ECONOMIC EVALUATION OF THE PRUNING FREQUENCY OF PECANS

By

Placide Hiol

A Thesis Submitted to the Faculty of the

DEPARTMENT OF AGRICULTURAL AND RESOURCE ECONOMICS

In Partial Fulfillment of the Requirements

For the Degree of

MASTER OF SCIENCE

In the Graduate College

The University of Arizona

2013

STATEMENT BY AUTHOR

This thesis has been submitted in partial fulfillment of requirements for an advanced degree at the University of Arizona.

Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgement of source is made. Requests for permissions for extended quotation form or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the Dean of the Graduate College when in his or her judgment the proposed use of the material is in the interest of scholarship. In all other instances, however, permission must be obtained from the author.

SIGNED: ______________________

APPROVAL BY THESIS DIRECTOR

This Thesis has been approved on the dates shown below

Russell Tronstad ______________________ 7-1-13 __________

Russell Tronstad
Professor of Agriculture and Resource Economics

Date

ACKNOWLEDGEMENTS

I would to thank first my advisor, Professor Russell Tronstad. Without his support and guidance, the fulfillment of this research would have not been possible. He has been an extraordinary mentor who helped me grow professionally and personally this past year. I am very thankful for the opportunity he gave me to pursue this applied research.

I would also thank my committee members, Professors Gary Thompson and Jim Walworth. I am grateful for the dataset Professor Walworth provided and the econometric modeling support provided by Professor Thompson. I am also thankful for their willingness and availability anytime I had questions.

I would also like to acknowledge the incredible support I have gotten from the Green Valley Pecan Company (GVPC) especially from sales VP Bruce Caris and the Plant manager Brenda Lara. Their willingness in providing insight about the pruning and processing of pecans strengthened my knowledge of pecan farm management.

Finally, I would like to present my gratitude to my AREC Master Degree colleagues, the AREC department.

DEDICATION

To my lovely family and my fiancée Hortensia Lobe

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Employing a simultaneous equation model applied to panel pecan data, the study presents a model to quantify the profitability of different annual pecan pruning frequencies. Production data estimated are from The Green Valley Pecan Company (GVPC) located in Sahuarita, Arizona, which started a pruning program 9 years ago. Profit maximization is attained where the value of the marginal productivity exceeds or equals the marginal cost for discrete annual increments. The simultaneous model transposes two major variables: yield and quality. A simultaneous model was utilized to evaluate the tradeoff of pecan yield and quality by computing the marginal productivity of pruning frequency. After estimating the simultaneous design by three stages least squares (3SLS) and progressively adding covariates, we found that the tradeoff between yield-quality and the pruning frequency coefficient were all significant and appropriate to be used in the computation of marginal productivities. The marginal cost was obtained by adding both pruning and processing costs. Optimal pruning frequencies were identified for two price scenarios using the value marginal product marginal cost (VMP-MC) condition where the marginal cost equals the marginal productivity for the Wichita and Western Schley varieties. Under the low (high) price scenario, the optimal pruning frequency is every three (four) years for both varieties.

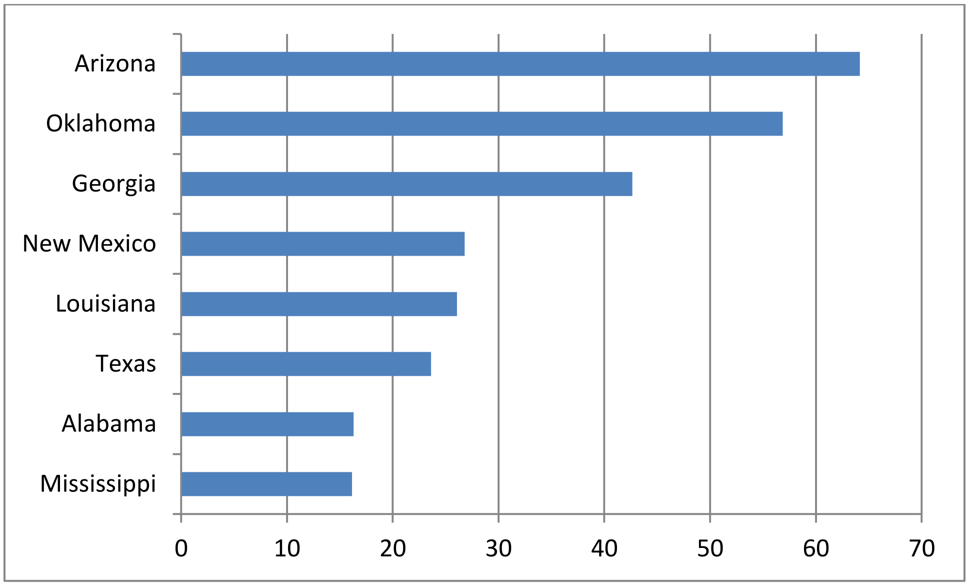
CHAPTER 1: INTRODUCTION

The pecan, *Carya illinoensis*, is a member of the plant family *Juglandaceae*. This family includes walnuts and hickories. Brison (1974), in *Pecan Culture* writes that the pecan is the most important native horticultural crop to the United States. The pecan is a large tree, often growing to 100 feet in height or more and has a stately appearance. It is the state tree of Texas.

1.1. The pecan market in the US

Pecans are the only tree nut native to North America. It is a significant contributor to the agricultural economy in 24 out of 50 states in the U.S. . Pecan production is typically partitioned into four production regions: southeast (Georgia, Florida South Carolina., North Carolina, Virginia, Alabama, Mississippi, Louisiana, and Arkansas), south-central (Texas and Oklahoma), northern (Tennessee, Kentucky, Indiana, Illinois, Iowa, Nebraska, Missouri, and Kansas), and southwestern (New Mexico, Arizona, California, Utah and Nevada). Pecan production practices tend to be similar among these different regions. The U.S. has an estimated 19,900 pecan farms. Most of these (62%) manage more than 15 acres of orchards. There are 905 (5.4%) farms managing more than 100 acres and 124 (0.7%) managing more than 500 acres of trees (Wood, 2000).

Figure 1: Average pecan acreage per farm



Worldwide pecan production generally exceeds 250 million pounds of nuts per year. The pecan has been introduced to foreign countries such as Israel, South Africa, Brazil, and Australia, as well as states on the Eastern Seaboard.

1.2. Characteristics of pecan production

Pecan trees, native or improved, are cultivated subject to specific characteristics that can be different across regions or countries.

a. Site and soil

Pecans grow best in alluvial (riverbed) soils that are deep and well drained. However, pecans can be grown in any soil that allows water penetration to a depth of four to five feet or more. Water should be able to move down through the soil (drainage) at a reasonable rate and the soil should not have any layers which would prevent water from draining downward (University of Georgia Pecan Team, 2005). Poor drainage will result in poor root development which may result in tree death. The majority of pecan roots will be in the top three to four feet of soil. The root system width will be four or more times as wide as the tree canopy.

b. Tree training

Many consistently bearing and high yielding pecan varieties like Desirable and Cape Fear are susceptible to limb breakage, particularly during high winds, as a result of weak crotch angles. Proper training of young trees facilitates the development of a strong framework necessary to support wood growth, crop load and prevent limb breakage (University of Georgia Pecan Team, 2005).

c. Fertilization

Pecan production requires standard inputs such as fertilizers and pesticides. Fertilizers, including trace elements can enhance yields and compensate for deficiencies in soil productivity detected through soil and leaf analysis. Pesticides are especially important for some regions as pecan trees are attacked by several diseases and are commonly infested by insects that can inflict catastrophic damage to the crop volume and quality. Pecan trees are attacked by fungi such as scab (University of Georgia Pecan Team, 2005), so fungicide treatments must be applied on a regular basis in orchards to control fungal diseases which can interfere with the photosynthesis responsible for the enlargement and filling of nut kernels.

d. Watering

Irrigation is used throughout the southwest to maintain soil moisture in order to achieve optimal yield and nut quality. Poor water management can lead to several issues such as poor leaf color, summer water stress and fall stick tights.

e. Alternative Bearing

Alternate bearing is a major problem faced in pecan production and occurs when a large crop is followed by one or more years of low to no crop (Florkowski & Elnagheeb, 1993).

1.3. What is Pecan Pruning?

Unlike fruit trees, pecans do not require early pruning; in many cases the pruning is only done when the tree is more than 30 years of age.

Figure 2: Pecan Hedger (courtesy: The Pecan Shed)

Figure 3: Pecan Hedger in action (courtesy: The Pecan Shed)

Pruning is a horticultural tool used by commercial pecan enterprises to prevent orchard crowding and moderate alternate bearing (Wood & Stahmann, 2004). There are three types of pruning: mechanical fruit thinning, selective limb pruning, and mechanized hedge type pruning also called topping.

Mechanical pruning is a common practice to prevent crowding, in dry climate areas such as Arizona and New Mexico where trees are planted closer to each other than in other areas (Lombardini, 2006). Because mechanical pruning tends to be expensive, growers often use selective limb pruning. Selective limb pruning involves creating an imaginary box around the pecan tree with the bottom of the box at a level high enough for sprayers and equipment to pass below. The top of the box will reach 30 ft. above the bottom of the box and the sides of the box will extend half-way to the trees on all sides of the one being pruned. Any limb extending outside the box should be pruned back to an intersection with another limb within the box and removed without leaving a stub. Only one to three limbs are removed from a tree at a time. This helps distribute energy into the remaining limbs and will keep the tree within manageable dimensions for spray coverage. This is probably the most conservative method of opening up the orchard to light for those who are hesitant to remove entire trees. However, this method is very labor intensive and generally costly.

Alternate-row thinning is a common method of getting light into the orchard. This involves removing every other tree (depending on the age of the orchard) in alternating rows, usually on the diagonal. Removing every tree in alternating rows takes out one-half the trees, while leaving them in a square, although the orientation is rotated 45° (Worley, 1991). This type of thinning normally results in a loss of yield per acre for the first few years after thinning, but the loss will normally be made up in succeeding years. Alternate-row thinning is the most aggressive manner of opening up light to the orchard; it does not take into account the yield potential of each tree and undoubtably removes some high yielding trees.

Selective thinning is probably the most efficient method of bringing light into the orchard but it can be complicated and labor intensive, and requires knowledge of the orchard and individual trees (Worley, 1991). This method was developed by Dr. Bill Goff at Auburn University and has been used with success in many orchards. Trees are individually rated by making a visual assessment of a tree's profit potential. This is determined by yield, pest pressure, nut quality, and value.

The traditional pruning frequency and method for most growers is to arbitrarily select the rate of pruning and even the type of pruning. More often, decisions about pruning are based on the size of the orchard and the budget; the economic evaluation of this activity is often put aside due to time and budget constraints.

1.4.The Pecan Industry

The United States is the world's largest producer of pecans (National Agricultural Statistics Service, 2007). The U.S. grows about two-thirds of the world's pecans and consumes about 62% of its own crop (Economic Research Service USDA, 2012). For generations, pecan prices have fallen with bumper crops and soared with bad crops. But lately, they have experienced a solid upward trend.

Players in the pecan industry include growers, accumulators, and shellers. Growers include small-scale backyard operations and commercial orchards extending over thousands of acres; accumulators are the middlemen between the small-scale growers and shellers. Shellers are the commercial processors of pecans; they convert in-shell to shelled pecans (Ibrahim & Florkowski, 2004) and also clean inshell pecans to marketable pecans.

In Arizona, pecan farms occupied an area of 12,365 acres in 2007 (NASS, 2007). The nuts used in this study were collected from the Green Valley Pecan Company (GVPC), located in Saharuita in south-central Arizona. Trees were configured in three blocks (Continental-24 and Sahaurita 24 and 29). The three blocks were planted on a 33 x 33 ft square spacing and were either the Wichita or Western variety, both improved varieties.

1.5. Field of Study

The Green Valley Pecan Company operates a large pecan orchard just south of Tucson, Arizona. The orchard produces a crop from which GVPC processes several million pounds a year of shelled, roasted and unroasted, whole, halved, chopped, and ground pecans. Green Valley grows the Western Schley and Wichita varieties, which are well suited to the high Sonoran Desert environment. Vertically integrated, the company raises, harvests, processes, packages, and ships its crop. Established in 1948 by the late Keith Walden on a ranch that in the early 1900s grew guayule plants for rubber, Green Valley Pecan is today owned and operated by Keith's son, Richard (Green valley Pecan Tradition, 2013).

History of the Pruning Program

The pruning program at GVPC started 9 years ago. For practicality, a four year pruning cycle (Walworth, 2012) was initially adopted. In this cycle, each row is pruned once every four years.

Research on pecans

Little economic research has been completed on pecans, particularly the economics of pruning pecans. Most economic research on pecans has taken a global approach, analyzing the industry from the supply or demand side. Florkowski & Elnagheeb (1993), in an attempt to model perennial crop supply (using data from Georgia's pecan industry), used two models to predict the supply of the crop. Their goal was to predict the number of new plants by improving methods for estimating the number of non-bearing trees. Onunkwo & Epperson (1999) focused on the demand side by analyzing the impact of factors such as federal promotion programs[1] on the demand for U.S. pecans in Asia and the European Union. The market price of pecans has experienced a high increase in the last ten years. In a recent study, Ibrahim & Florkowski (2004) provided insights on fluctuations in shelled pecan prices in response to inventories of shelled and in- shell pecans and total stored volumes of pecans, in order to improve the general understanding of the complexities of the pecan market.

Few studies have focused on farm-level management decisions. Springer (2011) developed a net present value model to determine the profitability of planting an irrigated improved pecan orchard. By using financial calculations, he analyzed how land, labor

[1] These federals programs include Targeted Export Assistance Program (TEA), Market Promotion Program (MPP)

and management activities maximize the expected net return from a farm in southern Oklahoma.

Pecan pruning has received little attention in the literature. Lombardini (2006) conducted an experiment on a non-irrigated pecan orchard for three years, with the aim of comparing light interception and productivity of unpruned mature pecan trees with other trees that were mechanically pruned and selectively pruned. He found that although selective pruning and mechanical hedge pruning translated to some positive effects on light interception yield and nut quality, most of these effects were limited and had disappeared by the third day in more humid areas such as the southeast U.S. Wood (2009) performed a similar experiment for four years in the same area, this time studying the response of 25 year old pecan trees to different mechanical hedgerow type pruning strategies.

Given the general lack of studies related to pecans and nuts in general, this study aims to provide insights into how to utilize a straightforward framework to evaluate the optimal pruning frequency for pecan trees from a commercial orchard. This research is designed to analyze how the outcomes, such as quality of nuts, yield, and profit per acre can be affected by the pruning frequency chosen.

1.6. Research problem

The tradeoff between quality and yield for pecans must be established. Currently, more attention is paid to pecan quality due to market conditions. However, details of the yield-quality tradeoff for pecans have not been formally researched. Understanding the yield-quality tradeoff will help pecan growers make better decisions on how often they should prune their trees.

An optimization function was formulated to derive the optimum level of pruning frequency to maximize profit. The optimization presented consists of assessing the profit variation subject to two scenarios of relatively high and low prices. The choice or decision variable for this profit maximization problem is pruning frequency, which can take only integer values such as from 1 to 4. In addition to specifying the type of choice variable, it was necessary to determine whether the decision maker would choose from a set of constrained or unconstrained values.

In this analysis, a profit maximization framework was implemented that utilizes a simultaneous model with two equations (yield and quality), we derived the expected Value Marginal Product (VMP) and Marginal Cost (MC) which can help decision makers at GVPC in choosing the optimal pruning frequency which maximizes the profit per pound.

CHAPTER 2: LITERATURE REVIEW

The analysis of dynamics in agriculture has benefited from significant refinements in analytical tools including the development of dynamic programming as well as optimal control methods.

2.1. Dynamic optimization in agricultural economics

Stochastic programming is a framework for modeling optimization problems that involve uncertainty. There is a large variety of approaches for formulating or solving stochastic programming problems under uncertainty. The general stochastic problem is set to optimize (maximum or mininimum) a particular objective function g(x) = Expected Value (G(x, w)) subject to some constraint related to the expected value. The domain of the decision variable x can be finite (discrete programming) or continuous. Stochastic optimization with recourse is known as sequential decision problems. Bertsekas & Shreve (1996) defined sequential decision models as mathematical abstractions of situations in which decisions have to be taken in several stages while facing costs at each stage.

2.2. Stochastic decision solutions vs. mean variance (E-V) models

For many years optimization was looked at using the mean-variance framework. The mean variance framework which relies on a utility framework that presents a trade-off between risk and return (Markowitz, 1952) is regarded as one of the foundational risk-return theories in financial economics

a. Mean-Variance Model

The mean-variance optimization framework called E-V was originally developed by Markowitz (1952), and is often used in farm analysis because it incorporates a risk factor in the objective function. Originally deployed in financial economics, the E-V optimization theory has a basic structure such that "an alternative A is preferred to an alternative B if $E(A) \geq E(B)$ and $V(A) \leq V(B)$" (Hardaker & Tanago , 1973). The E-V model relies on two major assumptions in order to be equivalent to expected utility theory. First, the decision maker's utility function has to be quadratic and secondly, net returns must be normally distributed (Dillon, 1999).

The E-V optimization framework can be used in several ways and for multiple purposes. Hardaker and Tanago (1973), for example, applied both E-V analysis and the stochastic decision model to assess the results of a systems simulation model of Lucerne haymaking on irrigated farms in southwest Spain. The objective was to choose between two alternative sets of haymaking equipment. Hardaker and Tanago (1973) analyzed the first two moments of the outcomes distribution for the E-V analysis. In order to determine optimal production practices for Kentucky vegetable growers of tomatoes, bell peppers, and sweet corn, (Vassalos, Dillon, & Coolong, 2012), defined their E-V objective function as the maximization of net returns over selected costs, less the risk aversion multiplied by the variance of net returns. Shockley, Dillon, & Stombaugh (2011) developed a resource allocation E-V model in order to assess the risk and production implications of the adoption of auto-steer navigation technology. In some studies, E-V models are modified or combined with a simulation.

Shortcomings of the Mean Variance Model

The mean-variance model first developed by Markowitz faces two major limitations. First, the estimation of the risk by variance is only appropriate in the case of the normality of net returns and that is not always the case. Second, the mean variance framework assumes that investors focus on a single time horizon, with no change in assets.

b. Stochastic decision model in agriculture

In agricultural economics, stochastic decision models are applied in several ways depending on the crop, the stage of production and the type of decision, such as timing for applying inputs (e.g. pesticides, irrigation, and planting), and agricultural practices (e.g. cutting and pruning frequency).

Blank et.al. (2001) employed a sequential stochastic model to predict how the cutting schedule of alfalfa in California could affect quality and yield, which could affect revenue and thus profit. The first issue dealt by with Blank et.al is the tradeoff between quality and yield, which leads to a tradeoff between yield and price as the agronomic issue of the model. Blank et.al. (2001) found that a shorter frequency of cutting resulted in higher quality but lower yield. Before designing the dynamic decision model, Blank et.al. (2001) converted the agronomic issue to economic metrics where the yield-quality tradeoff becomes a yield-price tradeoff. The objective of the decision model is to maximize the expected utility under risk subject to stochastic change in wealth. Blank et.al. (2001) identified an optimal cutting schedule based on the present value model so that the result of each cutting is a combination of price and yield. Blank et.al. (2001)

divided the decision process into three levels: the choices of 1) a particular cutting, 2) timing of each cutting, and 3) number of cuttings.

Antle et al. (1994) developed a sequential production model where the number and timing of production decisions are all endogenous. The model, applied to the usage of fungicide on Ecuadorian potatoes, considers N+2 stages of production from planting to harvesting so that one can easily derive the endogenous timing variable $\delta_i = t_i - t_{i-1}$, $\delta_H = t_H - t_N$, $\sum_1^H \delta i = tH$. This model has two major steps. In the first step, he derives a composite production function

$q_H = q_H[\,^H x,\, ^N t,\, ^N\delta,\, ^H\varepsilon]$

The farmer's objective is to maximize expected profit subject to the concavity of the profit function. Therefore, the application of dynamic programming on the farmer's object function yields the following equations:

$$x_i^* = x_i^*\left[E_{i-1}[p], w^i, q_{i-1}, t_{i-1}\right]$$

$$\delta_i^* = \delta_i^*\left[E_{i-1}[p], w^i, q_{i-1}, t_{i-1}\right]$$

q_{i-1} are not observed econometrically. The composite production function is substituted into the previous equation and yields a system of equations with variables that are all observable and estimable parameters. The approach used to estimate the model was the parameterization of the production functions the first-order condition was then derived and yielded to the demand function. But there are two main issues related to this approach: first, few functional forms provide a closed-form solution to the factor demand equation and, second, the total number of inputs is a random variable. The result, after

OLS estimation, finds a good fit for the demand equation; both the demand and the timing equation are significant functions of price, while the own price elasticity of quantity and timing are significant variables.

Hatch et al. (1989) devised a first probability limit to implement a discrete stochastic farm management programming model. Specifically a sequential decision making model developed for farm-raised catfish. The main objective was to develop a methodology for assessing the economic viability of alternative sequential production strategies using chance constraints.

Larson & Mapp (1997) evaluated alternative cultivar, planting, irrigating and harvesting choices as to how they can affect the expected value for cotton production. For each information scenario (nonupdated, updated, and revised), the objective is to determine the cultivar, planting, irrigating, and harvesting decisions that maximize expected net revenue, minimum net revenue (maximin) and maximum net revenue (maximax)

c. Discrete stochastic decisions in farm management

The main drawback of stochastic dynamic optimization relates to the inability of the method to obtain a solution for many problems. However, discrete stochastic programming has the advantage of being more solvable with simpler algorithms that are easier to implement. Discrete stochastic programing is widely used in agricultural economics; Garoian, Conner, & Scifres (1987) used it to determine the optimal burning schedule under uncertainty for rangeland in Texas. Cocks (1968), the pioneer in discrete stochastic programming research, built the framework of discrete programming optimization, starting with the linear programming problem of maximizing an objective function subject to a set of constraints. The introduction of probability distributions leads to two major approaches, passive and active. In the passive approach, the maximization is done under certainty and the issue is to characterize the prior distribution of outcomes. With the active approach, all resources are allocated in advance and their coefficient values are known so that the optimization is subject to these coefficients.

2.3. Profit maximization framework in agricultural economics

The present study profit maximization framework involves the derivation of the value marginal product (VMP) from the stochastic production using the pruning frequency as the main input. In general according to Beattie et al (2009), the profit is at its maximum level when the VMP equals the Marginal Factor Cost (MC) in a three stage production framework (VMP MC Condition). In agricultural economics profit maximization are designed several ways and for multiple kind of input. First and foremost, the VMP is computed as a product of the Marginal Physical Product (MPP) and the price of the input. The MPP is mostly computed through production elasticity; here the estimated coefficient of the input is multiplied by the average production of that input Beattie et al (2009).

2.4. Tradeoff between yield and quality

The tradeoff between yield and quality is often materialized in agriculture by the fact that farmers want to know how much yield they have to give up in order to produce a higher quality. Orloff et al, (2000), in choosing an optimal alfalfa cutting schedule, designed an equation to express the breakeven point for two cutting timings (t1 and t2), in terms of price (P) and yield (Y) as follows: $P_{t1}. Y_{t1} = P_{t2}. Y_{t2}$

Manipulating this equation gives a decision rule to aid producers in deciding whether to cut at t1 (for quality) or at t2 (for yield). Expressed as a breakeven point, the relationship between price and yield is: (Price differential) (Pt1 - Pt2)/ Pt2 = (Yt2 – Yt1)/ Yt1 (Yield differential). If the price differential equals the yield differential, both cutting times would result in equal revenues. However, if the price differential (relative change in price from higher quality to lower quality) is greater than the yield differential (relative change in yield between the two cutting times), it is better to cut for quality. Conversely, if the yield differential is greater than the price differential, it is better to cut for yield.

CHAPTER 3: MODEL SPECIFICATION AND ESTIMATION METHODS

Stochastic programming is a mathematical method in which the parameters are replaced by distributions. In order to solve a stochastic programming problem, one needs a model and the values of the parameters.

There can be several kinds of stochastic programming methods, depending on the number of stages, the existence or lack of recourse, and the usage of simulation but three approaches are most often used to solve optimization problems. First, allowing inequality constraints, the Kuhn-Tucker theorem approach to nonlinear programming generalizes the method of Lagrange multipliers, which allows only equality constraints. Second, the maximum principle is an analytical tool widely used to study second-order linear and nonlinear elliptic and parabolic equations. Finally, dynamic programming is both a mathematical optimization method and a computer programming method. In both contexts it refers to simplifying a complicated problem by breaking it down into simpler sub-problems in a recursive manner.

During this research, the value marginal product (VMP) was evaluated as well as the Marginal Cost (MC) in currency per pound with respect to the frequency of pruning; the objective was to choose a pruning frequency which would maximize the profit by having the Value Marginal Product equal to the Marginal Cost. I will first specify the general framework supporting the decision function and, then the specifics of the model as related to the pruning of pecans.

3.1. Decision function

a. Basics of two-stages programming with recourse

For the theoretical model, we developed a two stage stochastic discrete programming framework. The main advantage of discrete programming is that the problem can be formulated in a linear programming framework (Garoian, Conner, & Scifres, 1987).

Two-stage stochastic programming problems derive from models where decisions are taken in two stages and the observation of some random event takes place in between. Hence the first decision must be made when the outcome of the random event is not yet known (Fabian & Szoke, 2000). For example, the first stage may represent the decision on the pruning frequency of the tree; while the second stage represents the decision whether or not to replicate the precedent decision under certain circumstances.

The objective is to maximize the expected profit per acre subject to the fact that price and yield are functions of the pruning frequency. A discount factor β is included in the equation because the decision occurs before the output is realized.

$V_t(pf_x) = MAX\ \pi^T(pf_x,\ \ P_t) + \beta E\{\left(TVP(hf_x)\right) - TC(pf_x)\}$, t=1,2 are the stages

$$Max\ E\left(\pi(pf_x)\right) = \pi^T(pf_x) + \beta E\{\left(TVP(pf_x)\right) - TC(pf_x)\} \qquad \textbf{(3.1)}$$

Where $V_t(pf_x)$ is the present value of the profit per acre, pf_x is the pruning frequency considered here as our decision variable. $P_t$is the price at time *t*.

$\pi^T(pf_x,\ \ P_t)$ is the first stage profit value. In our case, the first stage is related to all the results and choices prior to the present moment, i.e., prior to the end of 2012.

TVP is the total value product which is equal to total revenue under the assumption of perfect competition in the US pecan market.

TC is the total cost, which takes into account the cost of pruning and the cost of processing. The cost of processing depends on each category of pecans; some of them need more sorting than others. The cost of processing will depend on the cost of one sort.

Max

$$\pi(pf_x) = \pi^T(pf_x) + E(Price(pf_x) * category\% * Yield(pf_x)) - (Cost\ of\ hedging(pf_x) + Cost\ of\ processing(pf_x)) \quad \textbf{(3.2)}$$

$pf_x \in \{1,2,3,4,5\}$

Subject to

$\left(Cost\ of\ hedging(pf_x) + Cost\ of\ processing(pf_x)\right) < B$ Budget constraint

$$Yield_t = Yield_t(pf_x, variety, years, Yield_{t-1}, Quality_t)$$

$$Quality_t = Quality_t(Quality_{t-1}, Yield_t)$$

$Price$ is the price per pound of processed pecan halves. The price per pound depends on the category of pecan (Mammoth halves, Jr Mammoth halves, Jumbo halves, Large and Medium Pieces). Therefore, "$category\%$" represents the percentage of each category of pecan in the yield per acre depending on the overall quality (high, low, medium and no cutting). We gathered value for "$category\%$" during a field interview with GVPC's sales VP Bruce Caris and the Plant manager Brenda Lara, who supplied the possible values for " $category\%$" depending also on the quality level:

Table 1: Possible values of category% depending on the quality

Categories	No cutting	Low quality	Medium quality	High quality
Jr Mammoth halves	55.80%	41.70%	51.20%	62.30%
Extra large pieces	16.47%	3.85%		14.20%
Large pieces	16.69%	15.64%	21.28%	15.28%
Large/Medium pieces		1.59%		
Medium pieces	3.85%	20.26%	18.70%	3.96%
small/medium pieces	1.91%	3.21%		
small pieces	2.71%	8.60%	4.28%	2.43%
midget pieces	1.76%	2.91%	3.22%	0.85%
granule	0.00%	0.04%		
meal	0.00%	0.04%		
mill loss	0.73%	2.16%	1.30%	

The common way of solving for the present profit maximization consists of finding the level of pf_x which maximizes the profit function.

$$\frac{d\pi}{dh} = Price(Quality) * category\% * MPP(pf_x) - MC_h(pf_x) - MC_p(pf_x) = 0 \quad \textbf{(3.3)}$$

$MPP(pf_x)$ is the Marginal physical product of pruning, MC_h and MC_p are respectively the marginal cost of hedging and processing.

For profit maximization it is necessary to find the level of pf_x for which the Marginal Value Production equals Marginal Cost

The price $Price(Quality)$ is a function of the quality of pecan. In the model we assume that each variation of quality affects the variation of the price. $\Delta Price = \Delta Quality$, we considered the price with two components$(\overline{Price}, \Delta Price)$.

3.2. Estimation procedure

a. First step: yield and quality

The first step of our specific model consists of getting MPP (pf_x) and Quality (Yield)

The MPP is obtained by a regression of the yield on the set of input using a Cobb Douglas production function

$$Yield = A(pf_x)^{\beta} x^{\delta} \quad \textbf{(3.4)}$$

x represents other determinants of the yield, such as the average humidity level of year t, and the levels of nitrogen and zinc applied to the tree.

The choice of Cobb Douglas function is based on the fact that the estimated coefficients are input elasticities. This function allows diminishing returns and is straight forward to estimate econometrically.

We then applied the log to both sides of the equation in order to have a linear model.

For the *ith* farm's row at *t* year,

$$Log(Yield)_{it} = \beta_0 + \beta_1 log(Quality)_{it} + \beta_2 Pfx_{it} + \beta_3 WICHITA_i + \beta_4 WESTERN_i + \beta_5 D2009 + \beta_6 D2011 + \beta_7 D2012 + \beta_8 WICHITA * Log(Pfx_{it}) + \beta_9 WESTERN * Log(Pfx_{it}) + \varepsilon_{it} \quad \textbf{(3.5)}$$

A major assumption is the tradeoff between yield and quality; therefore, we will use the relation between price and yield of Orloff et.al. (2000) expressed as a breakeven point between price and yield where the equilibrium occurs when price differential is equal to yield differential between two types of pruning frequencies.

(P1 - P2)/ P2 = (Y2 – Y1)/ Y1

Where Px is the average price for a particular pf_x pruning frequency, Yx is the yield for each particular pruning. In a more general frame we have

$$(P_x - P_{x+1})/_{P_{x+1}} = (Y_{x+1} - Y_x)/_{Y_x} \quad \textbf{(3.6)}$$

The equation becomes $P_{xy}\gamma = Y_{xy}\beta + \varepsilon$ where $P_{xy}$the price differential between is x and y and $Y_{xy}$is the yield differential between x and y. The price differential can be replaced with a quality differential because the price is closely related to quality in the pecan industry. We can change variations into log transformation and also adapt this differential equation to a panel data structure to have the following:

$$log(Quality)_{it} = \alpha_0 + \alpha_1 log(Quality)_{it-1} + \alpha_2 Log(Yield)_{it} + \varepsilon_{it} \quad \textbf{(3.7)}$$

Depending on the values generated for $Quality_{it}$, during the second stage, we compute the corresponding quality standard (Low, medium and high) and then we will get the quantity related to each category of processed pecans.

These two equations helped predict the yield for each row and kernel percentage.

Finally, we estimate the following system of simultaneous equations:

(1)$Log(Yield)_{it} = \beta_0 + \beta_1 log(Quality)_{it} + \beta_2 Pfx_{it} + \beta_3 WICHITA_i + \beta_4 WESTERN_i +$
$\beta_8 WICHITA * Log(Pfx_{it}) + \beta_9 WESTERN * Log(Pfx_{it}) + \beta_5 D2009 + \beta_6 D2011 +$
$\beta_7 D2012 + \varepsilon_{it1}$

(2)$log(Quality)_{it} = \alpha_0 + \alpha_1 \log(Quality)_{it-1} + \alpha_2 Log(Yield)_{it} + \alpha_3 WICHITA_i +$
$\alpha_4 WESTERN + \varepsilon_{it2}$ **(3.8)**

Estimation of a dynamic panel data with simultaneous equations

In the literature, three major procedures are used to estimate a dynamic panel with simultaneous equation. The first consists only of two separate fixed effect (or random effect) estimations of each equation; and the predicted values of one equation will then be inserted as one of the independent variable in the other equation. The second procedure consists of performing a fixed effect transformation before a classic three stages least squares. The third and most tedious method consists of using an error component three stage least square developed by Baltagi (2005). The error component three stage least square method uses dependent variables, independent variables, and instruments corrected by an error matrix combining the within and between error from the two equations. After the estimation of these equations, it is important to compute and test the direct and indirect effects of pruning. As the path diagram shows, the pruning frequency variable has only an indirect effect on the Quality variable of pecan. After sweeping out the fixed effect, the system (3.8) is transformed to

$$(1)(Log(Yield)_{it} - \overline{Log(Yield)_i}) = \beta_1\left(log(Quality)_{it} - \overline{log(Quality)_i}\right)$$

$$+\beta_2 Pfx_{it}$$

$$+\beta_3 WICHITA_i + \beta_4 WESTERN + \beta_5 D2009 + \beta_6 D2011 + \beta_7 D2012$$

$$+\beta_8 WICHITA * (Log(Pfx_{it}) - \overline{Log(Pfx_i)})$$

$$+\beta_9 WESTERN * \left(Log(Pfx_{it}) - \overline{Log(Pfx_i)}\right) + \varepsilon_{it1} \quad \textbf{(3.9)}$$

$$(2)\ \left(log(Quality)_{it} - \overline{log(Quality)_i}\right) = \alpha_1\left(\log(Quality)_{it-1} - \overline{log(Quality)_i}\right)$$

$$+\alpha_2(Log(Yield)_{it} - \overline{Log(Yield)_i})$$

$$+\alpha_3 WICHITA_i + \alpha_4 WESTERN + \varepsilon_{it2}$$ **(3.10)**

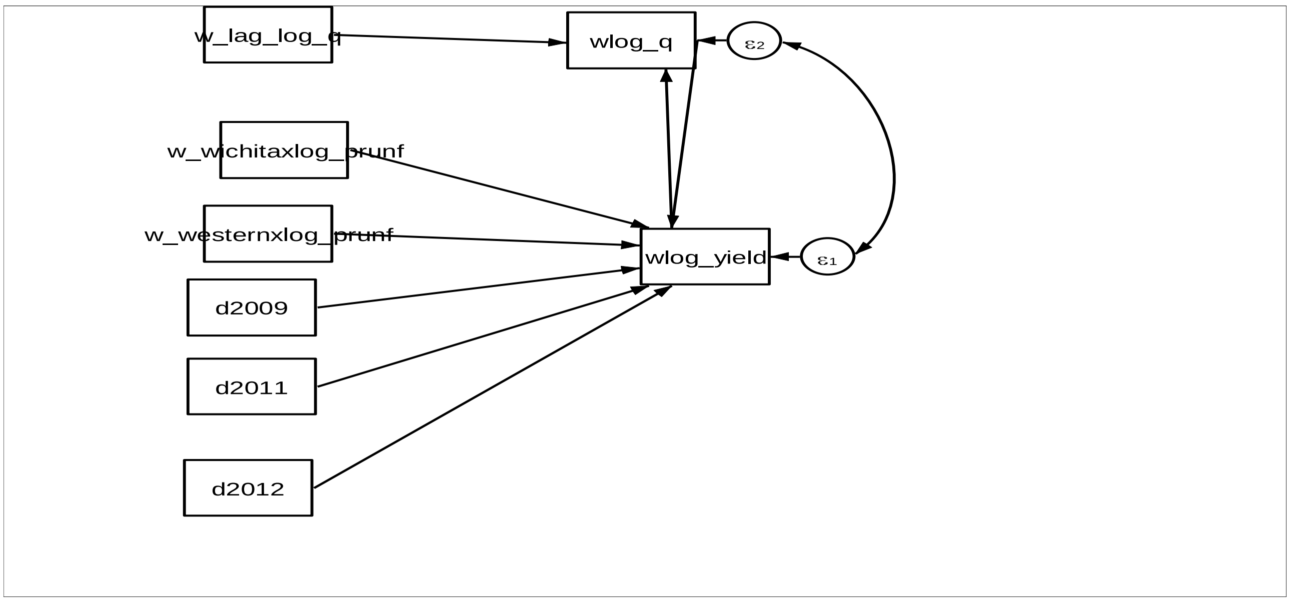


Figure 4: Path Diagram

At the end of the estimation, the MPP will be generated using (Orloff, Ackerly, & Putman, 2000) method of just subtracting the expected yield between two consecutive values x and y of the pruning frequency. $MPP_{xy} = (\widehat{Yield}_y - \widehat{Yield}_x)$ **(3.11)**

For any given $\overline{Price}$, the Value Marginal Product (VMP) is computed as an addition of the MPP valued by $\overline{Price}$ and the Average expected yield between two pruning frequency $\overline{Yield}_{xy}$ valued by $\Delta Price$ ($\Delta Price = \Delta \widehat{Quality}$).

$$VMP_{xy} = \overline{Price} * MPP_{xy} + \Delta Price * \overline{Yield}_{xy}$$ **(3.12)**

b. Second step: Estimation of the Marginal cost of pruning and processing

The pruning variable cost is a function of the standard pruning cost per acre divided by the pruning frequency.

The Pruning frequency variable cost (PC) is

$$PC(Pf_x) = \frac{Pruning\ Cost}{Pf_x} \quad \textbf{(3.13)}$$

The marginal cost of the pruning (MCPruning) will then be computed the same way as the MPP by just subtracting between two consecutive frequency of pruning

$$MCPruning_{xy} = (\mathrm{PC}_{\,y} - \mathrm{PC}_{\,x}) \quad \textbf{(3.14)}$$

The processing cost of inshell pecans varies depending on the sheller because some shellers may have more processing steps than others. In this study we took into account common processing steps such as cracking, shelling, sorting and shelling plus. Each type of processing has a particular cost per pound *c*. The marginal cost of processing has two component. The first one is a the average cost times the MPP. The average cost is the difference between shelled and inshell price of pecans.

$$\overline{cost} = \overline{Price}_{shelled} - \overline{Price}_{inshell} \quad \textbf{(3.15)}$$

The first component of the marginal cost of processing $MCP_{xy1} = \overline{cost} * MPP$ **(3.16)**

The second component is the cost variation times the average yield between two pruning frequencies. The cost variation here is derived by a linear interpolation from an actual cost variation provided by GVPC. According to GVPC, when the variation in quality goes from good (62.0% kernel) to poor (kernel % of 46.89) i.e. $\Delta Quality_0 = 15.11$, average processing costs go up by 8.1 cents per pound i.e., $\Delta Average\ Cost_0$ =8.11 cents. For each $\Delta Quality$ between pruning frequencies, $\Delta Average\ Cost_{xy} =$ $\Delta Quality_{xy}$*$\Delta Average\ Cost_0 / \Delta Quality_0$ **(3.17)**

The second component of the marginal cost of processing is then

$MCP_{xy2} = \Delta Average\ Cost_{xy} * \overline{Yield}_{xy}$ **(3.18)**

The Marginal Cost of Processing (MCP_{xy}) is then generated by the summation of MCP_{xy1} and MCP_{xy2}. $MCP_{xy} = MCP_{xy1} + MCP_{xy2}$ **(3.19)**

The Marginal Cost (MC) is just a summation between Marginal Cost of Pruning and Marginal Cost of Processing.

$MC_{xy} = MCPruning_{xy} + MCP_{xy}$ **(3.20)**

CHAPTER 4: EMPIRICAL RESULTS

4.1. Data

The data were collected by a team from the department of Water and Environmental Sciences (SWES) during the 2009, 2010, 2011, 2012 and 2013 harvest seasons. They began in 2009 by monitoring pruned Wichita and Western Schley trees to evaluate the impact of pruning. In 2009 and 2010 they began monitoring Wichita trees planted in 1967 and spaced 30 feet apart in rows, and Western Schley trees planted in 1969 on 60' x 60' foot spacing.

The nuts were harvested using a Thomas bank-out runner; the runners were weighted empty and after collection to generate the net weight and yield for each row of interest. Afterwards, the researchers took samples of 100 and 50 nuts to be graded and weighed.

Starting prior to the 2006 growing season, trees had been side-hedge pruned approximately 20 feet from their trunk, with about a 5^{o} angle. Western Schley trees are topped at 50 to 60 feet at the peak, and angled at 45^{o}. Wichita trees are topped at 50 feet.

Each year the team separately harvested rows of trees that had been pruned 1) in the previous winter [labeled '1st leaf'], 2) two winters prior [2nd leaf], 3) three winters prior [3rd leaf], and 4) four years prior [4th leaf]. Nuts were graded to separate marketable nuts, stick-tights, and pre-germinated nuts. Marketable nuts were weighed, shelled, and graded (Walworth, 2012).

4.2. Variables description (including descriptions of how each variable reacted to changes in pecan pruning)

The dataset used for this study is a panel with 248 data points representing 76 rows, of 2 varieties, Wichita and Western Schley, and located in three areas: Sahuarita 24 (Sah24), Sahuarita 29 (Sah29) and Continental 24 (Cont24). Most of the rows in Sah24 and Cont24 were monitored for 4 years, from 2009 to 2012,; data from Sah29 were collected for two years, 2011 to 2012. Thus, the panel data is unbalanced.

Table 2: Number of observations per location and variety

location		**variety**	**Total**
	Western	Wichita	
Continental 24	80	0	80
Sahaurita 24	0	112	112
Sahaurita 29	0	56	56
Total	80	168	248

In this study, three main variables were used to find the optimal value of the Value Marginal Product: pruning frequency, yield, and quality.

a. *Pruning frequency*

The decision variable, pruning frequency, is represented by leaf, which describes the number of seasons after the most recent pruning. The normal sequence of pruning should have an increasing pruning frequency on each row from 2009 to 2012; thus, the year 2012 should not have a 1 season pruning frequency treatment in a normal sequence. During the period of observation, pruning frequencies from 1 to 4 were equally applied to all the rows within the two locations. Sah29 did not have treatments in the years 2009 and

2010. In 2012 GVPC changed the sequence of treatment on many rows; that is why in 2012 they started to apply a pruning frequency of 1 and 2. In a few rows a pruning frequency of 5 was applied.

Table 3: Number of time each leaf treatment was evaluated

Pruning Frequency	2009	2010	2011	2012	Total
1	12	12	19	19	62
2	12	12	19	17	60
3	12	12	19	18	61
4	12	12	19	17	60
5	0	0	0	5	5
Total	48	48	76	76	248

b. Yield

In this study, the proxy of the yield is the quantity per acre of cleaned in-shell pecans harvested from selected rows. The alternate bearing characteristics are quite similar among varieties but more intense for the Wichita variety.

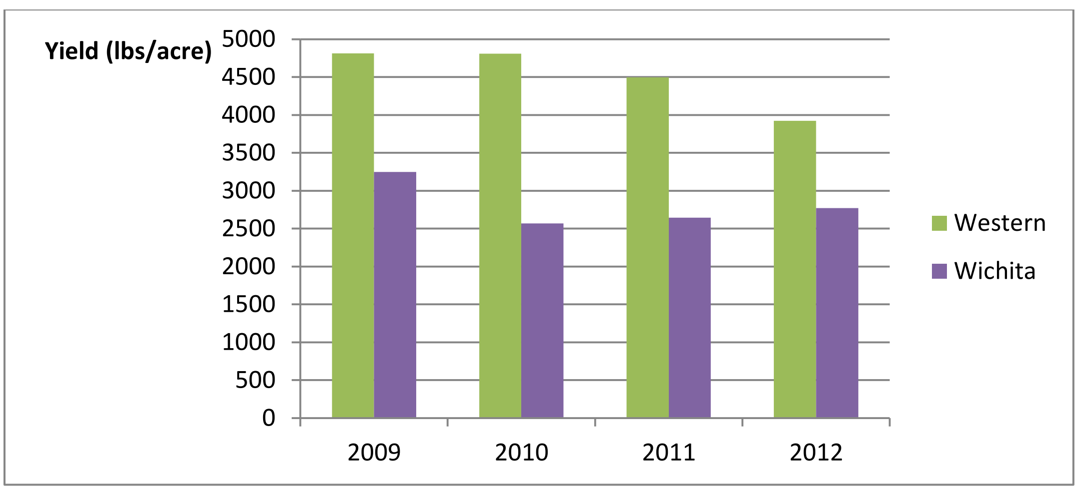


Figure 5: Variation of the average yield by year, by frequency

By including the pruning frequency, the alternative bearing assumption is highly observable for the Wichita. But, for the Western Schley the yield appears to be significantly higher and increasing as the pruning frequency decrease.

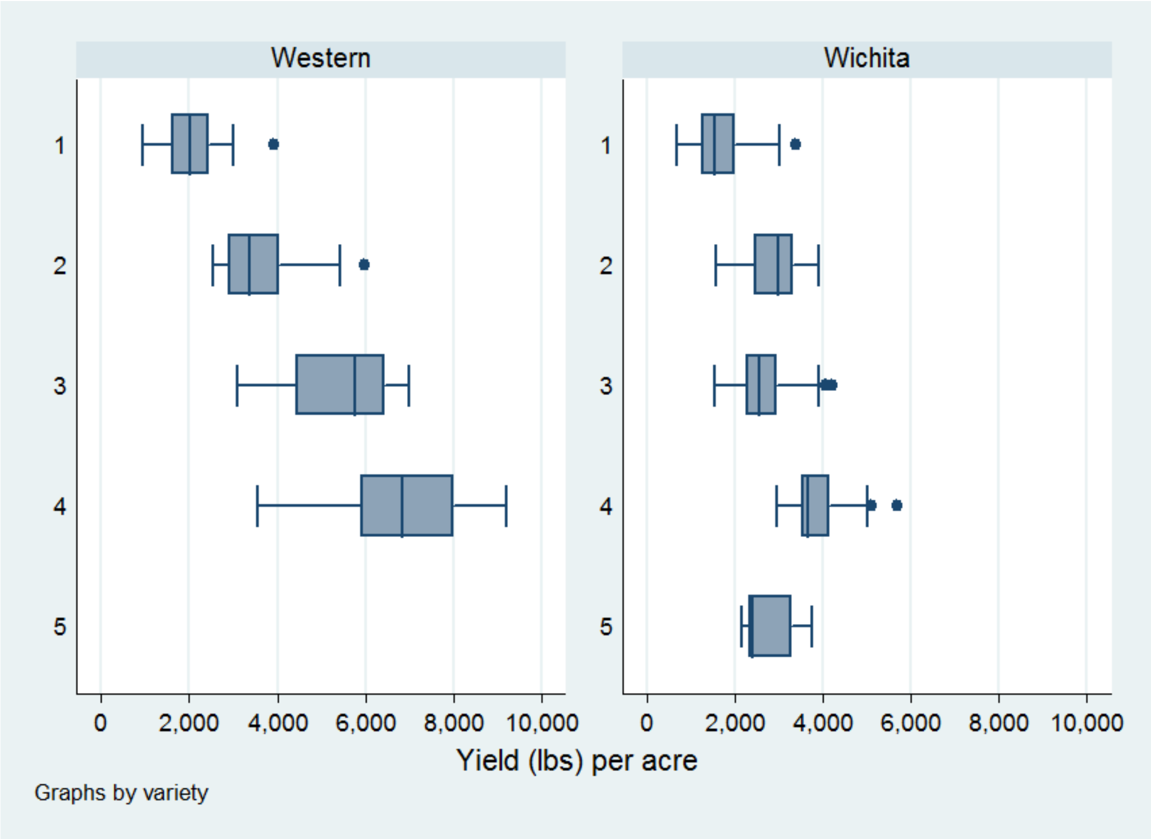


Figure 6: Yield per acre patterns across pruning frequency values

Depending on the pruning frequency sequence used, there is also a strong variation in yield per acre. Looking at Figure 7, for the normal constant sequence 1234, the average yield shows a constant increase between 2009 and 2012. In every case when the trees were pruned after many seasons, i.e., the pruning frequency 4 to 1, the average yield experienced a sudden and consistent drop, indicating a strong response in yield to pruning frequency variation.

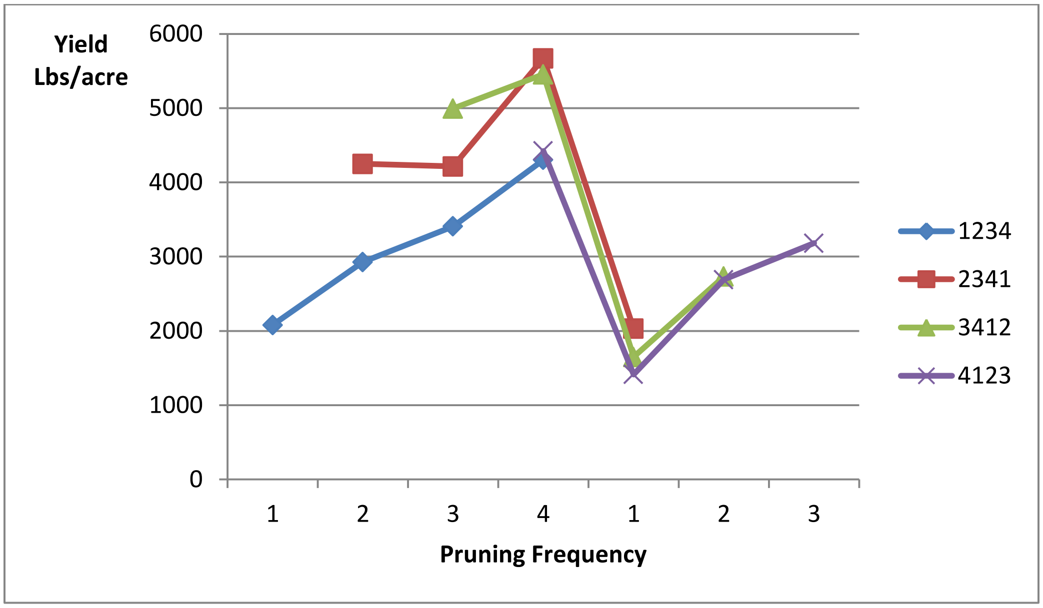


Figure 7: Variation of the yield per acre for each sequence of pruning

Differentiating these effects by varieties shows more divergence in the response of the yield per acre to the pruning frequency. Looking at scatter plot in Figure 8 of a basic regression of yield per acre on pruning frequency, the response shows a similar path depending on the variety, Wichita or Western Schley. In the estimation we made two variety dummies to interact with the pruning frequency to test the significance of each variety in response to the treatment.

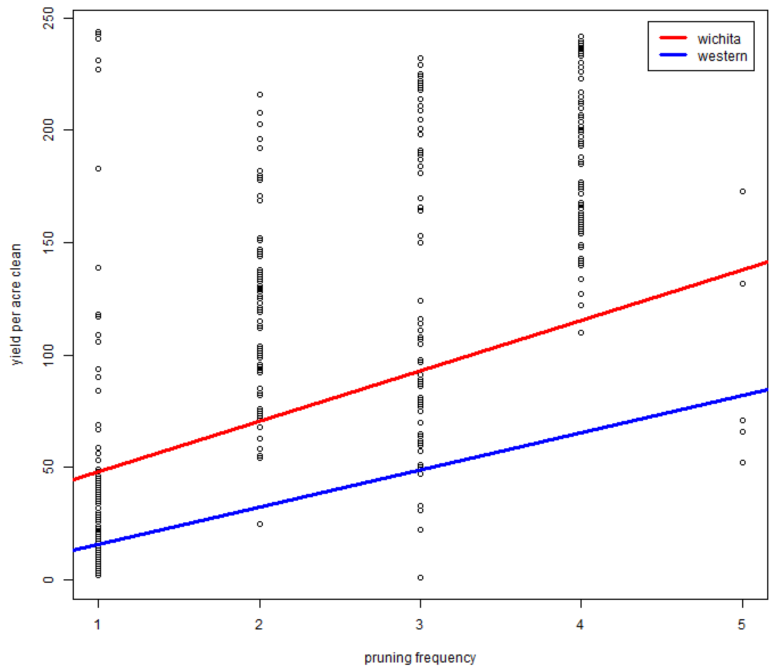


Figure 8: Effect of the pruning frequency on the yield for Wichita and Western Schley

c. The Quality

The main quality variable is kernel percentage, which is the percentage of nutmeat from a sample of 50 nuts. Other quality variables are also used, such as the *Blackeye* percentage, *pregerm* percentage and *insect* percentage. Kernal percentage is key in maximizing farm profitability (Wood, 2009). Kernel quality shows different patterns depending on pruning frequency; the median of the quality variable is higher for lower pruning frequencies.

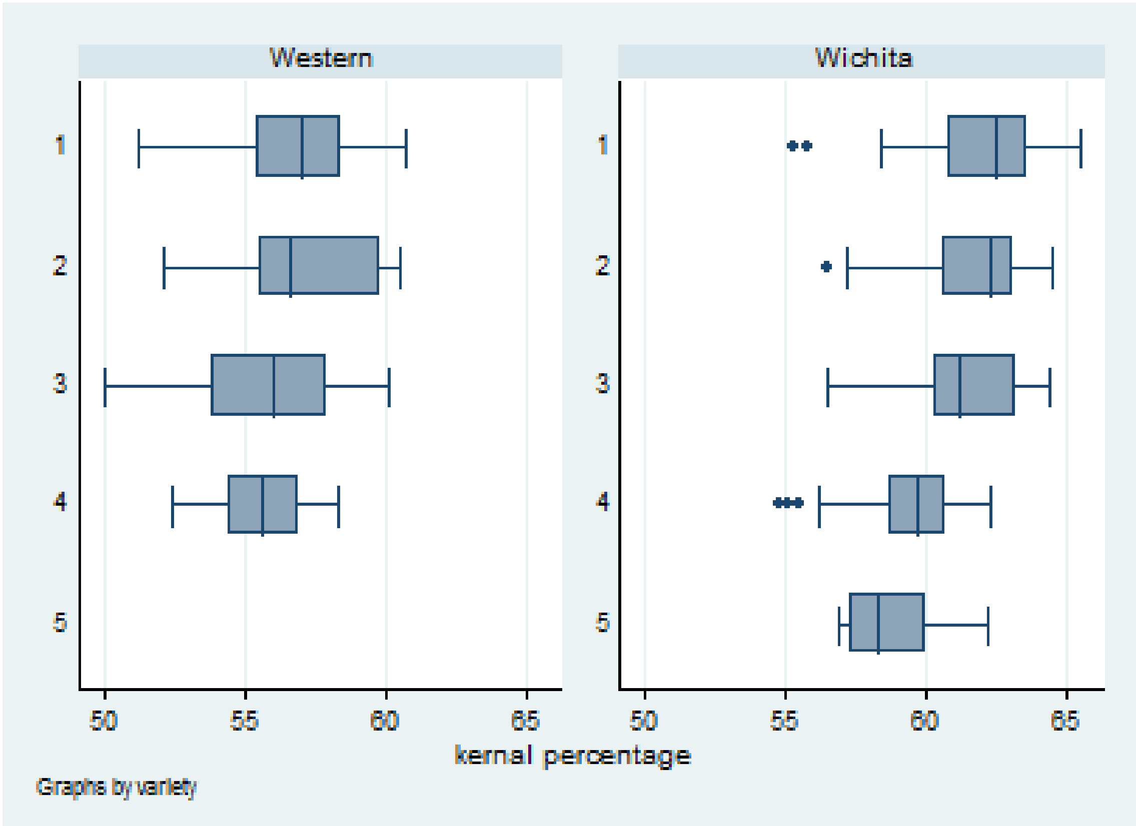


Figure 9: Distribution of the kernel quality variable

The kernel quality variable shows an opposite response (compared with the yield's response) to each different sequence of pruning frequency. The kernel percentage, on average, decreases when the number of seasons between pruning treatments becomes higher. In addition, when pruning after a longer period (when the sequence changes from 4 to 1), quality consistently improves. Pruning also seems to have a strong effect on variations in nut quality.

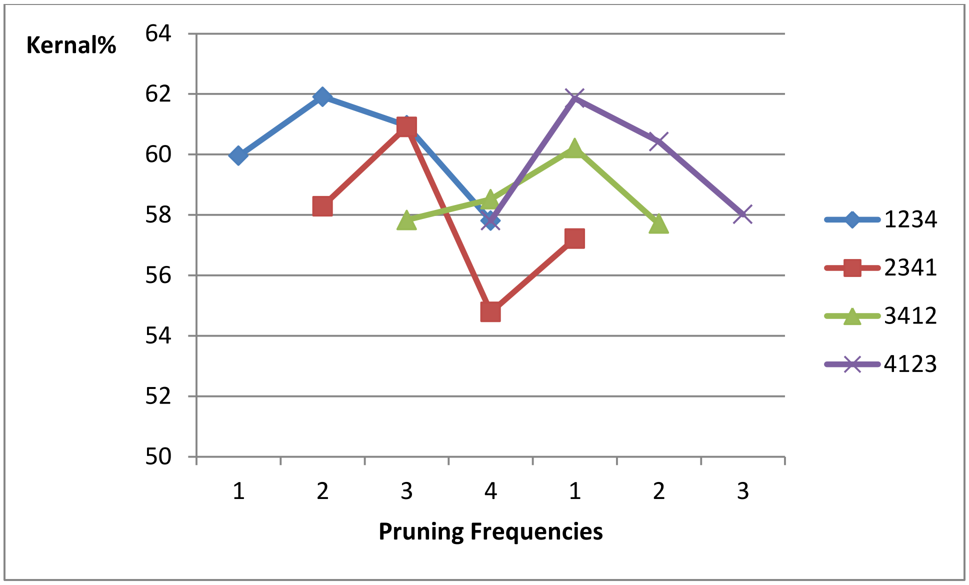


Figure 10: Kernel percentage variation for alternative pruning sequences

The pruning frequency affects yield and quality differently; when pruning happens after many seasons there is a drop in terms of yield per acre but an amelioration of the quality, so the tradeoff between yield and quality needs to be formally quantified.

4.3. Estimation Results and discussion

a. Hausman test for the fixed or random effect nature of the observation

In order to remove the panel effect before estimating the simultaneous equation system, we have to know whether the effects are fixed or random. In other words, we need to perform a Hausman test. Commonly in agricultural design, effects tend to be fixed because each individual plot may experience specific other treatments such as sunlight, level of nitrogen, watering, etc.

Fixed and random effect models were estimated for each of the equations and we found that the fixed effect was the logical approach to each equation. We modeled yield and quality as an endogenous variable with their regressors as instrument. The main difficulty consisted in dealing with an incomplete or unbalanced panel dataset. Observations from the Sah29 location were collected for only two years instead of 4.

b. Simultaneous estimation results

After performing a within transformation by removing each time the group mean for each row, two three-stage least squares were estimated for the simultaneous equations and the results are summarized in Table 4. Two models were specified to ascertain whether interactions between pruning frequencies and variety in the yield equation were statistically significant..

Table 4: Coefficient estimates for 3SLS[2]

	Model			**Model**	
Equation1: Within Log(Yield)	**1**	**2**	**Equation2:** Within Log(Quality)	**1**	**2**
Within Log(Quality)	-2.739**	-1.497**	Within Log(Yield)	-0.319**	-0.328**
Pruning Frequency	0.218**	-0.0128**	Within Lag Log(Quality)	-0.035**	-0.03**
Wichita	-0.56**	0.0131**	Wichita	0.00061	0.000619
Western Schley	-0.545**	-0.010**	Western Schley	-6.62E-08	-6.68E-08
Wichita X Log(Pruning Frequency)		0.580**			
Western X Log(Pruning Frequency)		0.860**			
d2009		0.203**			
d2011		-0.035			
d2012		0.00014			
System R^2	0.4612	0.708			

[2] (**) significant at 5%, (*) significant at 10%

Pruning frequency alone has a significant positive effect on the variation on yield. When we take the pecan variety (Wichita or Western) into account the effect does not change in sign, but the pruning treatment induces more substantial yield fluctuation for the Western variety. The more seasons there are between subsequent pruning treatments, the more the yield will increase. These results are consistent with Worley (1991), for whom yield reductions are always expected after heavy pruning. In order to improve yields, the farm manager should wait the maximum number of seasons between pruning treatments.

The yield-quality tradeoff, respectively represented by the negative sign taken by both endogenous variables in the two indicating as the literature suggesting that a higher yield leads to a lower quality. The tradeoff is consistent in the two models, and it suggests that the pruning frequency affects indirectly the quality thru the yield.

The Year dummies don't play a significant role on the yield per acre variation except for 2009. The year dummies indicate that only 2009 is substantially different from the base year of 2010. Year dummies can account for climate, humidity, and other natural effects that may vary by year.

4.4. Profit per acre maximization

a. Marginal Physical Product (MPP)

The MPP is computed as mentioned earlier in Chapter 3 in equation (3.14) and it is calculated using the differences between two consecutive pruning frequencies. The expected yield values were computed using the coefficients resulting from the second estimation. In the following Figure 14, the MPP for Wichita and Western both reach their maximum positive variation of yield at a pruning frequency of 4 which is consistent with the descriptive statistics. Both varieties experienced a significant drop at the change of sequence from 4 to 1.

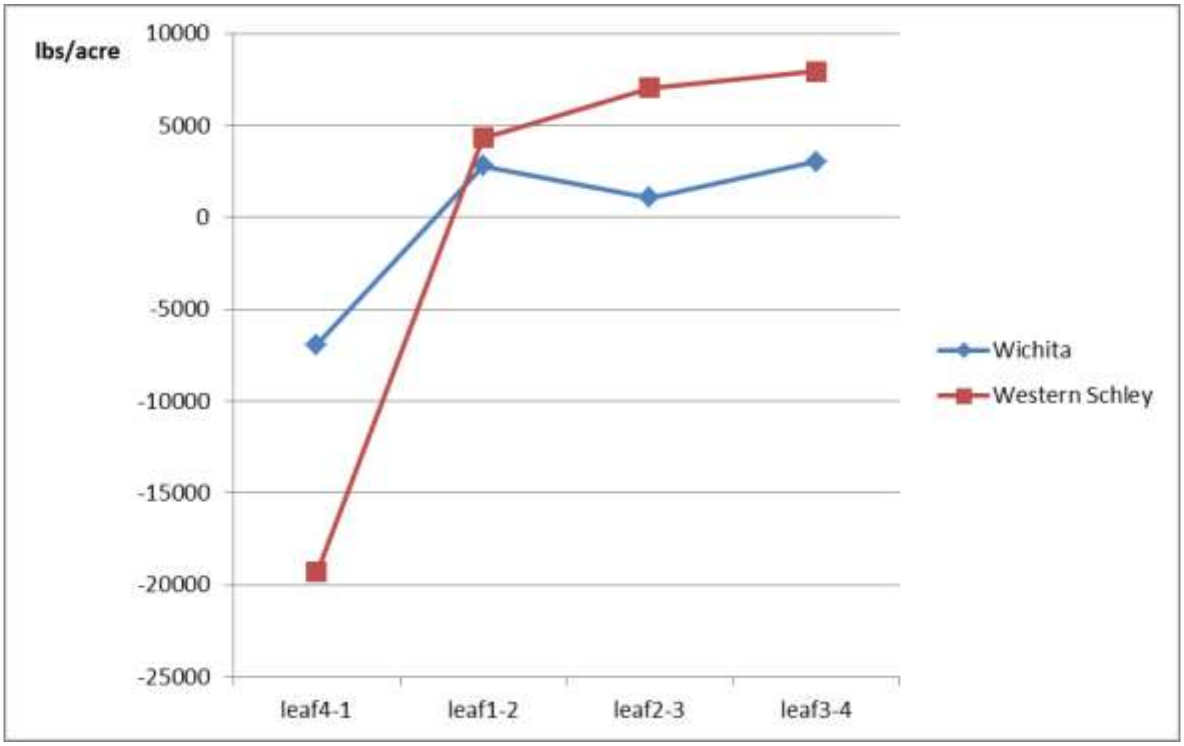


Figure 11: MPP for Wichita and Western

In both case, the change of sequence was done to improve the quality. Figure 15 below maps the variation of quality for the two varieties. When the pruning frequency change from 4 to 1, the quality improves significantly for both varieties, the Western Schley is more responsive to the change. The Wichita has a prior improvement of quality at a pruning frequency of 3.

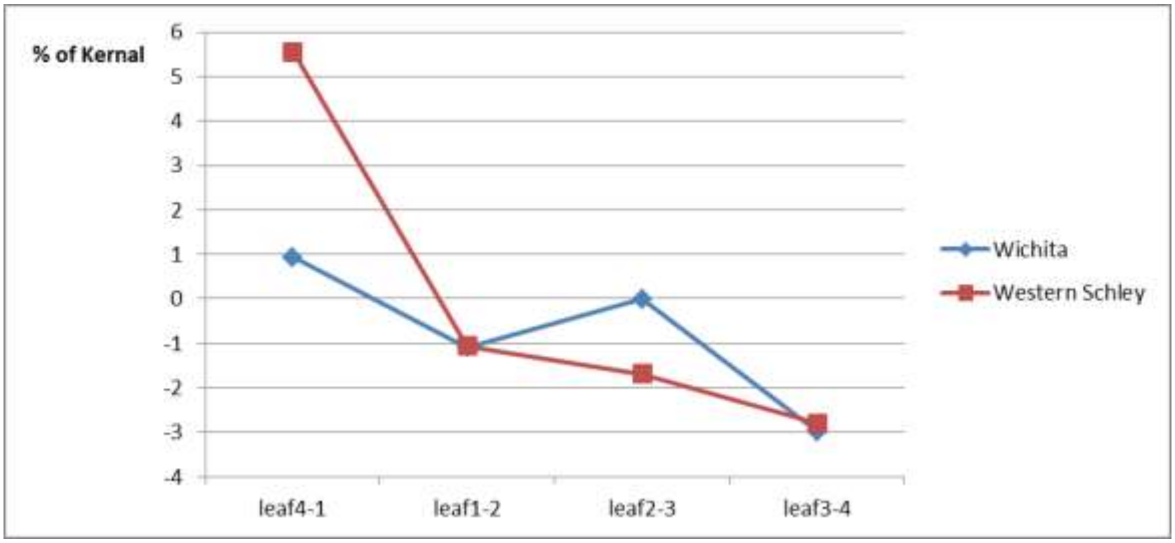


Figure 12: Marginal Quality for Wichita and Western

b. Value Marginal Product (VMP)

The expected VMP values as mentioned in chapter 3 are computed by multiplying Price by the MPP plus adding any price differential for quality times the average expected yield for the next pruning frequencies. We used Price values of \$ 3.5 and \$ 6 for our low and high price scenarios. These numbers represent price of one pound of processed pecan halves. In the following Figures (13 and 14), the farm's revenue per pound is decreasing as the number of season between pruning decrease in the two scenarios. The Western Schley in the first scenario is experiencing an increase because of the significant increase in yield when a change is made between the pruning frequencies of 4 and 1.

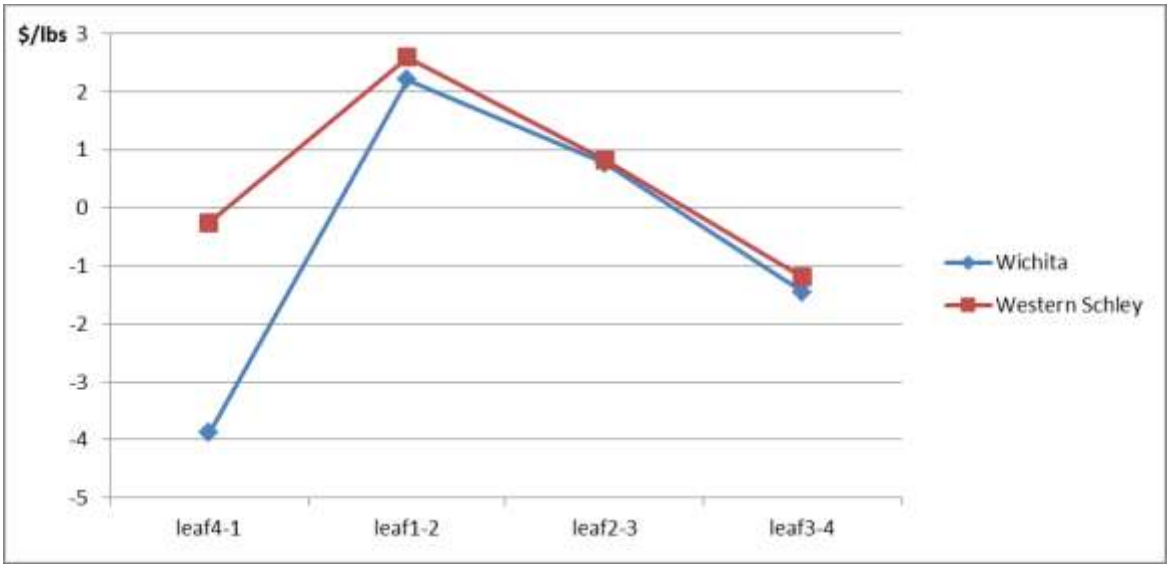


Figure 13: VMP Low Price Scenario P=$3.5

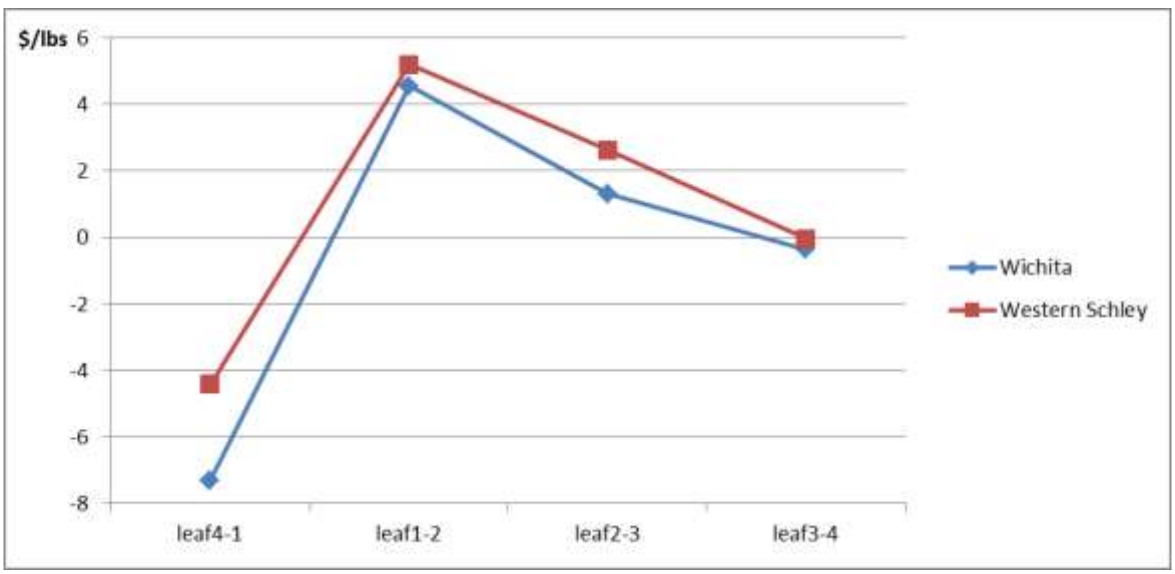


Figure 14: VMP high price Scenario P=$6

c. Marginal Cost

As mentioned in the preceding chapter, the marginal cost computed the same way as the MPP using equation 3.15 to 3.19

According to an interview with one of GVPC's pruning program manager, the pruning cost is around $290 per hour and the topping cost is around $270 per hour. At GVPC they can hedge prune around 8 to 10 acres per hour and top 5 to 7 acres per hour. The final cost of hedge pruning per acre will be around $ 29 to $ 36.25 and the cost of topping is around $ 38.57 to $ 54, for a total of $ 92.57 per acre.

During the processing of pecans, as mentioned earlier in Chapter 3, pecans are given a hot water bath for disinfection and then are cracked and shelled, just the same as the small batches. After being shelled, they are sized into pecan halves and pieces and are picked clean by human eyes. There exist many types of processing, depending on the market, the consumer, and nut quality. We summarized each type of processing with its related estimated cost taken from a sheller's website (Russell's Pecan Orchards). Unfortunately, we did not have access to GVPC's estimated processing cost information.

Table 5: pecans processing costs

step	Description	Estimated cost
cracking	Nuts are processed through a cracking machine. After cracking, nuts are processed through an air cleaner to remove as much shell and unwanted debris as possible.	0.40 per pounds
shelling	Nuts are cracked and then processed through a shelling machine set for the correct size of pecan. After shelling, nuts are processed through an air cleaner to remove as much shell and unwanted debris as possible.	0.85 per pounds
Satake Sort	Including cracking and shelling, this process uses air, infrared and near-vision sensors to remove rejects, i.e., black, or dried-up halves, along with heavy shells.	1.25 per pounds
Shelling plus	After being cracked, shelled, and sorted, nuts are then sent to a processing room where all shell material is removed.	1.50 per pounds

Source: (http://www.russellspecans.com/services.htm)

There were sufficient insights about the type of processing used by GVPC in order to use one the previous cost of processing, we then used equation 3.8 and derived and average cost of $2.27 by using the inshell price of 2007 for improved varieties and a shell price of

3.5 corresponding to our low price scenario. We then added the marginal cost of processing to the one of pruning using equation 3.23.

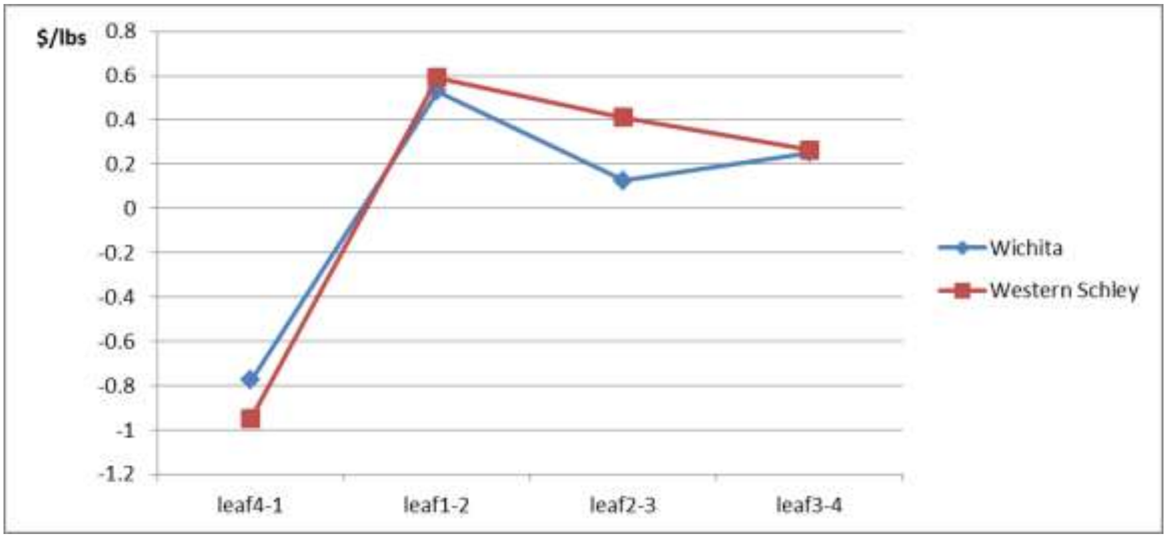


Figure 15: Marginal Cost for Wichita and Western Schley

d. *VMP-MC decision*

The decision under the scenario of low price guides us to a pruning frequency of 3 for both Wichita and Western Schley. When the price is low, the company should wait the third season after the pruning before reaching the maximum profit per pound.

For the high price scenario, the optimal value of the pruning frequency shift from 3 to 4. There a shift of optimal pruning from the low price scenario to the high price scenario because in the low price scenario profit maximization is obtained through the quality. for a pruning frequency of 3 as described in the descriptive statistics, the quality is higher for both varieties and the yield is just above average. In the pecan market, when price is low, customers are more discerning of quality of the nut and the farm management has to choose the pruning frequency improving the quality.

The yield reaches its maximum level for both varieties at a pruning frequency of 4. When the price is high, customers are demanding a high quantity of nuts and they are less concerned about quality, the farm management will then need a considerable amount of nut to satisfy the demand. They may then choose a pruning frequency which maximizes the yield with an above average overall quality.

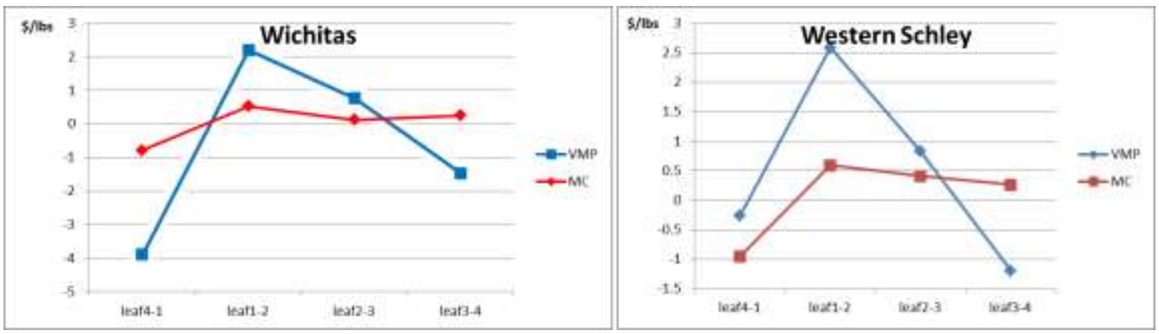


Figure 16: Profit Maximization Low Price Scenario

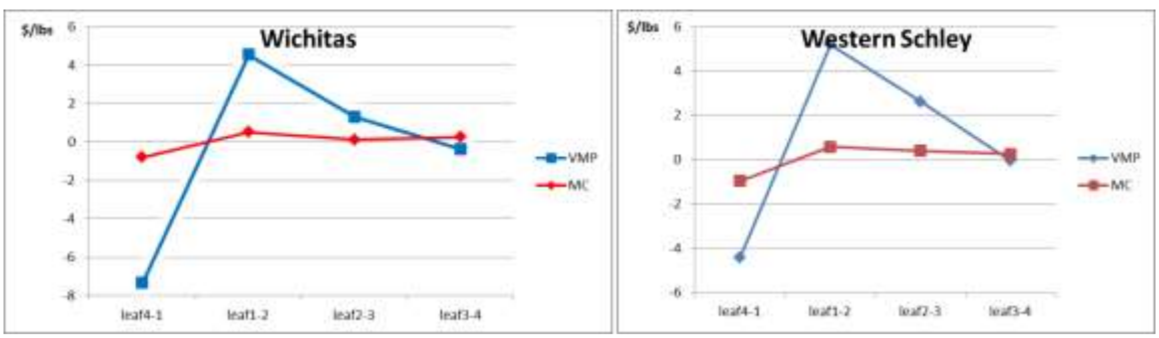


Figure 17: Profit Maximization High Price Scenario

These results give useful informations to the farm management in choosing the optimal pruning frequency. When the market has a low price, they can choose to prune pecan trees every three season to maximize the quality in order to face the competiveness of the market because customers are more sensitive to the quality of nuts. An improved quality will also reduce the processing cost that will keep the company competitive. In another hand, when the price goes up, and customers need more nuts than the market can supply, the farm management will then move from a quality goal to a yield maximization goal because customers are less concerned by the quality than in the preceding low price scenario. The farm management chooses an optimal pruning frequency of 4 which maintain an average quality but improve substantially the yield.

These results are affected by two situations one is market related: the Law of supply and another one more specific to the crop: the tradeoff yield-quality. GVPC with these optimal results could use the situation they have on hand to respond to any market and price fluctuation. When market prices fall, the only way to make revenues higher again is by improving the quality of nut. The quality of the nut as mentioned here is improved by choosing a pruning frequency maximizing the kernal percentage and any other techniques related to watering, fertilization. The improvement of the quality would lead to a decrease in yield. An improved quality will also mean a significant decrease of processing cost.

When market prices rise, GVPC could adjust by making some concessions on the quality in order to get higher yield. Increasing the production is the best way to increase the profit in a high price scenario.

CHAPTER 5: CONCLUSION

In farm management, optimization implies obtaining maximum possible net benefit over time from farm system operations. For pecan growers and shellers, pruning is one of those decisions for maximizing profit. Throughout this study, we presented the specificities of the pecan industry; in Chapter one we described more precisely how the pruning of the pecan plays an essential role in reducing orchard crowding and slowing alternate bearing. Three methods of pruning are often used: mechanical fruit thinning, selective limb pruning, and mechanized hedge type pruning. The pecan industry in the U.S. is composed of three main actors, growers, accumulators, and shellers. GVPC, a sheller located in Sahuarita, Arizona, 9 years ago started a pruning program by arbitrarily selecting a frequency on alternate rows within 3 locations (Sah24, Cont24, and Sah29). After this 9-year period, enough data was available to more formally analyze the effects of the pruning frequency on nut quality and per acre yields. The model consisted of maximizing the expected profit per acre subject to major constraints restraining the expected yield and quality values to functions of other variables, such as the yield per acre and prior year's quality, pruning frequency, and the dummy variables related to varieties and years. The value marginal product and marginal cost condition (VMP-MC) was used as the optimization framework which was then summarized in a simultaneous equation model involving panel data. We used a simultaneous design because throughout the literature on pecans, most studies noticed a tradeoff between yield and quality. If growers want more yield they will lose in quality and vice versa.

This relationship between yield and quality was estimated using a simultaneous two equation model. A fixed effects model was determined most appropriate. Thus, the fixed effects were sweeped out by performing a within transformation and then estimating a regular three stages least squares model of simultaneous equations with no constant terms. We did the estimation by progressively adding covariates. Results from the estimated model showed a strong positive effect on pruning frequency for yield regardless of the variety of pecan (Wichita or Western Schley). Results imply that the more seasons between pruning treatments, the better the yield. We also found that the yield-quality tradeoff represented by the negative signs in both endogenous variables of Yield and Quality was significant in all the models.

The MPP and VMP were generated from the estimated coefficients. For both varieties, the MPP reached its maximum level at a pruning frequency of 4. The VMP was computed by multiplying Price by the MPP plus adding any price differential for quality times the average expected yield under two prices levels (low: $3.5/lb. and high: $6/lb.) representing average low and high prices of processed pecans.

We then computed the Marginal Cost (MC), which is a sum of the marginal costs of pruning and processing. The marginal cost of pruning was computed by using a variable cost of pruning divided by the pruning frequency. Two components were used for the computation of the marginal cost of processing. The first component,is the difference between the average price of shelled and inshell pecans for 2007, or marginal processing costs for season average quality. The second component is the cost variation associated with lower quality and the labor associated with more processing for lower quality nuts.

The optimal pruning frequency was then chosen using the VMP-MC condition. Under the low price scenario, the optimal pruning frequency is nearby the third leaf which is the leaf maximizing the quality for both varieties. The optimal leaf for the high price scenario is located around four years. These results suggest that pecan producers need to shift in how aggressively their pecan trees are pruned, depending on market price levels.

Throughout this study there are some relevant limitations. An improved analysis could be done if prices were made stochastic. However, given that a one year shift in pruning frequency results between the low and high price scenario, it is doubtful that much benefit would be derived from treating price as a stochastic variable. More detail regarding how pecan processing costs shift from having high versus low quality nuts be useful to compute more accurate marginal costs. A general cost analysis across shellers would have also helped us to understand the specificities of the costs of processing pecans.

The dataset used had 245 observations over only 4 years of data; this study could have drawn better empirical results if the sample was larger or the treatments were observed for more years. During the present research we were not able to have a control sample with rows that were not pruned at all. A control sample would have served as a validation or comparison to the optimization framework.

An instrument to explain Quality that does not directly impact Yield (e.g., possibly night temperatures) would improve the simultaneous modeling approach. The study may also be improved by adding more input covariates in the yield equation in order to sustain the effect of the pruning frequency.

REFERENCES

Green valley Pecan Tradition. (2013). Retrieved March 15, 2013, from Green valley Pecan: http://www.greenvalleypecan.com/tradition/

Antle, J. M., Capalbo,, S. M., & Crissman, C. C. (1994). Econometric Production Models with Endogenous Input Timing: An Application to Ecuadorian Potato Production. *Journal of Agricultural and Resource Economics*, 1-18.

Baltagi, B. H. (2005). *Econometric Analysis of Panel Data.* West Sussex, England: John Wiley & Sons, Ltd.

Beattie, B., Taylor, R., & Watts, M. (2009). *The Economics of Production.* Malabar, Florida: Krieger Publishing Company.

Bertsekas, D. P., & Shreve, S. E. (1996). *Stochastic Optimal Control: The Discrete-Time Case.* Belmont, MA: Athena Scientific.

Blank, S. C., Orloff, S. B., & Putnam, D. H. (2001). Sequential Stochastic Production Decisions for a Perennial Crop: The Yield/Quality Tradeoff for Alfalfa Hay. *Journal ofAgricultural and Resource Economics*, 195-211.

Brison, F. R. (1974). *Pecan culture.* Madison: Capital Print.

Cocks, K. D. (1968). Discrete Stochastic Programming. *Management Science*, 72-79.

Dillon, C. R. (1999). Production Practice Alternatives for Income and Suitable Field Day Risk Management. *Journal of Agricultural and Applied Economics*.

Economic Research Service USDA. (2012, July 11). *Fruit and Tree Nut Data* . Retrieved June 22, 2013, from USDA Economic Research Service: http://www.ers.usda.gov/data-products/fruit-and-tree-nut-data/data-by-commodity-imports-and-exports.aspx?programArea=fruit&stat_year=2006&top=5&HardCopy=True&RowsPerPage=25&groupName=Tree%20nuts&commodityName=Pecans#Pc4785a3d59374d92a3f5235438b8e1ff_3_203

Fabian, C. I., & Szoke, Z. (2000). *Solving Two-Stage Stochastic Programming Problems with Level Decomposition.* Budapest, Hungary: University of Budapest.

Florkowski, W. J., & Elnagheeb, A. H. (1993). Modeling Perennial Crop Supply: An Illustration from the Pecan Industry. *Agr. and Applied .Econ*, 187-196.

Garoian, L., Conner, J. R., & Scifres, C. J. (1987). A Discrete stochastic Programming Model To Estimate Optimal Burning Schedules on Rangeland. *Southern Journal of Agricultural Economics*, 53-60.

Hardaker, J. B., & Tanago, A. G. (1973). ASSESSMENT OF THE OUTPUT OF A STOCHASTIC DECISION MODEL. *AUSTRALIAN JOURNAL OF AGRICULTURAL ECONOMICS*, 170-178.

Hatch, U., Atwood, J., & Segar, J. (1989). AN APPLICATION OF SAFETY-FIRST PROBABILITY LIMITS IN A DISCRETE STOCHASTIC FARM MANAGEMENT PROGRAMMING MODEL. *SOUTHERN JOURNAL OF AGRICULTURAL ECONOMICS*, 65-72.

Ibrahim, M., & Florkowski, W. J. (2004). Price-Inventory Relationship in the Pecan Industry: A Study of Long- and Short-Run Effects with Seasonal Consideration. *Southern Agricultural Economics Association.* Tulsa, Oklahoma.

Larson, J. A., & Mapp, H. P. (1997). Cotton Cultivar, Planting, Irrigating, and Harvesting Decisions Under Risk. *Journal of Agricultural and Resource Economics*, 157-173.

Lombardini, L. (2006). One-time Pruning of Pecan Trees Induced Limited and Short-Term Benefits in Canopy Light Penetration, Yield, and Nut Quality. *HortScience*, 1469-1473.

Markowitz, H. (1952). Portfolio Selection. *The Journal of Finance*, 77-91.

National Agricultural Statistics Service. (2007). *AGRICULTURAL STATISTICS 2007.* WASHINGTON DC: UNITED STATES GOVERNEMNT PRINTING OFFICE.

Onunkwo, I. M., & Epperson, J. E. (1999). Export Demand for US Pecans: Impacts of US Export Promotion Programs. *American Agricultural Economics Association.* Nashville, Tennessee.

Orloff, S., Ackerly, T., & Putman, D. (2000). Quantifying the Yield/Quality Tradeoff. *National Alfalfa Symposium.* Las Vegas: UC Cooperative Extension, University of California, Davis.

Russell's Pecan Orchards. (n.d.). *Pecan nut Cracking and Shelling*. Retrieved April 15, 2013, from Customer Services Russell's Pecan Orchards: http://www.russellspecans.com/services.htm

Shockley, J. M., Dillon, C. R., & Stombaugh, T. S. (2011). AWhole Farm Analysis of the Influence of Auto-Steer Navigation on Net Returns, Risk, and Production Practices. *Journal of Agricultural and Applied Economics*, 57-75.

Springer, J. (2011). Profitability of Irrigated Improved Pecan Orchards in the Southern Plains. *Southern Agricultural Economics Association.* Corpus Christi, TX.

University of Georgia Pecan Team. (2005). *Southeastern Pecan Growers' Handbook.* The University of Georgia College of Agricultural and Environmental Sciences.

Vassalos, M., Dillon, C. R., & Coolong, T. (2012). Choice of Optimal Planting and Marketing Decisions for Fresh Vegetable Producers: A Mathematical Programming Approach. *Southern Agricultural Economics Association Annual Meeting.* Birmingham, AL.

Walworth, J. (2012). Impact of Hedge Pruning. *46th Annual WESTERN PECAN GROWERS ASSOCIATION*, (pp. 5-11). Las Cruces, New Mexico.

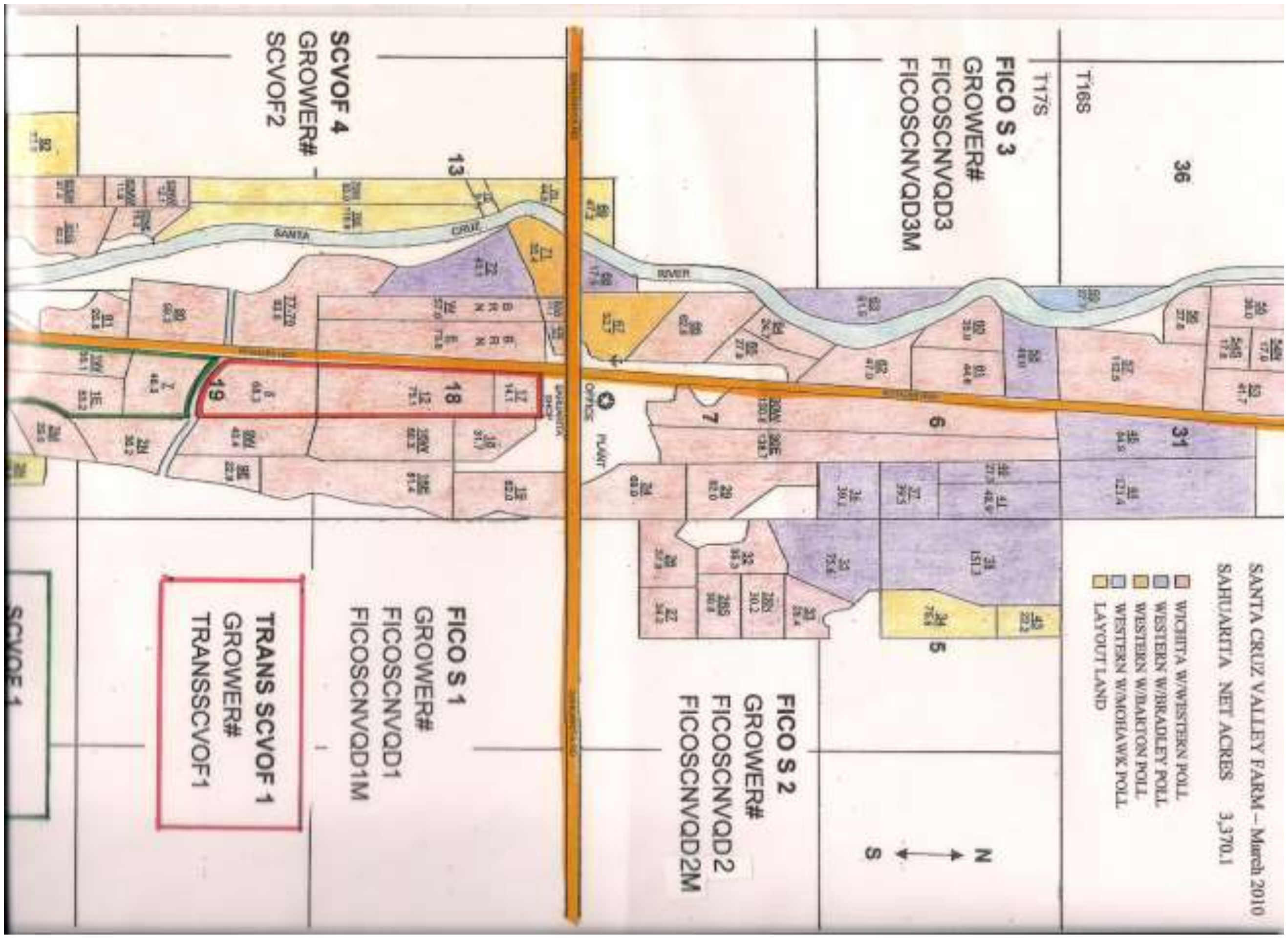
Wood, B. (2009). Mechanical Hedge Pruning of Pecan in a Relatively Low-light Environment. *HortScience*, 68-72.

Wood, B. W. (2000). *Production Unit Trends and Price Characteristics within the United States Pecan Industry.* Byron, Georgia: USDA.

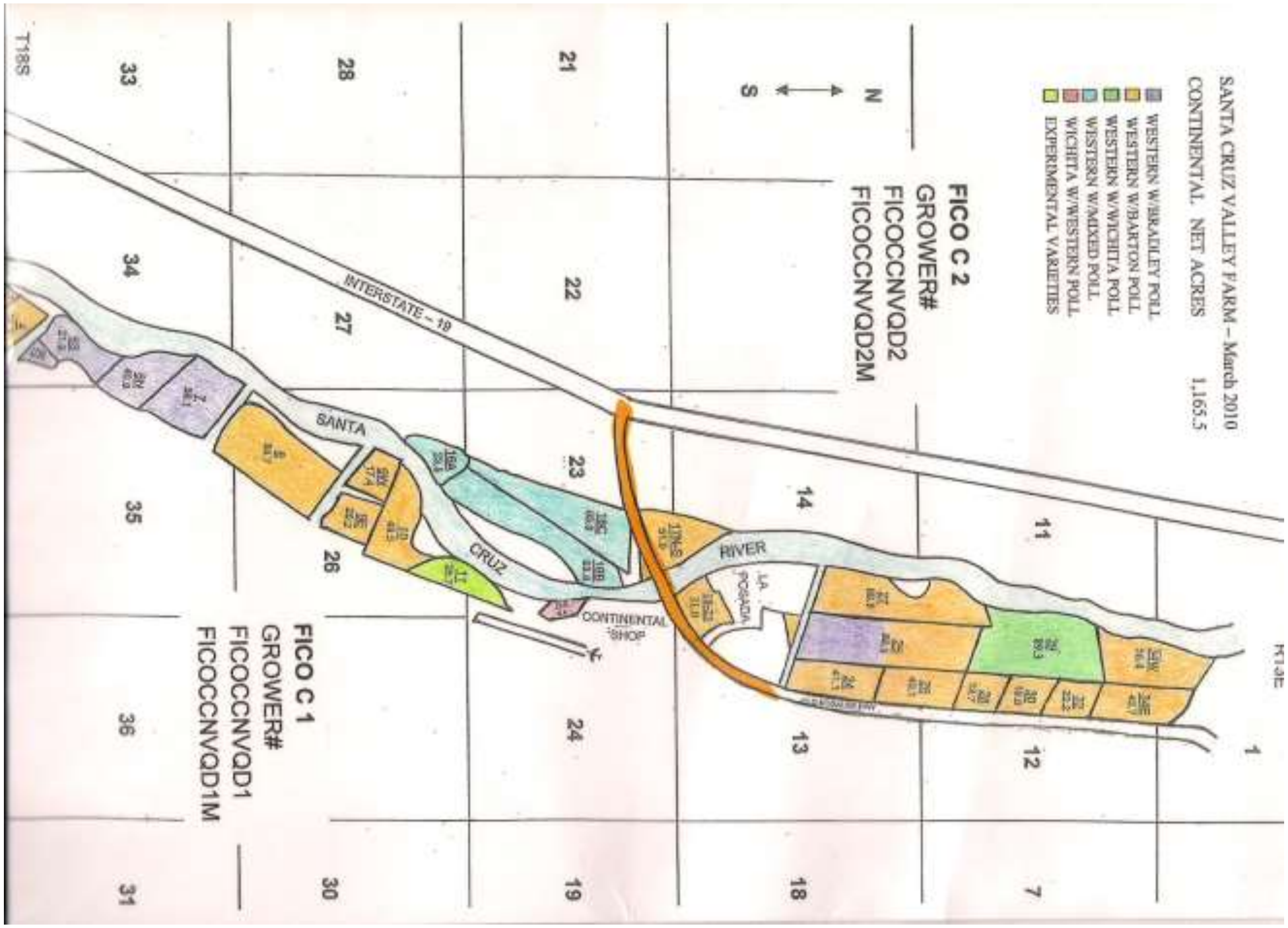
Wood, B. W., & Stahmann, D. (2004, January-March). Hedge Pruning Pecan. *Hortechnology*, 63-72.

Worley, R. E. (1991). Selective Limb Pruning Intensity Influences Mature Pecan Tree and Nut Characteristics. *Hortscience*, 126-129.

Appendix 1A Map of the Study Area: FICO S 2, FICO S 1, FICO S 3, SCVOF 4, SCVOF 1 AND TRANS SCVOF 1



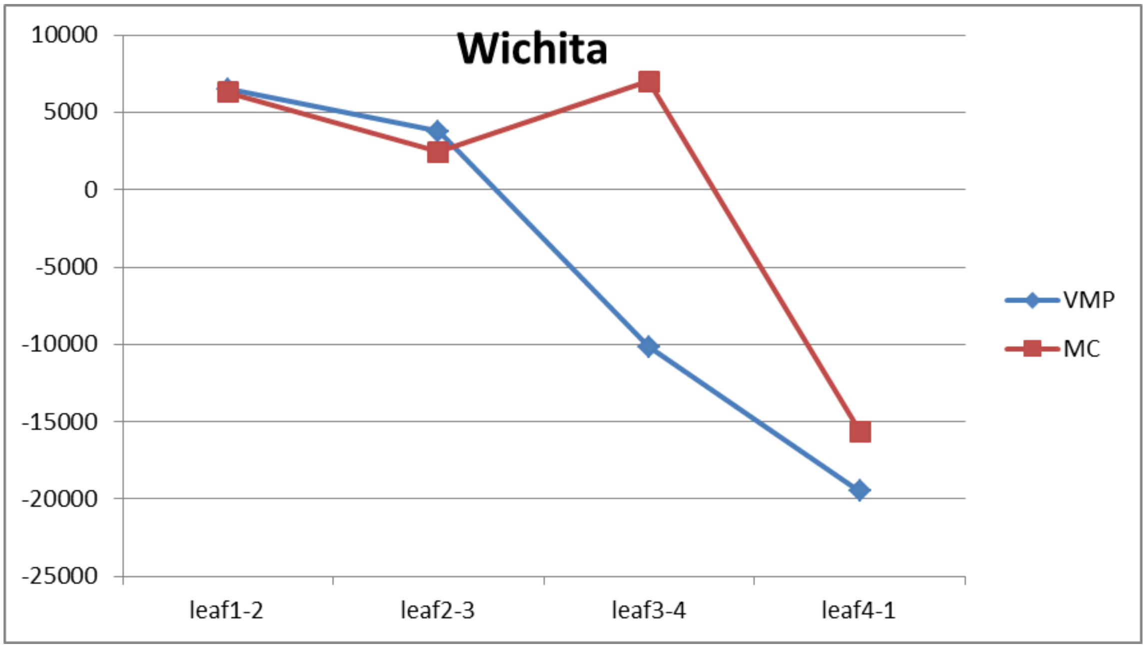
Appendix 1B: Map of the Study Area: FICO C 1 AND FICO C 2

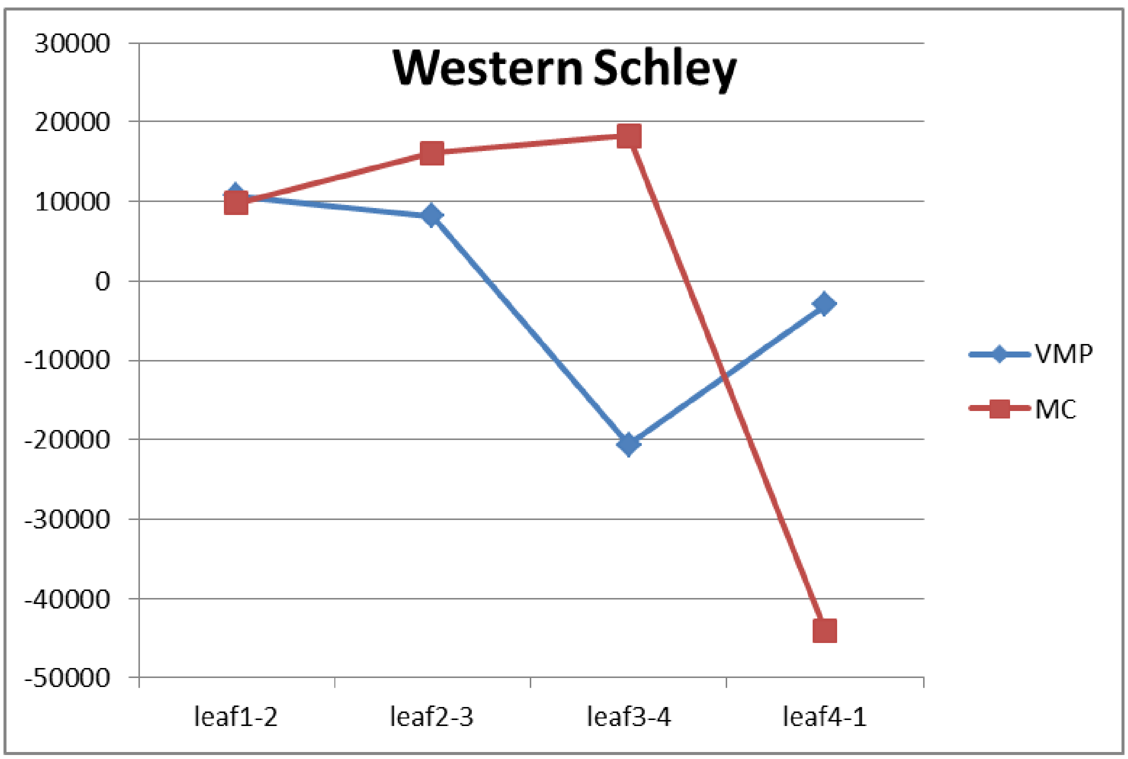


Appendix 2 Price and Production of Inshell pecans from 1980 to 2010

Year	Improved varieties 1/				Native and seedling				All pecans 2/		
	Production	Price	Value		Production	Price	Value		Production	Price	Value
	1,000 lbs	*Cents/pound*	*$1,000*		*1,000 lbs*	*Cents/pound*	*$1,000*		*1,000 lbs*	*Cents/pound*	*$1,000*
1980	128,500	84.8	109,015		55,000	62.3	34,254		183,500	78.1	143,269
1981	174,550	64.7	112,987		164,550	43.7	71,855		339,100	54.5	184,842
1982	169,000	72.6	122,776		49,600	49.8	24,715		218,600	67.5	147,491
1983	167,250	67.7	113,199		102,750	44.0	45,190		270,000	58.7	158,389
1984	169,230	68.2	115,406		63,170	46.6	29,424		232,400	62.3	144,830
1985	152,500	79.1	120,582		91,900	49.7	45,706		244,400	68.0	166,288
1986	182,650	79.3	144,765		90,050	57.6	51,884		272,700	72.1	196,649
1987	179,650	60.1	107,953		82,550	37.7	31,156		262,200	53.1	139,109
1988	185,500	62.6	116,210		122,700	41.1	50,448		308,200	54.1	166,658
1989	161,000	78.6	126,491		73,200	53.8	39,350		250,500	71.5	179,040
1990	143,500	128.0	184,135		41,250	90.2	37,212		205,000	121.0	247,590
1991	163,300	114.0	186,917		115,000	83.5	95,969		299,000	104.0	309,524
1992	104,800	154.0	164,333		41,100	112.0	46,794		166,000	145.0	240,362
1993	237,100	62.9	149,189		109,200	39.6	43,270		365,000	58.6	213,862
1994	118,900	115.0	136,945		59,600	76.4	45,531		199,000	104.0	207,345
1995	174,800	112.0	195,216		76,800	72.5	55,678		267,500	101.0	271,377
1996	165,125	68.9	113,749		44,375	46.4	20,606		209,500	64.1	134,355
1997	202,900	93.3	189,226		132,100	53.0	69,994		335,000	77.4	259,220
1998	112,000	135.0	150,908		34,400	77.2	26,544		146,400	121.0	177,452
1999	219,400	101.0	222,647		186,700	57.7	107,751		406,100	81.4	330,398
2000	160,550	126.0	201,575		49,300	75.4	37,193		209,850	114.0	238,768
2001	246,550	66.2	163,204		91,950	41.2	37,897		338,500	59.4	201,101
2002	130,720	107.0	139,597		42,180	60.3	25,436		172,900	95.5	165,033
2003	202,900	110.0	223,547		79,200	68.3	54,082		282,100	98.4	277,629
2004	138,970	192.0	267,215		46,830	128.0	59,709		185,800	176.0	326,924
2005	228,700	154.0	351,353		51,550	108.0	55,567		280,250	145.0	406,920
2006	152,130	173.0	262,544		55,170	109.0	59,949		207,300	156.0	322,493
2007	303,462	123.0	373,131		83,843	72.2	60,513		387,305	112.0	433,644
2008	173,660	142.0	246,590		28,420	88.3	25,097		202,080	134.0	271,687
2009	249,720	153.0	381,550		52,300	93.4	48,838		302,020	143.0	430,388
2010	232,560	249.0	578,149		61,180	158.0	96,679		293,740	230.0	674,828

Appendix 3 VMP MC Decision in at an area level Low Price Scenario





Appendix 4 VMP MC Decision in at an area level High Price Scenario