey of 146 native pecan trees from a orchards in S.E. Kansas, 25% of all nut shucks were infested with shuckworm larvae (Reid, 1990b). However, infestation rate could not be related to decreases in nut fill (Figure 7) or number of indehiscent nuts. Shuckworm larvae may not pose a significant threat to kernel fill in the northern pecan states, where pecans are adapted to a short season climate. Northern natives fill their kernels before shuckworm larvae grow large enough to reduce the flow of carbohydrates to the seed.

The apparent differences in potential damage from hickory shuckworm between northern and southern pecan regions point out the importance of developing management strategies for specific bio-regions. Collection of basic biological information on all agroecosystem components is necessary for the development of site-specific, low-input strategies.

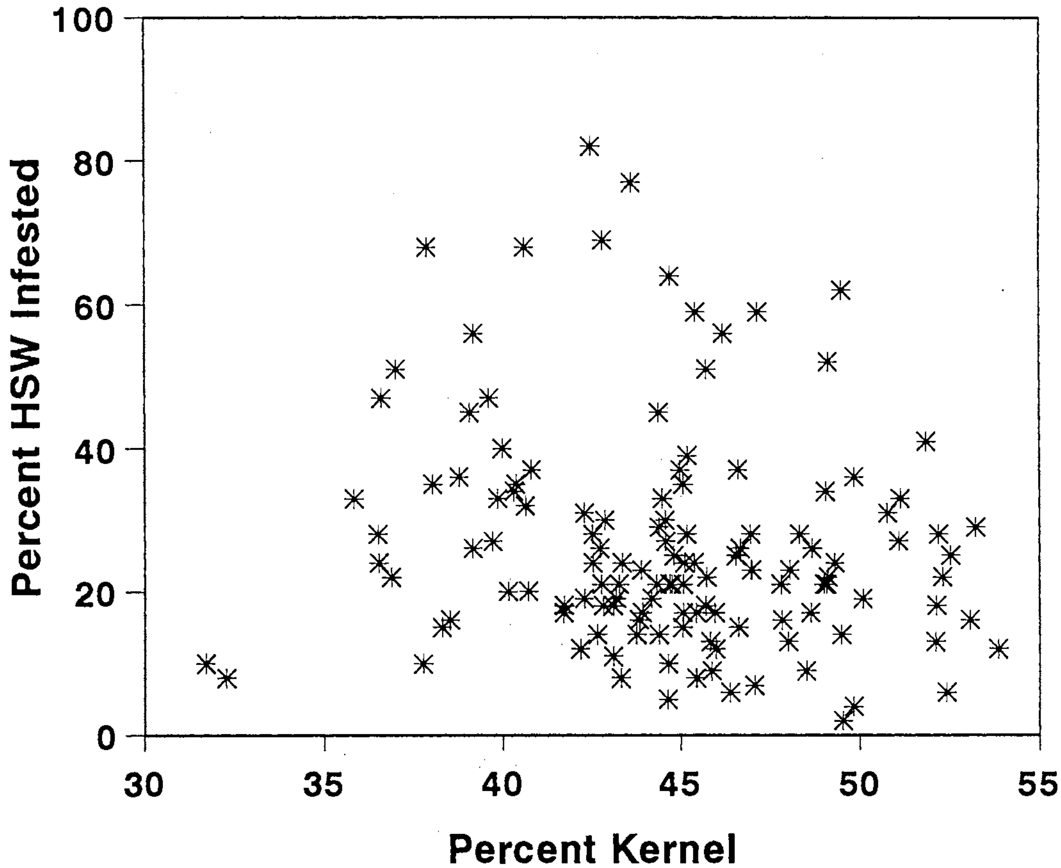

Figure 7. The Lack of Relationship Between Hickory Shuckworm Infestation and Kernel Quality for 167 Native Pecan Trees Growing in S.E. Kansas in 1988.

Future Research Needs

Implementation of low-input management systems is dependent on total agroecosystem research programs. History provides evidence of how narrowly focused research can lead to economic disasters for growers who rely on university research for production guidelines. The pecan aphid problem that currently plagues southeastern pecan growers was created by the overuse of pesticides. After nearly 20 years of attempts at chemical quick fixes, scientists have adopted the total agroecosystem approach as the only solution to aphid management (Tedders, 1986). Research opportunities abound for pecan scientists wishing to develop low-input pecan-management systems. An integrated approach to crop load estimation and pest monitoring techniques should become a research priority across all pecan production areas.

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CHAPTER II

A METHOD FOR PLACING PHEROMONE TRAPS WITHIN THE CANOPIES OF MATURE PECAN TREES

Introduction

Pheromone traps have proven to be important tools for the detection of phytophagous insects (Carde and Elkinton, 1984). Proper methods for effective deployment and use of pheromone traps have been documented for pests of several tree crops (Baker et al., 1980; Grant, 1991; Houseweart et al., 1981; Reidl, 1980; Reidl et al., 1979). General guidelines for trap use include:

a) placing traps where insects occur.

b) installing traps at the proper density.

c) choosing the correct pheromone at the proper concentration.

d) cleaning and reading traps at the proper frequency.

Recently, the sex pheromone of the hickory shuckworm (*Cydia caryana* Fitch)) has been identified (Smith et al., 1987) and field tested (McDonough et al., 1990). The utility of this new technology will depend on the development of reliable action thresholds based on trap catches and the development of simple and inexpensive deployment methodology that growers will accept.

Trap catches should be greatly enhanced by setting traps within the canopy of pecan trees if the hickory shuckworm behaves like the codling moth (both are members of the genus Cydia)(Reidl, 1979). Pecan production in Kansas, Missouri, and Oklahoma is largely based on the production of nuts from native trees (Reid, 1990). Trees in native pecan groves often grow to more than 20 m. Therefore, placing a pheromone trap within the canopy of a mature pecan tree without the aid of a hydraulic lift presents a major logistic problem. This study was initiated to test the efficacy of an inexpensive trap hanging system that could be used to deploy hickory shuckworm pheromone traps in pecan tree canopies.

Methods and Materials

Design of trap hanging system

Two design features were required in developing a method for hanging pheromone traps in the canopy of mature pecan trees; the method had to be inexpensive to install and a single person should be able to set a trap in a tree standing on the ground or in the bed of a truck. These design requisites were met by a simple line and pulley system designed for hanging traps in the canopy of a tree. The system was composed of three principle components; a large steel hook, braided nylon twine, and an installation pole. The large steel hook was made from a 61 cm (24 in.)

piece of 1 cm (3/8 in.) diameter mild steel rod. The rod was bent into a fish hook shape with a 9 cm (3.5 in.) diameter bend. One cm (0.5 in.) from the long end of the hook, a 3.7 mm (9/64 in.) hole was drilled through the rod. This hole was used to attach a baler wire "pulley". The pulley was made by placing the ends of a 15 cm (6 in.) piece of 16 gauge steel wire (baler wire) into the 3.7 mm hole from each direction and forming a wire circle. This wire circle was then twisted below the end of the steel hook until a small 1 cm (3/8 in.) wide wire loop remains. A minimum of 18 m (60 ft.) of braided nylon string is threaded through the wire loop. The string ends were tied together to make a large string loop. The hook and string form the basic hanging system. The hook was placed over a tree limb as high as possible into the mid portion of the tree canopy.

The hook and string were easily placed into the tree using a 6 m (20 ft.) joint of 2.5 cm (1 inch) PVC pipe (schedule 40). The PVC pipe was fitted with steel collars on each end of the pipe to prevent nylon string from cutting into the PVC. A 12 m (40 ft.) piece of nylon string was fed through the pipe and tied together on the outside of the pipe to form a continuous loop. A fisherman's swivel was tied to this string. The string loop attached to the PVC pipe (feeding line) was used to feed the string attached to the steel hook (trap line) through the center of the pipe. The trap line was attached to the feeding line with the swivel. The trap line was pulled through the center of the pipe by pulling on the feeding line. The entire trap line was pulled through the pipe until the long end of the steel hook was also inside the pipe. Once the trap line and hook are fed into the pipe, the pipe was hoisted into the tree. The exposed portion of the hook was then positioned over a suitable limb and the pipe was lowered leaving the steel hook in the tree. The trap line was exposed as the pipe was lowered. The position of the string could be selected to avoid entanglement by carefully directing the decent of the pipe. A pheromone trap was attached to the string attached to the hook then hoisted into the tree. The trap was held in place by tying the string to a nail positioned into the tree trunk by hammering. The pheromone trap could then be raised and lowered throughout the growing season for inspection and trap replacement. The PVC pipe was used at the end of the season to remove the steel hook and trap line.

Field Test

Hickory shuckworm pheromone trap performance was evaluated in a native pecan grove using two trap hanging procedures; the hook and trap line system described above and a trap attached to the tree trunk at 2 m. During the fall of 1987, 100 nuts from each of 128 trees in a 8 ha grove were evaluated for the presence of hickory shuckworm larvae. This information was used to select 20 trees for this study. Each tree selected for the study met the following criteria:

1) The tree had a moderate to heavy crop in 1987.
2) 30 to 40 percent of the nuts evaluated were infested with shuckworm larvae.
3) The tree had to be at least 140 feet away from any surrounding tree chosen for the experiment.

Pheromone traps were installed on the pre-selected trees on 3 May 1988. Trees were in the leafburst stage of growth when traps were deployed. A completely randomized experimental design was used to test the two methods of trap deployment. Commercially prepared hickory shuckworm pheromone lures (Scentry, Inc., Buckeye, AZ) were placed in standard wing traps (Scentry, Inc., Buckeye, AZ). Traps were evaluated and cleaned weekly for a period of seven weeks. Analysis of variance and regression analysis was performed on the resulting trap catch data to estimate the differences between trap installation methods.

Results and Discussion

Pheromone traps placed within the canopy of pecan trees captured more male hickory shuckworm moths than traps attached to tree trunks (Figure 1). This finding is consistent with observations made by Reidl et

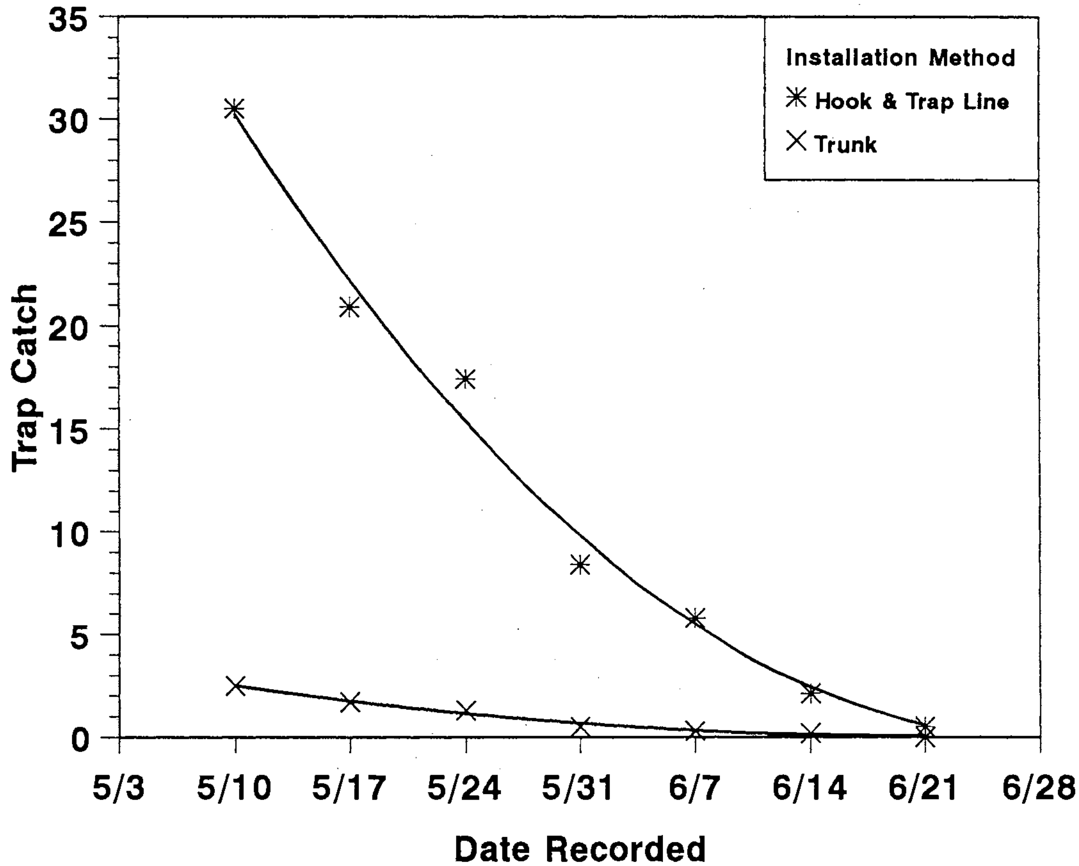

Figure 1. The Number of Male Hickory Shuckworm Moths Captured in Pheromone Traps Deployed by Two Methods Over a Seven Week Period. The points denote mean trap catch per week while the lines illustrate the relationship of trap catch to time. For the hook and trap line system, trap catch = 39.51 - $(9.9 * week) + (0.62 * week^2)$. When traps were attached to the trunk, trap catch = 3.39 - $(0.95 * week)$ + $(0.068 * week^2)$.

al. (1979) that lead the recommendation that codling moth pheromone traps should be placed in the upper canopy of apple trees to improve trap catch. The largest number of moths were captured during the first week of trap deployment. Trap catches decreased each week as the spring emergence period for hickory shuckworm came to an end in late June. Regression analysis of the data revealed that a quadratic model can be used to describe the changes in trap catch over the time period of 10 May to 21 June 1988. However, the relationship between moth capture and time differed between the two trap deployment methods (Table I). Detection of the rapid decline in hickory shuckworm numbers associated with the end of the spring emergence period was possible by using the trap and line system, (Figure 1). This decline was not observed when counting the number of moths captured in traps nailed to the trunk.

The hook and trap line was fairly easy to install and maintain. Although it took more time to install, maintain, and dismantle than simply attaching a trap to the trunk of the tree, improving trap catches should make prediction of population trends more precise. The biggest problem associated with using the hook and trap line system was that high winds could sometimes entangle the pheromone trap in the trap line. Freeing entangled traps took a little time and patience but all traps could be freed from the ground without having to remove the hook from the tree.

TABLE I

ANALYSIS OF VARIANCE FOR THE NUMBER HICKORY SHUCKWORM MOTHS CAPTURED OVER A SEVEN WEEK PERIOD IN TRAPS DEPLOYED BY TWO METHODS

Source	DF	Sum of Squares	F value	Pr > F
Position	1	4469.15	139.28	.0001
Main Plot Error	18	577.56		
Week	6	4298.19	25.94	.0001
Linear	1	4055.44	146.85	.0001
Quadratic	1	196.80	7.13	.0088
Residual	4	45.94	0.42	.7969
Week*Position	6	3072.70	18.54	.0001
Linear*Position	1	2912.02	105.45	.0001
Quadratic*Position	1	126.50	4.58	.0346
Residual	4	34.18	0.31	.8711
Sub Plot Error	108	2982.54		
Corrected Total	139	15400.14		

The hook and trap line system should be recommended for deploying pheromone traps in any tree crop system. The cost of materials for implementing this system was $2.86 per trap (1993 price not including the cost of pheromone lures and wing traps) but the hooks and trap lines could be used for several years. Once installed, growers have found the system easy to operate and maintain.

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CHAPTER III

STRATEGIES FOR USING PHEROMONE TRAPS TO SAMPLE CYDIA CARYANA POPULATIONS

Introduction

The hickory shuckworm, *Cydia caryana* (Fitch), is an important fruit feeding pest of pecan (*Carya illinoinensis* (Wangenh.) K. Koch)(Payne et al., 1979). Hickory shuckworm larvae feed on the entire fruit before shell hardening and cause fruit abortion (Payne and Heaton, 1975). Larval feeding is confined to the involucre after shell hardening, interrupting the flow of carbohydrates to the nut and reducing kernel quality (Calcote et al., 1984). Recently, the sex pheromone for *C. caryana* has been identified (Smith et al., 1987) and field tested (McDonough et al., 1990).

Pheromone traps have been used effectively for monitoring pests of several tree crops (Baker et al., 1980; Grant, 1991; Houseweart et al., 1981; Reidl, 1980; Reidl et al., 1979). The utility of using the hickory shuckworm pheromone as a pest management tool is dependent on the development of an adequate sampling scheme. This sampling plan should enable growers to determine the periods of peak moth activity that precede major periods of oviposition.

Knowledge of the spatial and temporal distribution of hickory shuckworm moths (as monitored by pheromone traps) within a pecan orchard is needed to devise a sampling scheme to produce pest information with an adequate level of precision (Southwood, 1978).

The dispersion of insects in an environment can be described using mathematical distributions (Taylor, 1984) and/or spatial models (Roberts et al., 1993). The binomial family of mathematical distributions is widely used by entomologists to describe the probability of finding a certain number of insects in a sample from a population with a given mean (Southwood, 1978). Parameters from these population models are used to determine optimum sample size and to construct sampling plans (Southwood, 1978). In contrast, spatial models map variation in insect population densities by measuring and analyzing spatial dependence (Schotzko and O'Keeffee, 1989). By knowing the range of spatial dependence, a minimum distance between sample locations can be determined to ensure that estimates of variance between samples are independent (Borth and Huber, 1987). Independent estimates of variance are needed in order to utilize traditional analysis of variance techniques.

This study was designed to examine the spatial and temporal distribution of male hickory shuckworm moths as monitored by pheromone traps. The data collected from this study were used to determine sample size and to discover a sampling scheme to economically estimate hickory shuckworm infestations in a native pecan orchard.

Methods and Materials

Pheromone Trapping

Over ninety percent of the pecans produced in Oklahoma, Kansas, and Missouri are harvested from native (seedling) trees (Reid, 1990). Trees in native pecan groves vary widely, both in genetic characteristics and tree spacing. From a pest management point of view, the native pecan grove represents a population of trees with varying degrees of susceptibility to insect predation. The native pecan grove chosen for this study is located near Faulkner, in southeastern Kansas. This grove has four characteristics that are ideal for studying the spatial and temporal distribution of hickory shuckworm: Trees were arranged in rows unlike naturally occurring native pecan stands, the trees were seedlings similar to surrounding native pecan groves, the trees had a history of hickory shuckworm infestation, and pesticides had not been applied to the orchard for more that 5 years. Trees in the study orchard were planted in 1958 in a quincuncial pattern with 21 meters between trees (Figure 1). The 8 hectare orchard contained 146 trees. One wing-type pheromone trap (Scentry, Inc., Buckeye, AZ) was hung in mid-canopy from each pecan tree using a hook and line system (Chapter II). Commercially prepared pheromone lures (Scentry, Inc.

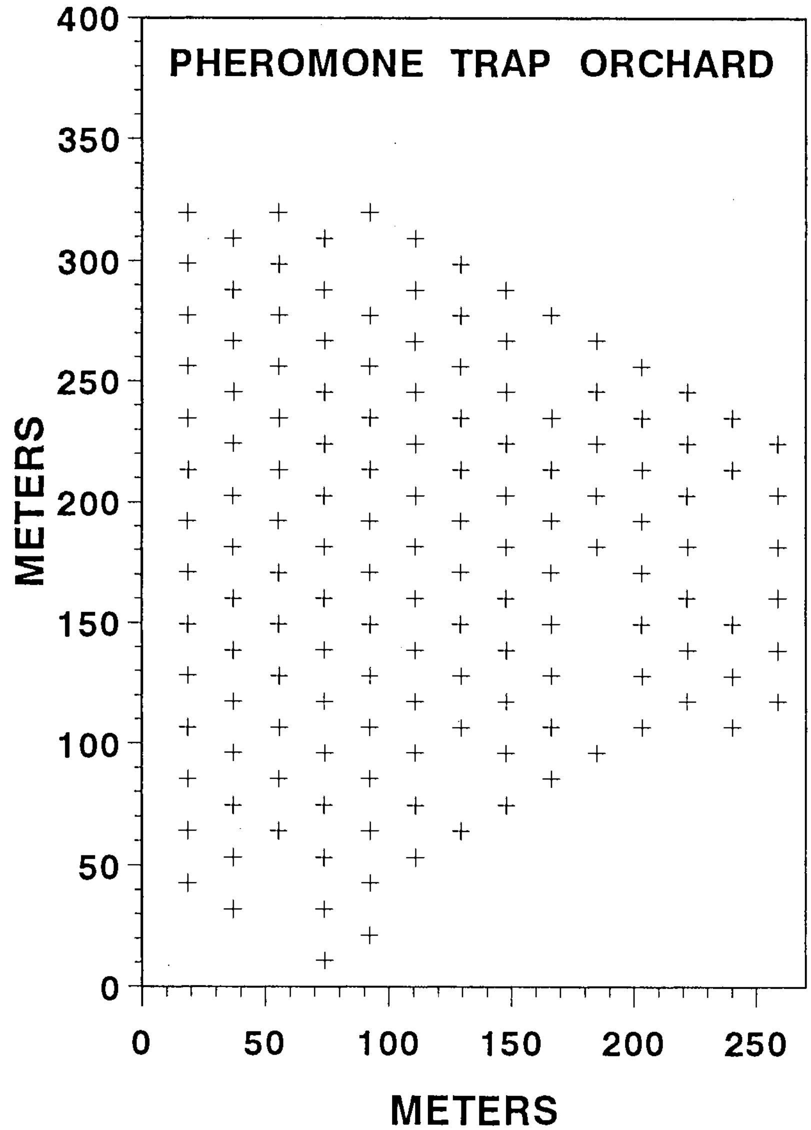

Figure 1. The Arrangement of Trees in the Pheromone Trap Orchard. The orchard is located near Faulkner in southeastern Kansas.

Buckeye, AZ) were used throughout the study period. Traps were installed during pecan tree bud burst on 2 May 1988. Traps were read and cleaned weekly until leaf fall. Trap bottoms and lures were changed every 4 weeks. Trapping was continued in 1989 when new traps were installed on 25 April 1989. The trapping procedures used in 1989 was identical to the procedures used in 1988.

One hundred fruit were harvested prior to the deployment of pheromone traps during October 1987 from each fruit bearing tree in the orchard. The shuck of each fruit was inspected for the presence of hickory shuckworm larvae or evidence of larval feeding. The relationship between larval damage in the fall of 1987 and the number of moths captured in the spring of 1988 was investigated using nonparametric linear regression methods (Conover, 1980). The nonparametric approach was chosen for this analysis to avoid the need for making the assumption that both damage level data and moth catch data are normally distributed.

Additional fruit samples were collected during the fall of 1988 and inspected for larval feeding using the same methods employed in 1987. The relationship between the number of moths captured in late summer of 1988 and larval damage levels in 1988 was investigated using nonparametric linear regression (Conover, 1980).

Test For Mating Disruption

Synthetic sex pheromones have been used to disrupt the mating of several arboreal pests (Birch and Haynes, 1982; Faccioli et al., 1993; Howell et al., 1992; Muirhead-Thomson, 1991). The placement of a pheromone trap in every tree, as described in the studies above, had the potential for reducing mating success. Reduced mating should lead to a decrease of larval damage to pecan shucks. Nut samples were collected in 1988 from the pheromone trap orchard and a companion orchard without pheromone traps to measure the potential for mating disruption. The companion orchard was planted in 1958 in a manner similar to the pheromone trap orchard. These two orchards were separated by a riparian timber area that measured no less than 100 meters wide. A 100 fruit sample was taken from each fruit bearing tree in October 1988. Fruit were harvested from 80 trees in the pheromone trap orchard and 87 trees in the companion orchard. The shuck from each nut was examined for the presence of hickory shuckworm larvae or evidence of larval tunneling. The percentage of damaged nuts was recorded. A negative binomial distribution was used to describe the damage levels in each orchard. The distribution of damage level for each orchard was compared using the chi-square test for differences in probabilities (Conover, 1980).

Influence of Larval Feeding on Nut Quality

The nut samples taken during the fall of 1988 were also used to measure the influence on hickory shuckworm feeding on kernel quality. After removal of shucks, nut samples were weighed, cracked, and kernels weighed to determine percent kernel. The influence of larval damage on percent kernel was evaluated using linear regression analysis.

Estimating Optimum Sample Size

The number of pheromone traps needed to detect an increase in hickory shuckworm activity is dependent on the precision required, the mean number of male moths captured, and the variance of the number of moths captured. The number of traps needed to estimate male moth trap catch with three predetermined levels of precision (coefficient of variation (CV) = 10, 15, or 25 % of the mean) was estimated using the procedure for estimating sample size described by Cochran (1977). Estimates of the mean and standard deviation from the weekly trap catch data collected in 1988 and 1989 were utilized to estimate a sample size (n_0) that could be used in future studies. Cochran (1977) estimated sample size as

$$n_0 = \frac{1}{C} \left[\frac{s}{\bar{Y}} \right]^2$$

To make this estimate of sample size the following terms must be defined:

n_0 = an estimated number of pheromone traps to used in a future study.

n = the number of pheromone traps (146) deployed in the studies conducted in 1988 and 1989.

Y_i = the number of moths captured per week in a pheromone trap (a single observation from the 1988 and 1989 studies).

$\bar{Y}$ = an estimate of the mean number of moths captured per in pheromone traps deployed in 1988 and 1989. An estimate of the mean is

$$\bar{Y} = \frac{\sum_{i=1}^{n} (Y_i)}{n}$$

s = an estimate of the standard deviation of the number of moths captured per week in 1988 and 1989. The standard deviation is estimated by taking the square root of the variance. An estimate of the variance (s^2) is

$$s^2 = \frac{\sum_{i=1}^{n} (Y_i - \bar{Y})^2}{n-1}$$

CV_0 = the desired estimate for the coefficient of variation (level of precision) for a future study, where

$$CV_0 = \frac{100 * s_0}{\bar{Y}_0} \text{ percent}$$

and where, $\bar{Y}_0$ and s_0 are future estimates of the mean and standard deviation in a future study.

C = The predetermined level of precision desired for a sample taken in a future study, where

$$C = (CV_0)^2$$

Sample size estimates, determined by the above method, were made for each week of moth counts. The relationship between the estimated sample size for a future study and the mean number of moths captured per week was estimated by linear regression techniques. Sample size curves were determined by estimating this relationship for each level of precision.

Determining Sampling Method

A simple random sample provides an unbiased estimate of the mean but does little to control variance estimates for insect populations that may be clumped in one area of the field. In comparison, stratifying the sampling process can reduce variance estimates (increase precision) of insect count means. To test the benefits of stratification in sampling hickory shuckworm with pheromone traps, the number and shape of strata had to be determined. Strata were constructed by first gaining an understanding of the spatial dependence of the data. Both larval infestation and number of moths captured per pheromone trap were viewed as spatial point processes. An estimation of how the variance of the difference between two points in the process changes with distance between points was made by estimating a variogram (Cressie, 1991).

Variograms where estimated in three directions; north - south, northwest - southeast, and northeast - southwest. The size and shape of the strata were determined by visual inspection of these directional variograms. The maximum distance where variogram estimates remained similar was chosen as the maximum size for a stratum in each of the three directions. Five strata were constructed based upon the results of the spatial analysis.

Two trees were selected at random within each stratum (5 strata). The gain in precision was estimated by comparing the variance of the weighted mean from the stratified sample to the variance of mean from simple random sample taken the same population (Cochran, 1977). The ratio these variances has been termed the design effect (Cochran, 1977). The process of selecting two trees at random from each stratum and estimating the variance associated with both a stratified random sample and a simple random sample was repeated 13 times. This repetition allowed for the evaluation the variation in design efficiency estimates. Random samples were taken by assigning a random number to each tree in a strata and drawing out sample pairs in numerical order by random number. This method of drawing two random samples from each strata was chosen to speed computations. The range and mean of the design efficiency estimates were determined for each week of the 1988 trap catch data. Student's t test was used to test the hypothesis that the weekly estimate of the mean design efficiency was equal to one (no improvement in precision of the estimate).

Results and Discussion

Pheromone Trapping

Large numbers of hickory shuckworm moths were captured during the early spring of 1988 (Figure 2). This early spring flight of shuckworm moths occurs before pecan nut set, but galls formed by the pecan stem phylloxera (*Phylloxera notabilis*) offer suitable oviposition sites for hickory shuckworm (Dinkins and Reid, 1989). Trap catch for the remainder of 1988 and during the entire 1989 growing season averaged under 5 moths per trap per week (Figures 2 and 3). The seasonal pattern of trap catch was similar during both years. Within each year, male moths were captured most frequently during early spring and again in the fall. This pattern of moth flight does not agree with previously recorded data derived from light trap data collected in Kansas (Dinkins and Reid, 1988). The light trap data suggested three major flight periods, mid-May, early-July and late-August. This discrepancy between trapping methodologies may be explained by seasonal changes in the ratio of males to females. By sexing the moths captured in a light trap, Reid and Dinkins (1986) found

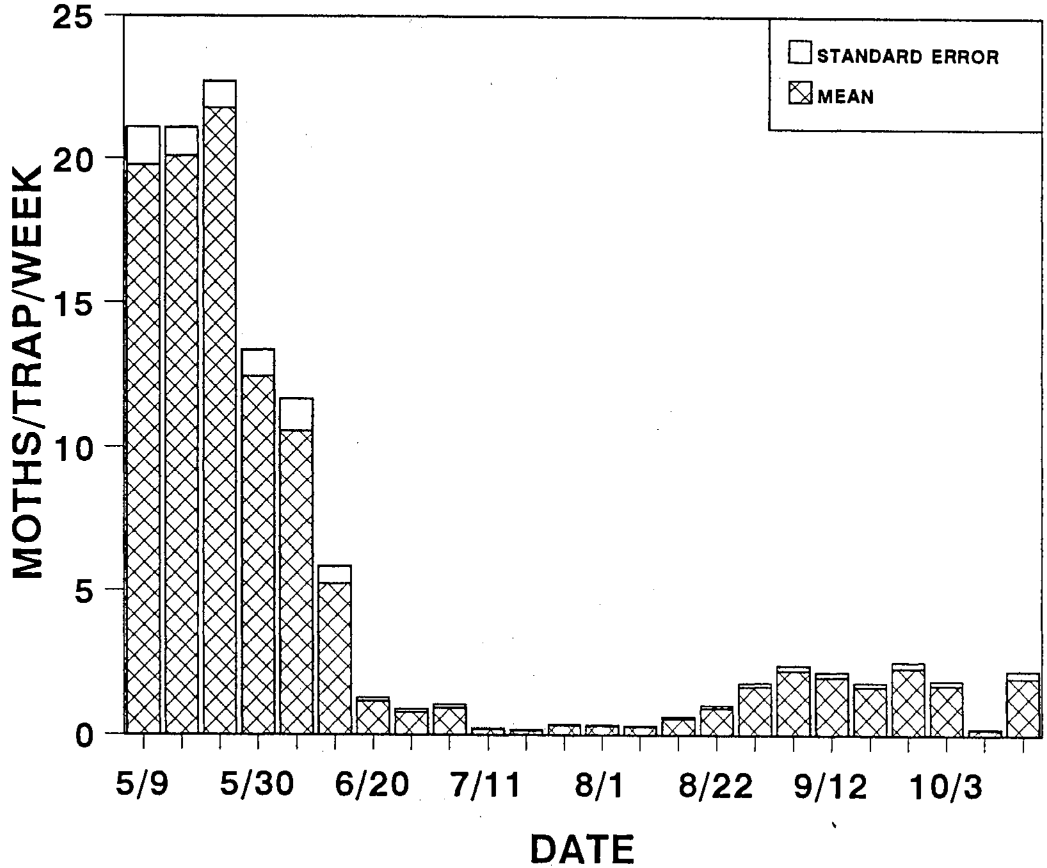

Figure 2. The Mean and Standard Error of the Number of Male Hickory Shuckworm Moths Captured in 146 Pheromone Traps Placed in a Pecan Orchard Near Faulkner, KS in 1988.

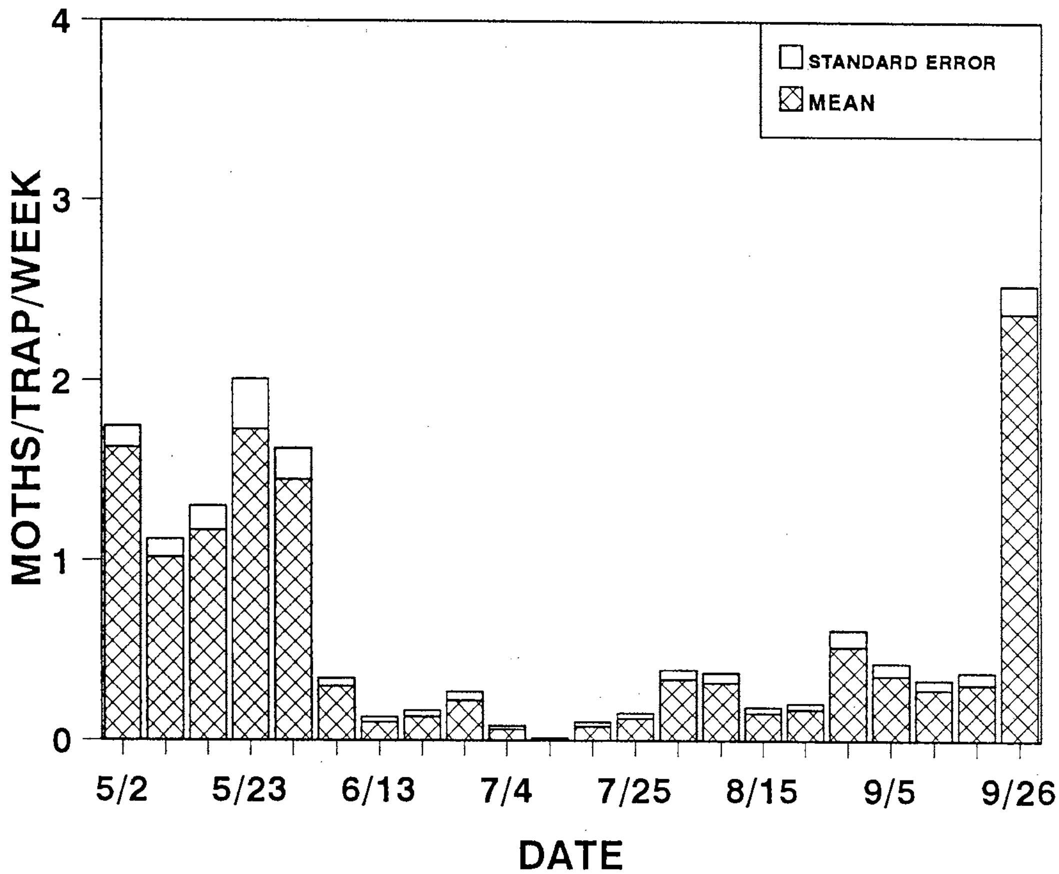

Figure 3. The Mean and Standard Error of the Number of Male Hickory Shuckworm Moths Captured in 146 Pheromone Traps Placed in a Pecan Orchard Near Faulkner, KS in 1989.

that the ratio of males to females changed seasonally (Figure 4). During the early spring (10 May to 6 June 1986) 2.15 males were captured for every female. During the summer (7 June to 15 August, 1986) the ratio of males to females decreased to 1.5. During the month of September, the ratio increased to 3.16 males for each female. Limited capture of male moths in pheromone traps during the summer might be explained by the inadequacy of the synthetic pheromone to compete with virgin females. During early spring and again in the fall the pheromone traps become more attractive to male moths when proportionally fewer virgin females are available for mating. Similar relationships between sex ratio and pheromone trap performance have been reported for several lepidopterous pests (Muirhead-Thomson, 1991).

Trees sustaining the greatest amount of larval damage in the fall of 1987 had the largest numbers of moths captured in pheromone traps during the first week of trap deployment in 1988 (Table I). The number of moths captured in subsequent weeks was not be related to the amount of the previous season's larval damage. Strong spring winds caused males to be blown from the trees where they over-wintered and to be redistributed in the orchard.

The number of moths captured in a pheromone trap during the late summer of 1988 could not be related to the damage level found in the same tree later that fall (Table II). Damage level is related to female behavior and a

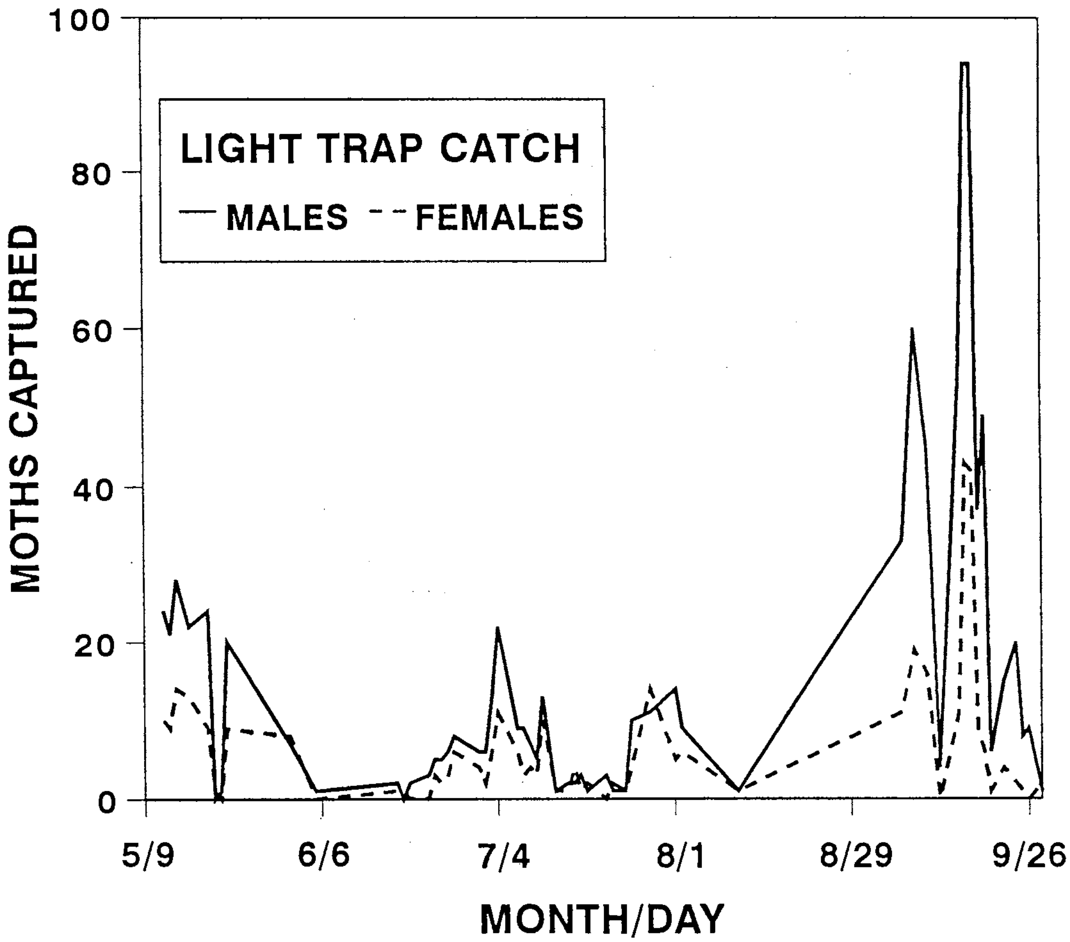

Figure 4. The Number of Male and Female Hickory Shuckworm Moths Captured in a Black Light Trap Located Near Faulkner, KS in 1986.

TABLE I.

A MEASURE OF THE RELATIONSHIP BETWEEN LARVAL DAMAGE LEVEL IN THE FALL OF 1987 AND THE CAPTURE OF HICKORY SHUCKWORM MOTHS IN PHEROMONE TRAPS DURING THE SPRING OF 1988

Date of Trap Reading	1987 Damage vs. 1988 Trap Catch[1]	
	Estimate of the Slope	Prob. > |T| for H0:Slope=0
9 May	0.30	.009
16 May	0.03	.748
23 May	0.07	.501
30 May	-0.11	.287
6 June	0.04	.717

1. Results of nonparametric regression analysis for the rank of 1987 larval damage level against the rank of 1988 moth catch.

TABLE II.

A MEASURE OF THE RELATIONSHIP BETWEEN THE CAPTURE OF HICKORY SHUCKWORM MOTHS IN PHEROMONE TRAPS DURING THE SUMMER OF 1988 AND LARVAL DAMAGE LEVEL IN THE FALL OF 1988

Date of Trap Reading	1988 Trap Catch vs. 1988 Damage[1]	
	Estimate of the Slope	Prob. > |T| for H0:Slope=0
15 August	-0.05	.496
22 August	-0.09	.193
29 August	-0.07	.288
5 September	-0.10	.132
12 September	-0.09	.132
19 September	-0.09	.253

1. Results of nonparametric regression analysis for the rank of summer moth catch against the rank of fall larval damage level.

direct relationship between the capture of males in pheromone traps and the incidence of larvae of the subsequent generation was not expected.

Test For Mating Disruption

The percentage of fruits infested with hickory shuckworm larvae in the pheromone test orchard and the companion orchard were similar (20.7% and 17.6% damage respectively, LSD(.05)=3.7). The distribution of damage in both the pheromone trap test orchard and the companion orchard was not significantly different from the negative binomial distribution (the observed chi-square (10 df) values of 14.5 and 8.0 respectively were not significant at the 5% level). The k values estimated by the method of moments were 2.96 for the pheromone trap test orchard and 2.77 for the companion orchard. The chi-square test for differences in probabilities revealed that the distributions were similar (the observed chi-square (10 df) of 8.85 was not significant at the 5% level). These results indicate that the behavior of female hickory shuckworm moths may not be altered by the removal of males captured by the pheromone traps placed in every tree in the orchard.

Influence of Larval Feeding on

Nut Quality

The percentage of shucks damaged per tree by hickory shuckworm larvae varied from 2% to 82% in the pheromone trap and companion orchards in 1988. The nuts collected from these same trees varied in percentage kernel from 31.7% to 53.9%. The number of nuts with damaged shucks was poorly correlated with kernel percentage (Prob.>F = .06, R^2=.026)(Figure 5). Shuckworm larvae may not pose a significant threat to kernel filling in the northern portions of the pecan native range, where pecans are adapted to a short season climate. Northern native pecans fill their kernels quickly, thus avoiding early fall frosts. In Kansas, shuckworm larvae may not grow fast enough to reduce the flow of carbohydrates to the seed (Reid and Eikenbary, 1991).

Estimating Optimum Sample Size

The number of moths captured per week in pheromone traps over the two year study period provided the mean and variance estimates necessary for the construction of sample size curves. Multiplicative models described the relationship between estimated sample size for a future study and mean moth catch (Figure 6). Regressions for each precision level explained 87% of the variation in the relationship between mean moth catch and estimated sample size (number of traps per hectare).

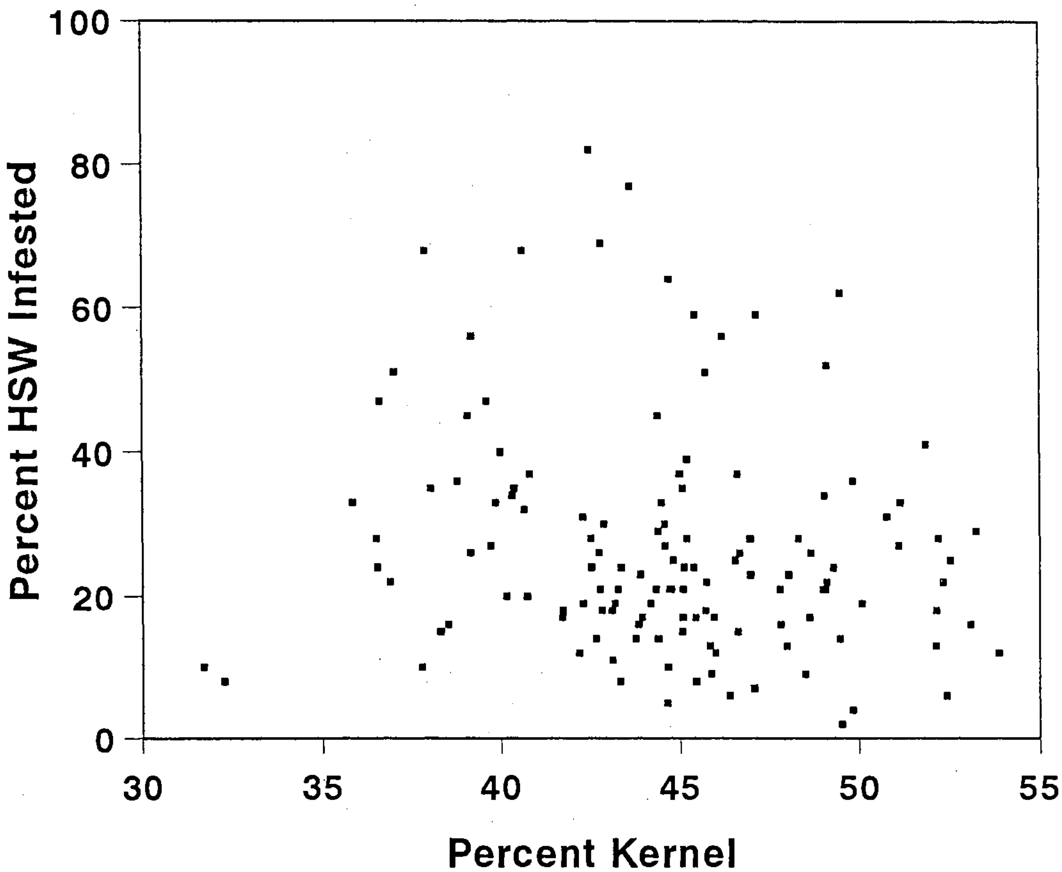

Figure 5. Hickory Shuckworm (HSW) Infestation Was Poorly Correlated With Percent Kernel for 167 Pecan Trees Growing Near Faulkner, KS.

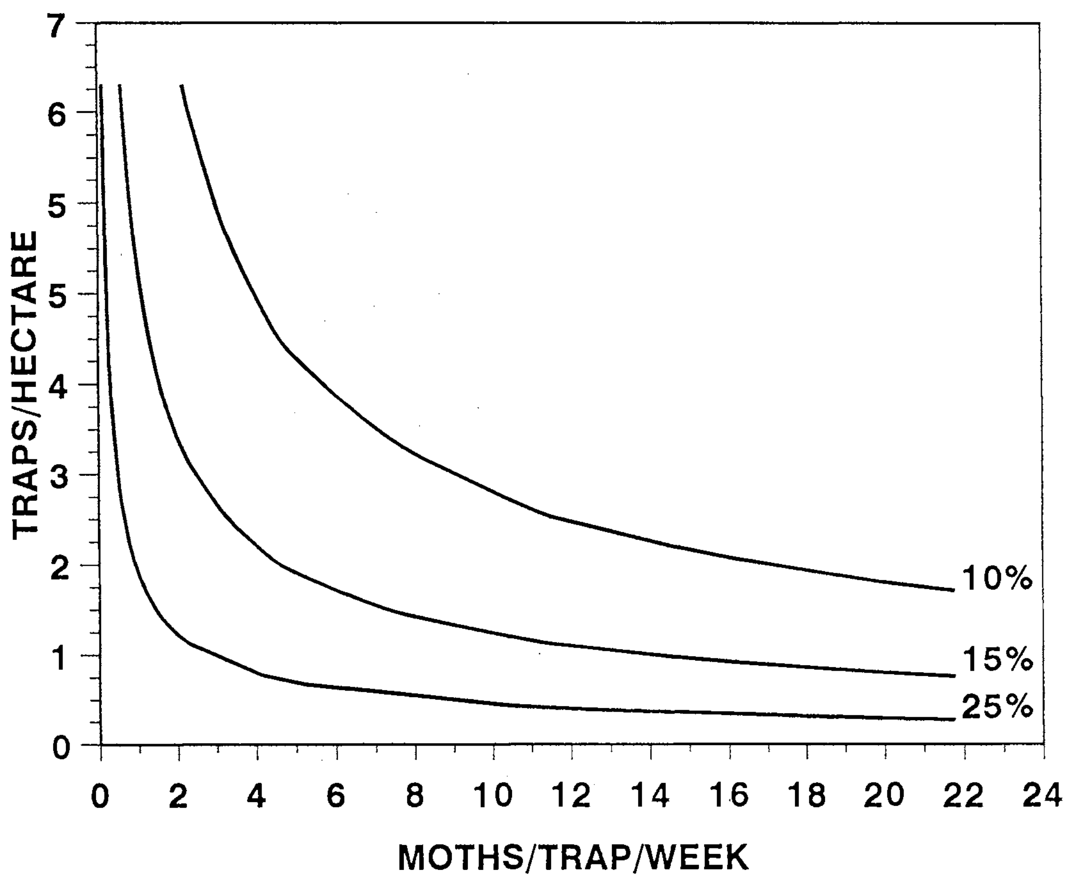

Figure 6. The Number of Pheromone Traps Needed per Hectare to Estimate the Mean Number of Moths Captured per Trap Per Week at Three Levels of Precision (CV = 10, 15, or 25 % of the Mean). R^2 for each regression was 0.87.

The number of traps that could be deployed in the pheromone trap orchard was limited by the number of trees in the orchard (22 trees/ha). Growers should balance the cost of deploying and monitoring a trap with the precision that a certain number of traps can provide. If large numbers of moths are caught, one to two traps per hectare can provide an estimate of mean moth catch per week with a CV of 25% of the mean. This level of precision is commonly used in integrated pest management systems for making insect control decisions (Metcalf and Luckmann, 1982). However, during the critical summer moth flights, very few moths were captured. In addition, mid-summer population increases were not identified by trapping at a density of 22 traps/ha (a trap in every tree). The hickory shuckworm pheromone, in its current, single-component form, must be improved to increase mid-summer trap catch for it to become a useful pest management tool.

Determining Sampling Method

Spatial analysis was limited to 1987 larval damage levels and to the first five weeks of trap catch data in 1988. These data sets provided ample non-zero data points for the unbiased estimation of variograms.

The shape of the variograms for 1987 larval infestation level (Figure 7) and pheromone trap catch from the first week of 1988 (Figure 8) were similar. Variogram estimators for both these response variables increased

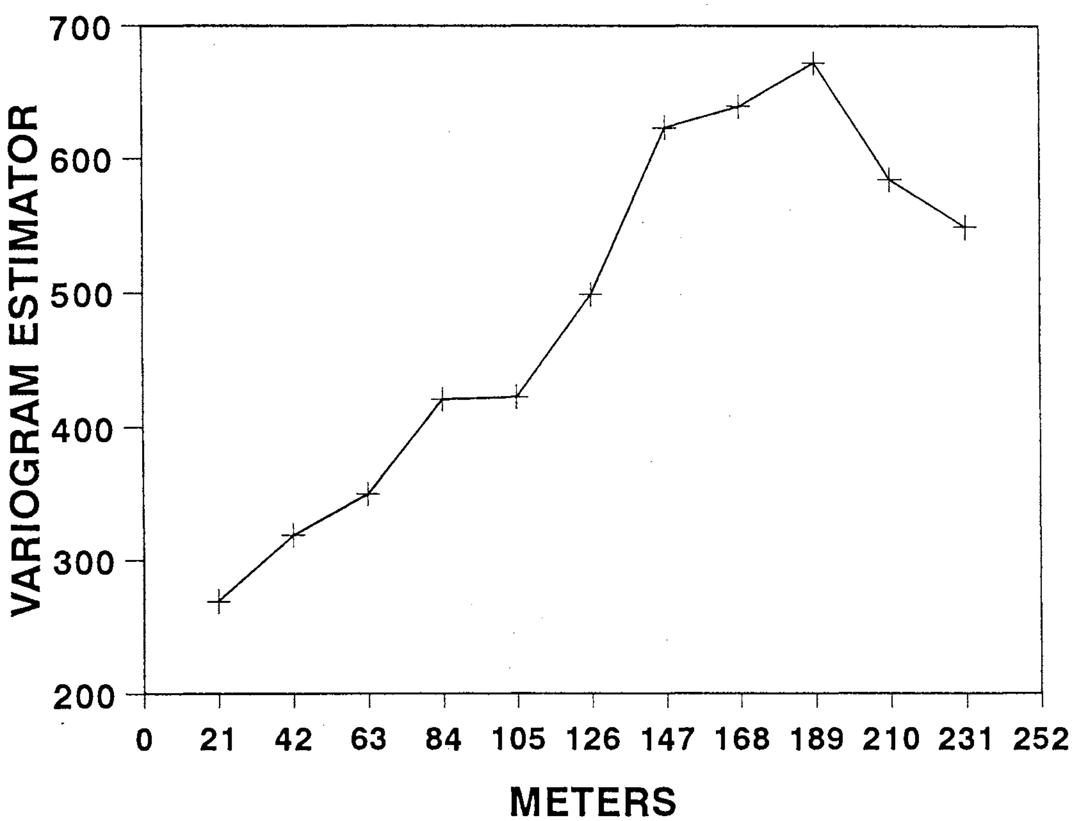

Figure 7. Estimated Variogram for the Distribution of Larval Infestation in 1987.

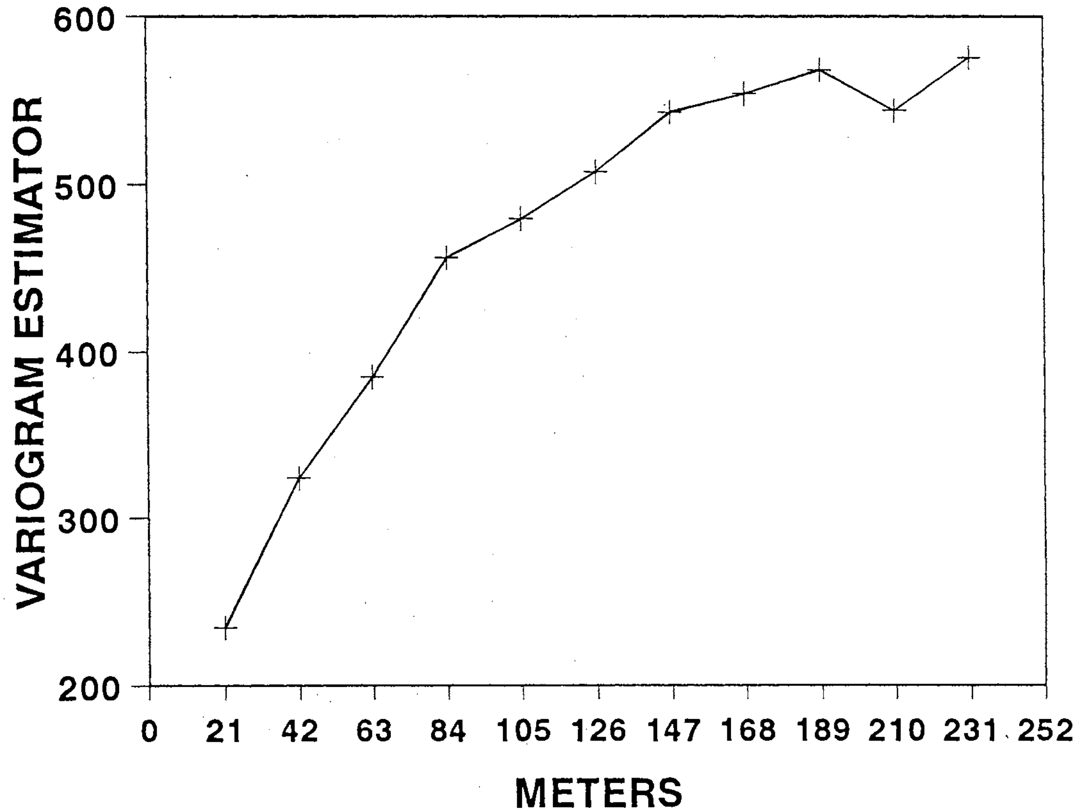

Figure 8. Estimated Variogram for the First Week of Trap Catch in 1988.

steadily with increasing distance before reaching a sill at about 147 m. Variograms of this shape have been associated with populations of organisms that are loosely aggregated (Chellemi et al., 1988). This observation was verified by estimating of the traditional measure of spatial clustering, the parameter k (Southwood, 1978). The k value estimated by the method of moments (Southwood, 1978) was 2.97 for 1987 larval infestation, and 4.50 for the first week's trap catch. Southwood (1978) stated that as k increases from 2 to infinity the distribution of insects increases from aggregated to random.

The variogram for the third week of trap catch was representative of variogram estimates for the second through fifth week of pheromone trap catches. Variogram estimators for the third week of trap catch increased with distance and did not reach a sill (Figure 9). Variograms of this shape are associated with organisms having a strongly aggregated distributions (Chellemi et al., 1988) The k parameter for the third week of trap catch was estimated by the method of moments to be 1.38 indicating a high degree of aggregation (Southwood, 1978). Changes in the spatial nature of the number of moths captured in pheromone traps were independent of the total trap catch. Mean trap catch for the first three weeks of trapping was nearly equal in 1988 (Figure 2) yet their variograms indicated differences in spatial arrangement. These differences have a logical biological explanation in terms

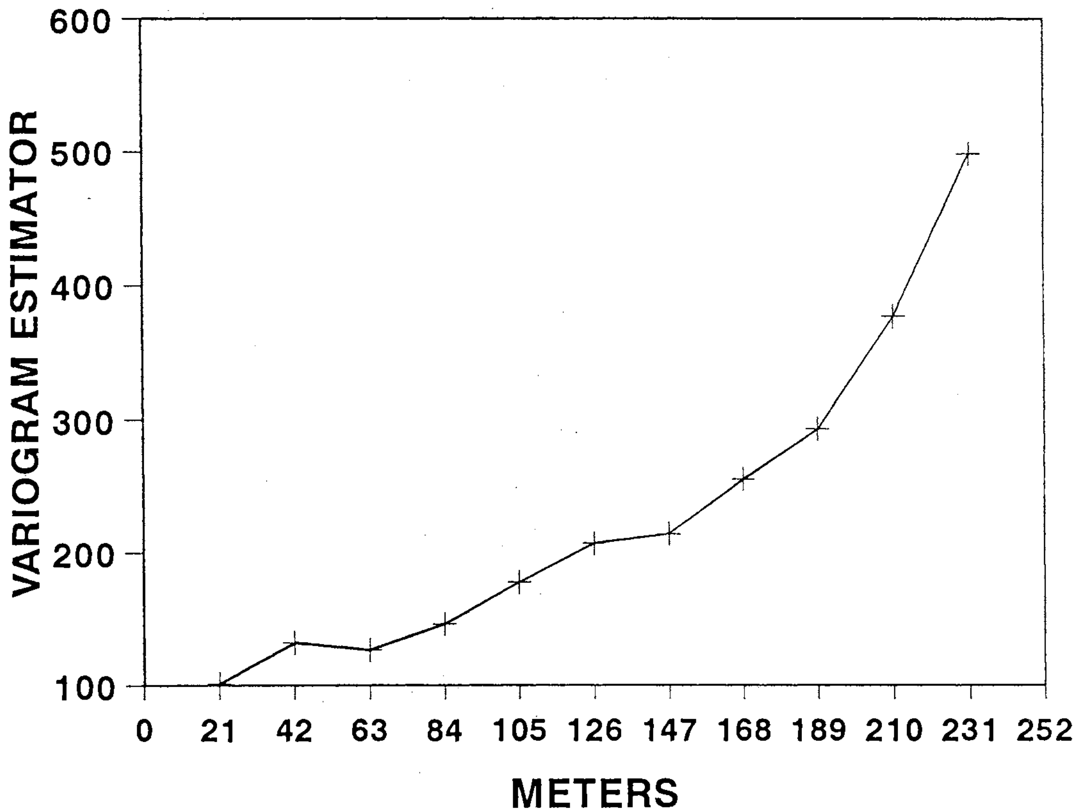

Figure 9. Estimated Variogram for the Third Week of Trap Catch in 1988.

of the life cycle of the hickory shuckworm. Female hickory shuckworm moths seek suitable oviposition sites during late summer. These females only lay eggs in fruit that have not been used previously as an oviposition site. This ensures that egg laying and the subsequent distribution of larvae are widely distributed. As the spring emergence period begins, trap catch reflects the emergence of moths from overwintering shucks. These shucks are widely dispersed throughout the orchard. Once the spring flight has begun, moths are redistributed in the orchard by wind. Wind aided dispersion leads to the concentration of insects in certain sections of the orchard .

Directional variograms for the third and fourth week of trap catch were very similar (Figures 10 and 11) and were used to determine the shape and size of strata for taking a stratified random sample. These variograms were chosen based on the result of spatial analyses performed on trap catch data for the remainder of the year. The spatial nature of the trap catch data did not change past the second week of trapping.

The directional variograms indicated that variance increased with distance most rapidly in the northwest to southeast (NW-SE) direction. In NW-SE direction, variance estimates were similar for the first 84 to 105 m before increasing sharply (Figures 10 and 11). Effective stratification relies on minimizing variance between units within a strata (Cochran, 1977). The directional variograms

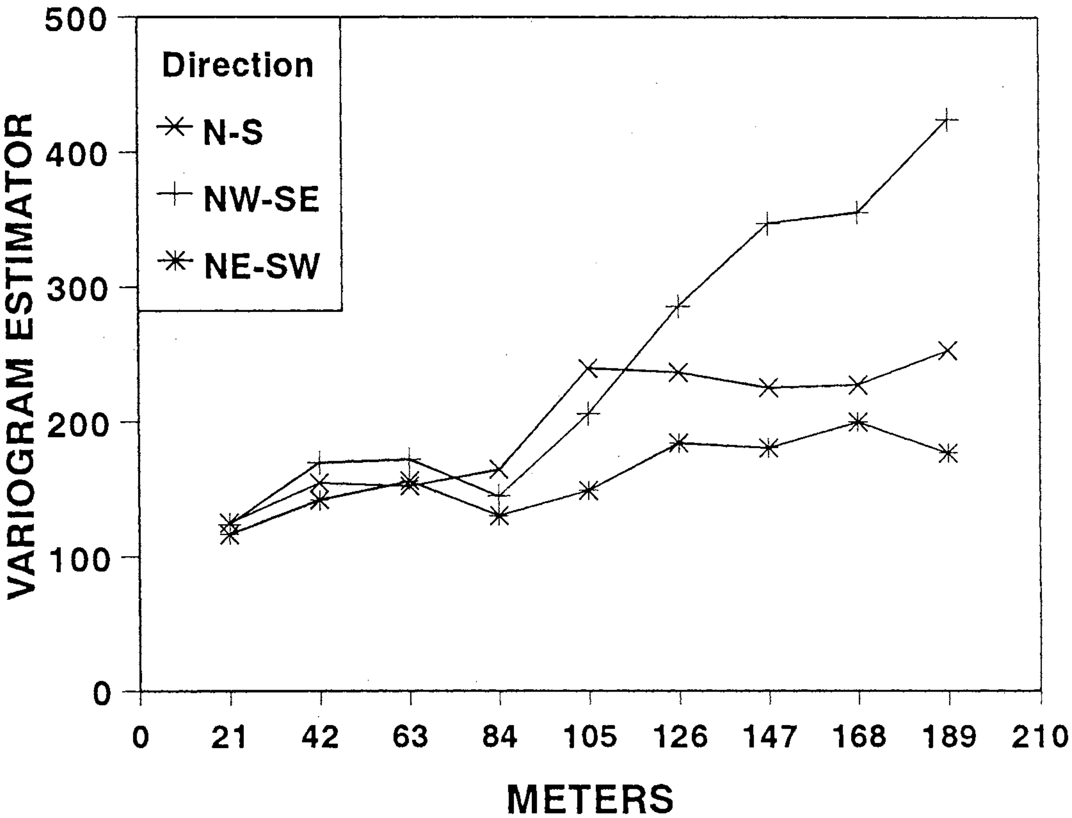

Figure 10. Estimated Directional Variograms for the Third Week of Trap Catch.

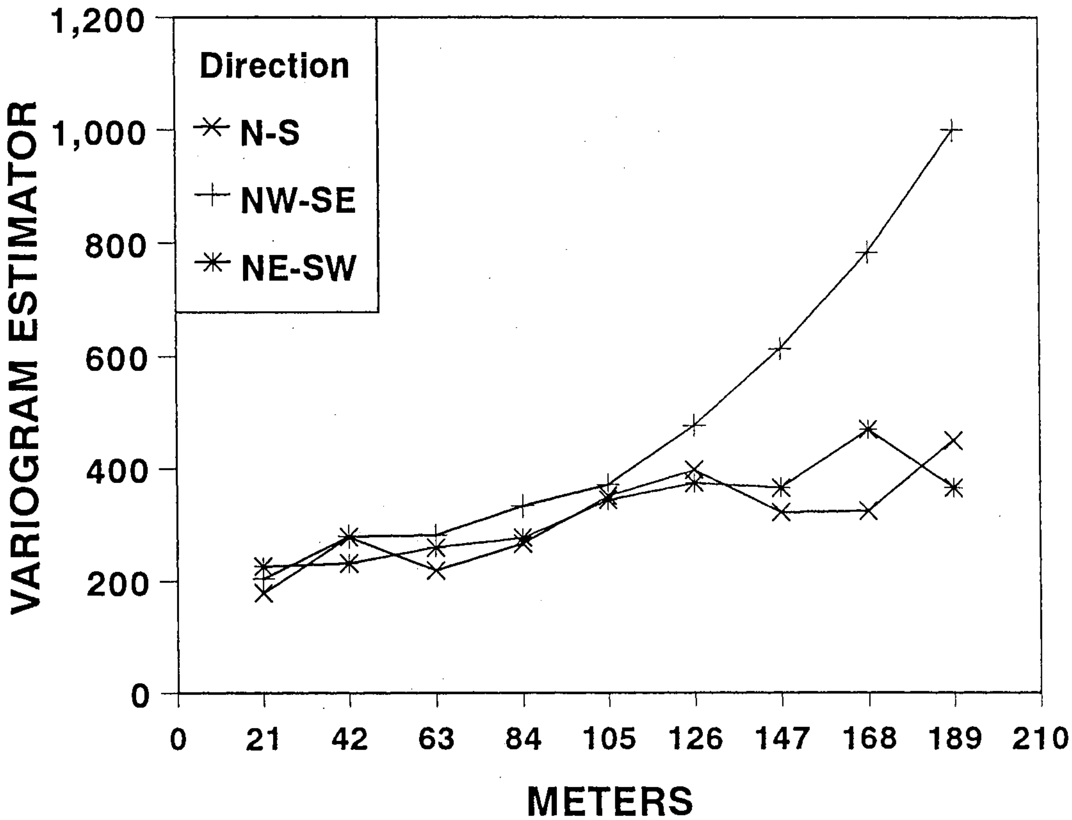

Figure 11. Estimated Directional Variograms for the Fourth Week of Trap Catch.

indicate that strata should be no wider than 5 tree rows in the NW-SE direction. To construct strata in the pheromone test orchard, the orchard was divided into 3 sections, each 5 rows wide, in the NW-SE direction. To create strata with nearly equal numbers of trees, two of the sections were divided in half to define 5 strata. The arrangement of strata is given in Figure 12.

Estimated design efficiency values indicated that stratification consistently reduced the estimates of the variance of mean trap catch for the whole orchard for only the first week of trapping (Prob.>|T| = 0.0001) (Table III). During subsequent weeks, stratification increased the estimate of the variance almost as frequently as it decreased the estimate of the variance. As mentioned earlier, the first week's trap catch was less aggregated than in subsequent weeks. Stratification increased the precision of the estimate of mean trap catch during the first week because the variation within the strata was less than the variation between strata. The increase in aggregation in trap catch observed during subsequent weeks caused the variation within a strata to become as great as the variation between strata, eliminating the advantages of the stratification process.

Obtaining a precise estimate of insect populations in a native pecan orchard can be extremely costly and time consuming. The results of this study indicate that native pecan growers should deploy no fewer than 2 traps/ha for a

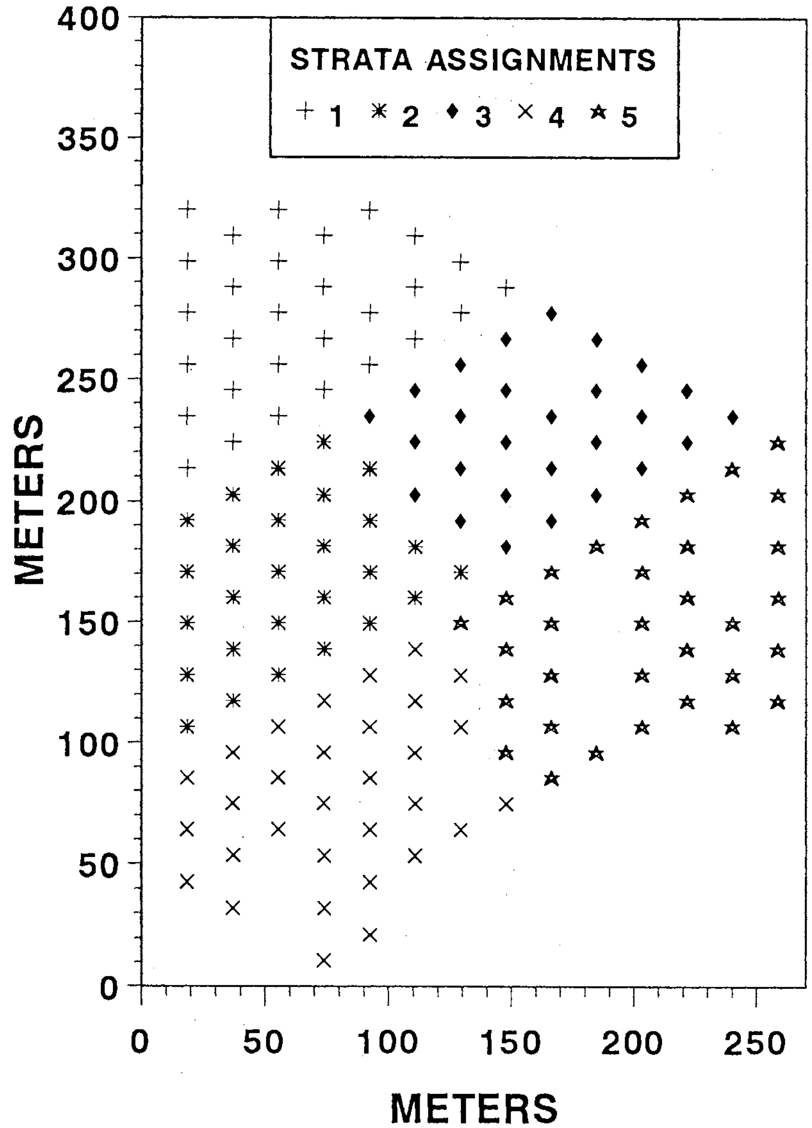

Figure 12. The Pheromone Trap Orchard Divided into Five Strata.

TABLE III.

THE RANGE AND MEAN OF DESIGN EFFICIENCY ESTIMATES FOR TRAP CATCH DATA COLLECTED OVER TWENTY-FOUR WEEKS IN 1988

Week	Trap Count Mean	Design Efficiency			
		Minimum	Maximum	Mean	Prob.>|T|[1]
1	19.78	0.244	0.955	0.599	0.0001
2	20.10	0.481	1.413	1.066	0.3622
3	21.77	0.126	1.648	0.874	0.3353
4	12.47	0.061	1.502	0.976	0.5317
5	10.59	0.165	1.490	0.912	0.8546
6	5.24	0.633	1.264	1.011	0.8098
7	1.16	0.550	1.533	1.099	0.2393
8	0.78	0.302	1.431	0.887	0.2935
9	0.92	0.292	1.379	0.857	0.1581
10	0.21	0.0	1.339	0.973	0.8308
11	0.15	0.919	1.217	1.099	0.0101
12	0.33	0.255	1.514	1.041	0.6554
13	0.30	0.0	1.174	0.908	0.3455
14	0.28	0.458	1.407	1.107	0.1762
15	0.57	0.238	1.304	0.812	0.1282
16	0.92	0.421	1.381	0.948	0.4828
17	1.66	0.092	1.452	0.956	0.6947
18	2.22	0.401	1.505	1.041	0.6568
19	1.99	0.248	1.452	0.966	0.7836
20	1.65	0.294	1.584	1.115	0.2732
21	2.30	0.602	1.305	0.969	0.6130
22	1.71	0.095	1.497	0.981	0.8768
23	0.19	0.756	1.145	0.995	0.8910
24	1.96	0.311	1.468	0.924	0.4539

1. Prob.>|T| under the hypothesis that the design efficiency equals 1.

precise assessment of hickory shuckworm activity. A random sampling scheme should be used for determining the location of traps in the orchard.

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CHAPTER IV

TIME OF FRUIT REMOVAL INFLUENCES RETURN BLOOM IN PECAN

Introduction

Pecan trees exhibit a strong tendency towards alternate or irregular bearing (Wood, 1991). An excessive fruit load one year precedes a year of little or no crop. Pecan growers suffer economic losses in both "on" and "off" years. During the "on" year, overcropping results in poor nut fill and kernel quality, often to the point of making the nuts unmarketable (Reid, 1986). Further, overcropping reduces cold hardiness, often leading to shoot dieback or even tree death (Smith and Cotten, 1985; Wood, 1986). Returns from low yields during "off" years frequently do not offset production and harvesting costs.

The depletion of carbohydrate reserves by a heavy crop load has been suggested as the sole trigger for the alternate bearing pattern in pecan (Davis and Sparks, 1974). Wood (1991) hypothesized that, without sufficient carbohydrates, a pecan terminal cannot initiate female flowers. Other workers have suggested a more complex regulatory mechanism for flower initiation that involves both a threshold level of storage carbohydrates and the appropriate balance of endogenous phytohormones (Smith et al., 1986; Worley, 1979). Although the question of how a pecan crop influences return bloom is still being debated, it is clear that heavy cropping inhibits the subsequent season's pistillate flower production. Thinning a heavy pecan crop has improved return bloom (Smith and Gallott, 1990) but the optimum time for fruit thinning has not been established. This study was initiated to help define the optimum time for fruit thinning.

Methods and Materials

The influence of time of fruit removal on return bloom of pecan was studied using two experiments conducted from 1988 through 1990. Although the site and experimental design differed from year to year, treatments for both experiments were identical. Fruit were removed at five different times during the season based on fruit phenological age. Fruits were removed immediately following post pollination drop, at 50% ovule expansion, at 100% ovule expansion or water stage (liquid endosperm), during the onset of the dough stage (deposition of cotyledonary storage carbohydrates), and two weeks after the onset of the dough stage. Treatments were applied by removing all nuts from a large pecan limb by hand. A treatment with all fruit retained served as a control.

Both studies involved the application of two or more treatments to a single tree. This 'split-tree' technique was employed to help separate the effects of seedling rootstock variation from treatment effects. Rootstock can influence alternate bearing (Sitton and Dodge, 1938) and has been linked to genetic differences in carbohydrate storage capacity among rootstocks (Wood, 1989). The split-tree approach has been successfully employed in other studies of alternate bearing in fruit trees (Monselise and Goldschmidt, 1982) and was proposed as a viable method for pecan (Wood, 1991). Radiographic studies indicated that carbohydrate translocation in pecan and redistribution is restricted such that units within a mature tree are independent of the tree as a whole (Lockwood and Sparks, 1978). Therefore, the application of treatments to large limbs should prove useful approach for studying alternate bearing in pecan.

All trees used in these experiments received recommended levels of pest control and fertilization (Reid, 1992b; Taylor et al., 1992; von Broembsen et al., 1992). All data collected in these experiments were analyzed using SAS (1988) to calculate means ± SE. The GLM procedure (SAS, 1988) was used to perform analysis of variance and regression analyses.

<u>Adair 1988</u>

Seven 'Mohawk' pecan trees were selected in 1988 from a commercial pecan orchard located in northeastern Oklahoma near Adair. Trees were uniform in size (avg. DBH=32.2 cm) and approximately 95% of their shoots were bearing pistillate flowers. Fruit development was monitored on each of two trees to time treatments on a phenological scale. A sample of 20 fruits was collected from these trees each week, dissected, and rated for stage of fruit development.

Six scaffold limbs (avg. diameter=8.6 cm) were selected on each of the remaining five trees for the application of the five fruit removal treatments and the control in this randomized complete block experiment. Twenty-five fruiting shoots, each supporting four fruit, were tagged on each limb following post-pollination fruit drop. Fruit were removed by hand from the entire limb on the specified treatment date. Fruit removal dates were 13 June 1988, 8 Aug. 1988, 22 Aug. 1988, 12 Sept. 1988, and 26 Sept. 1988 Treatment effects were evaluated the following growing season. The number of flowers and new shoots produced by tagged shoots were counted on 31 May 1989 and the number of fruits set were counted on 15 June 1989. .

<u>Chetopa 1989</u>.

Seventeen 'Giles' pecan trees were selected in 1989 from an orchard located on the Pecan Experiment Field near Chetopa in southeastern Kansas. Trees were uniform in size (avg. DBH=26.1 cm) and approximately 90% of their shoots were bearing pistillate flowers. Once again, fruit from two trees were collected weekly to determine development stage by using the same methods as described above. Four scaffold limbs (avg. diameter=8.2 cm) were selected on each of the remaining 15 trees to serve as the experimental units. Four of the six treatments were applied to each tree in a balanced incomplete block experimental design (Cochran and Cox, 1957). This experimental design resulted in each treatment being replicated 10 times.

Twenty-five fruiting shoots, each bearing three nuts, were tagged on each limb in a manner similar to that used in the previous experiment. The methods for treatment application and response measurements were also identical. Nut removal dates were 21 June 1989, 1 Aug. 1989, 22 Aug. 1989, 5 Sept. 1989, and 19 Sept. 1989. The number of flowers and new shoots produced by tagged shoots were counted on 23 May 1990 and the number of fruits set were counted on 20 June 1990.

Results

Adair 1988.

The number of fruiting shoots and fruit set in 'Mohawk' pecan was improved by the removal of fruit during the period of ovule expansion (the time from pollination to 100% ovule expansion)(Table I). Fruit removal shortly after pollination stimulated the greatest amount of return bloom and fruit set. Once the process of kernel deposition began, fruit removal had a rapidly decreasing influence on return bloom. The relationship between time of defruiting and the subsequent year's return bloom can be expressed by two

TABLE I.

THE INFLUENCE OF FRUIT REMOVAL TIME ON THE NUMBER OF FLOWERING SHOOTS AND FRUIT PER TERMINAL (MEAN±SE) ON 'MOHAWK' PECAN IN THE YEAR FOLLOWING FRUIT REMOVAL.

Fruit development stage at time of fruit removal	Flowering shoots/ 1-yr-old shoot	Fruit per terminal
Post-pollination	0.59 ± 0.05	1.44 ± 0.15
1/2 ovule expansion	0.39 ± 0.05	0.97 ± 0.15
Water stage	0.43 ± 0.05	1.05 ± 0.14
Dough stage	0.10 ± 0.04	0.23 ± 0.08
2 wks. after dough stage	0.04 ± 0.02	0.05 ± 0.04
Shucksplit	0.00 ± 0.00	0.00 ± 0.00

regression equations: the first describes the relationship when limbs were defruited during the period of ovule expansion, and the second describes the relationship when limbs were defruited during kernel deposition and fruit maturation. During ovule expansion, the regression of time of defruiting on the subsequent year's production of flowering shoots and fruit failed to identify a significant linear or quadratic trend. In contrast, regression equations could be used to describe the rapid decrease in number of fruiting shoots and fruit produced by limbs defruited the previous year during the period from 100% ovule expansion to shuck dehiscence. The reciprocal transformation of the variable, time of defruiting, was used in the regression analysis. Two regression equations were found to describe influence of time of defruiting on the number of fruiting shoots and fruit produced in the year following defruiting: Number of flowering shoots = $1.01 - (39.9*Z) + (396.8*Z^2)$ [Pr.>F = 0.0001] and number of fruit per terminal = $2.8 - (110.1*Z) + (1061.9*Z^2)$ [Pr.>F = 0.0001], where Z equals the reciprocal of time of defruiting measured in weeks from pistillate flower receptivity.

The number of new shoots (both vegetative and flowering) produced by each terminal branch was not influenced by the previous season's fruit-removal treatments (data not shown).

<u>Chetopa 1989</u>

Removal of fruit shortly after the post-pollination drop promoted the greatest amount of return bloom in 'Giles' pecan trees. Once fruit entered the period of kernel deposition, the number of flowering shoots and fruit produced in the subsequent year decreased rapidly (Table II). Two sets of regression equations were used to describe the relationship between defruiting and the subsequent year's flowering and fruiting. During ovule expansion, both the number of fruiting shoots and fruits per terminal decreased linearly as the time of defruiting advanced (fruiting shoots = 1.48 - (0.013*X), [Pr.>F = 0.0126] and fruit per terminal = 2.29 - (0.029*X), [Pr.>F = 0.0255], where X = time of defruiting during the period of ovule expansion measured in weeks after pistillate flower receptivity). However, time of defruiting explained less than 25% of the variation in numbers of fruiting shoots and fruit borne by limbs defruited the previous season during ovule expansion.

Additional regression equations could be used to describe the rapid decrease in number of fruiting shoots and fruit produced by limbs defruited the previous year during the period from 100% ovule expansion to shuck dehiscence. The reciprocal transformation of the variable, time of defruiting, was used in the regression analysis. Two regression equations were found to describe influence of time of defruiting on the number of fruiting shoots and

TABLE II

THE INFLUENCE OF FRUIT REMOVAL TIME ON THE NUMBER OF FLOWERING SHOOTS AND FRUIT PER TERMINAL (LEAST SQUARE MEAN±SE) ON 'GILES' PECAN IN THE YEAR FOLLOWING FRUIT REMOVAL.

Fruit development stage at time of fruit removal	Flowering shoots/ 1-yr-old shoot[z]	Fruit per terminal[z]
Post-pollination	0.44 ± 0.02	1.20 ± 0.06
1/2 ovule expansion	0.33 ± 0.02	0.99 ± 0.06
Water stage	0.36 ± 0.02	1.01 ± 0.06
Dough stage	0.13 ± 0.02	0.35 ± 0.06
2 wks. after dough stage	0.06 ± 0.02	0.18 ± 0.06
Shucksplit	0.01 ± 0.02	0.04 ± 0.06

[z] Least squares means

fruit produced in the year following defruiting: Number of flowering shoots = 1.2 - (44.4*Z) + (406.6*Z^2) [Pr.>F = 0.0001] and number of fruit per terminal = 3.27 - (120.4*Z) + (1116.2*Z^2) [Pr.>F = 0.0001], where Z equals the reciprocal of time of defruiting measured in weeks from pistillate flower receptivity.

Fruit removal treatments did not influence the number of new shoots (both vegetative and fruiting shoots) produced on one-year-old wood (data not shown).

Discussion

Alternate bearing in many fruit tree species can be moderated by the removal of a portion of the crop during "on" years (Monselise and Goldschmidt, 1982). Fruit thinning can reduce alternate bearing in pecan (Crane et al., 1934; Smith and Gallott, 1990; Wood, 1983), and the studies reported here indicate that the optimum time for fruit thinning is during the period of ovule expansion. In apple, fruit thinning during or shortly after bloom promotes the greatest return bloom (Williams, 1979). 'Mohawk' and 'Giles' pecan trees behave similarly, with the greatest return bloom measured on shoots defruited shortly after pollination. However, regression analysis revealed no strong advantage for early defruiting over defruiting later in the ovule expansion period.

'Mohawk' and 'Giles' pistillate flower production, even on limbs receiving the earliest fruit-removal treatment, was below the level needed to produce a full crop the following year. Extremely low temperatures (-24C on 12 Dec. 1988 and -29C on 20 Dec. 1989) injured the cambium of 'Mohawk' and 'Giles' trees during the winter after fruit removal treatments. Cold injury can weaken spring shoot growth (Wood, 1986) and decrease subsequent pistillate flower production (Reid, 1992a).

Thinning pecan fruits is a viable approach for the control of alternate bearing. These studies indicate that fruits must be thinned before kernel deposition starts to enhance return bloom. However, two additional problems must be solved before pecan fruit thinning becomes commercially feasible--how to thin and how much to thin.

Two approaches to pecan fruit thinning have been suggested. For high-value, large-fruited pecan cultivars, mechanical tree shaking has shown potential for fruit thinning (Smith and Gallott, 1990). For low-value native pecans, a low-input strategy for reducing alternate bearing has been suggested (Reid and Eikenbary, 1990). This low-input strategy involves the careful balancing of crop load and insect induced fruit drop. Both fruit thinning techniques need further refinements.

The maximum fruit load a tree can bear without inducing yearly fluctuations in yield, kernel quality, and return bloom has not been determined. Preliminary studies indicate that optimum fruit load varies with cultivar (Smith et al., 1993)

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Doctor of Philosophy

Thesis: DEVELOPING LOW-INPUT MANAGEMENT STRATEGIES FOR NATIVE PECANS

Major Field: Entomology

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