PRECISION FARMING TECHNOLOGY ADOPTION IN FLORIDA CITRUS PRODUCTION: A SURVEY AND ANALYSIS, CASE STUDY, AND THEORETICAL REVIEW

By

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This document is dedicated to my family. To my wife Danielle and son Tristan whom have endured the long hours of research and travel, data analysis and finally writing. Danielle you have provided confidence and comfort when needed, and that little extra kick when I didn't want to keep going!! Tristan, now that this is done we have more time to play football in the yard and be buddies again. To Mom and Dad, who were always there to give that extra push when it was needed too. To my brother Kevin, who was always ready to say let's go fishing, well bro' we finally have time to do that now.

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Abstract of Dissertation Presented to the Graduate School
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PRECISION FARMING TECHNOLOGY ADOPTION
IN FLORIDA CITRUS PRODUCTION:
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The research and analysis contained in this dissertation are driven by several objectives. First what is the current level of adoption of precision farming technologies in Florida citrus production? Second, what grower demographic characteristics can influence a citrus grower's decision to adopt precision farming technologies? Next, use a case-study methodology to analyze citrus caretaking firm that has adopted two precision farming technologies, variable rate technology (VRT) and an irrigation moisture control system. Last, what comparisons can be made between the adoptions of precision farming technologies in citrus production versus similar technologies in non-specialized row crops?

Precision farming technology adoption levels in Florida citrus production are still at infancy levels. However, the research has determined that grower age has a negative correlation to the willingness to adopt precision farming technologies. Second, growers

managing properties with a perceived level of moderate or high in-grove spatial variability are more likely to adopt precision farming technologies when compared to those indicating minimal variability.

The case study analysis was performed on a citrus care taking company that has adopted two precision farming technologies. Both the variable rate fertilizer application and the moisture and irrigation control system have resulted in net production savings and increased financial returns, as determined by increased marketable citrus yield.

Although still in its infancy, precision farming usage in Florida citrus faces many barriers to adoption. The technologies in some cases are not perfected, and the buy-in by grove owners and managers has not occurred. The potential for these precision farming systems are existent, especially considering the pricing structure that citrus producers operate under. They are price takers; so having the ability to decrease production costs is one way to gain additional revenue at the margin.

CHAPTER 1
INTRODUCTION

The Florida Citrus Industry

Overview

Florida agriculture consists of primarily what most agriculturists consider specialty or non-traditional crops. In the panhandle and northern end of the state, the production area is composed primarily of soybean, peanuts, tobacco and cotton. The majority of the production area from just north of Orlando, FL, spanning southward is dedicated to winter vegetables and fruit, nursery and horticultural crops; and sugarcane and citrus.

Citrus was introduced to Florida between 1513 and 1563. Citrus originated in the Orient, specifically China, and it was introduced into the New World by Christopher Columbus via the Mediterranean. The first planting of citrus in the Americas by Columbus was on the island of Hispaniola. Juan de Grijalva first recorded mainland plantings in 1518 when he landed in Central America (FASS, 2003). By the year 1563, many groves had already been established around the areas of St. Augustine and Orange Lake in northeastern Florida. Although these groves had been established for a number of years, commercial production did not begin until 1763. By 1890, commercial production in Florida consumed 46,458 hectares (ha) (Jackson and Davies, 1999).

The citrus industry began to transport fruit across the Atlantic back to Great Britain and other European countries in 1776. In the winter of 1894-1895, the citrus industry in northern Florida experienced its first true disaster. A major freeze killed 90-95 percent of the state’s plantings. The freeze brought the total area of citrus plantings down to 19,506 hectares in a single winter. Of this area, 97 percent were immature nonbearing trees. Six more catastrophic freezes occurred between 1899 and 1962. This forced many growers to relocate groves farther south, out of the reach of winter freezes. Much of this relocation and expansion occurred in the 1960's. By 1971 there were approximately 354,910 ha of citrus in Florida (Jackson and Davies, 1999).

In 2002, there were 322,658 ha of citrus in commercial groves in Florida, down 4.2 percent from 2000. Bearing production area in Florida is represented in Figure 1-1 as compared to other major citrus producing states. This figure illustrates the area in production by state, which has mature citrus that is producing fruit for commercial sales. Of the total production area in Florida, 81.4 percent was dedicated to orange production, 13.2 percent to grapefruit production, and the remaining 5.4 percent to specialty fruit (e.g., tangerines, tangelos, limes, etc.) (FASS, 2002).

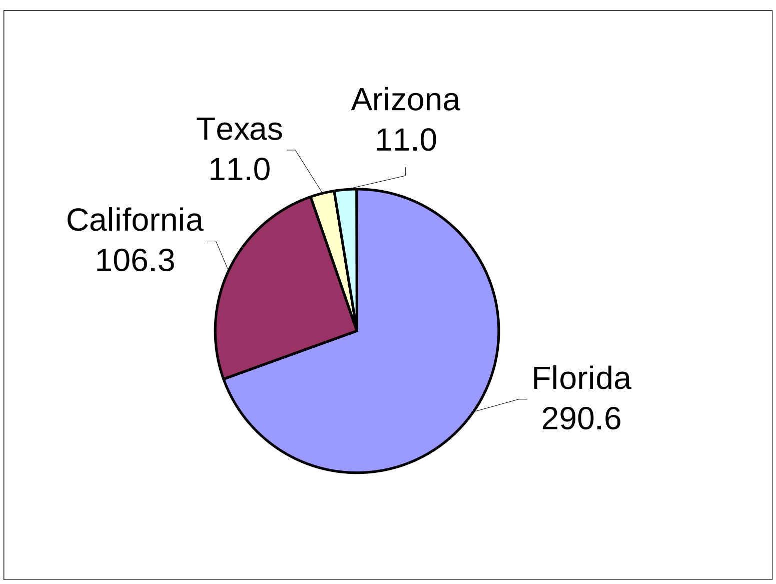

Figure 1-1. 2002-03 Citrus Production Area by State – 1,000 hectares

Figure 1-2 illustrates the total citrus production in metric tones by state for all citrus varieties. These varieties include oranges, grapefruit, tangerines, and lemons. As both figures reveal, Florida is the primary citrus producing state in both production area and total production in the United States (FASS, 2003).

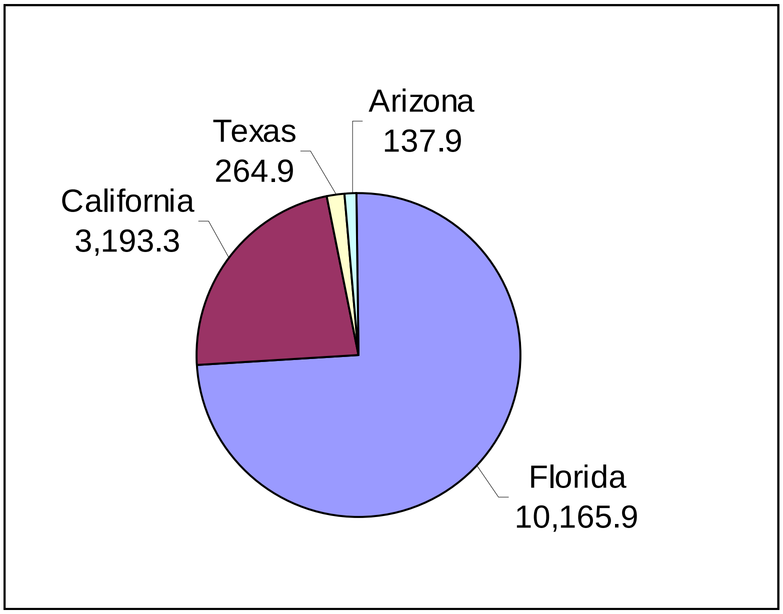

Figure 1-2. 2002-03 Total Citrus Production by State – 1,000 MT

Objectives

There is a large amount of literature discussing the feasibility, economics, and profitability of precision farming in agronomic crops; however there is currently no such study on citrus. In addition, precision farming technology adoption studies have been performed on various types of producers from many regions of the country, growing many types of crops; again no such study has been performed on the adoption of precision farming technologies in citrus. As illustrated in the figures above, Florida is by far the largest producer of citrus in the United States (in both MT of yield and commercial production area), so why wasn't any information on the adoption of precision farming technologies available? If the technology is available, and its effectiveness has been proven in other types of cropping systems, why hadn't Florida's citrus producers accepted it? Or have they?

This research study identifies the current level of adoption of precision farming technologies in Florida citrus production, by determining "how many" growers have adopted. Drawing from the body of literature on technology diffusion, citrus producers will be grouped into adopter categories. These categories represent the grower's willingness to adopt discoveries and innovations that are presented to them. These adopter categories assist in determining where the Florida citrus industry is in the technology adoption life cycle, with regard to precision farming technologies.

Knowing the current level of adoption is valuable, but that only answers the question of "how many". The next research question that needs an answer was "who". In order to answer this, this study identifies grower characteristics that influence the decision to adopt precision farming technologies. This study will also try and answer questions like, "Does the age of the grower influence their willingness to adopt new technologies?" or "Does the education level of the grower have an impact on their decision to adopt site-specific crop management practices?" By answering "who", a demographic profile can be created for adopters of precision technologies in Florida citrus.

In an effort to expound on "how many" and "who", the next objective is to determine "why". What is the driving force that causes a citrus producer to adopt a new technology and change their management practices? What considerations should the grower or the firm make before deciding to invest in new technologies? These are questions that can only be answered by a grower that has already made the adoption decision. A case study analysis will be used to investigate the technology adoption process imposed by a citrus care taking firm. By using a real company for the case study analysis, not only can the "why" be answered, but also "what" technologies were adopted.

Potential for Technology Adoption

There is a large potential for the adoption of precision technologies in citrus production. Per unit costs of production of Florida citrus have been volatile, causing producers to attempt to find ways to control this volatility. The premise behind site-specific crop management (SSCM) technologies seems to lend itself perfectly to the production scenario in citrus. If growers were able to manage their input applications based on a site-specific basis, then the cost of production has the potential to be maintained at a lower level. These inputs include herbicide, insecticide, nematicide, fungicide, fertilization, post-bloom sprays, and irrigation. In addition there are also tree maintenance issues with resets (newly planted nursery trees where mature trees have been removed), topping and hedging, and chemical or mechanical mowing (Muraro and Oswalt, 2002). If the grower is using mechanical harvesting, then chemical abscission agents are also required to assist in removing mature fruit from trees.

Table 1-1 below, shows the annual cost of production per hectare for several types of citrus. These figures represent the cost of production per hectare, and the percent change from one season to the next. In all four citrus types provided in Table 1-1, the cost of production during the 2001/02 season represents a net increase in production costs from the 1997/98 season. Several studies have shown that the adoption of precision agriculture technologies and practices would be biased towards crops or commodities that are input intensive (Daberkow, 1997).

Table 1-1. Selected per hectare cost of production for several geographic regions and varieties of citrus in Florida (Muraro and Oswalt, 2002; Muraro et al., 2002a; Muraro et al., 2002b).

Indian River - Fresh White Grapefruit	97-98	98-99	99-00	00-01	01-02
per hectare cost of production	$2,288.61	$2,279.67	$2,351.13	$2,407.94	$2,492.72
%change from previous season		-0.39 %	3.13 %	2.42 %	3.52 %
Southwest - Processed Hamlin Oranges	97-98	98-99	99-00	00-01	01-02
per hectare cost of production	$1,804.98	$1,841.38	$1,875.18	$1,900.34	$1,895.86
%change from previous season		2.02 %	1.84 %	1.34 %	-0.24 %
Southwest - Fresh Red Seedless Grapefruit	97-98	98-99	99-00	00-01	01-02
per hectare cost of production	$2,024.88	$2,085.49	$2,142.55	$2,136.94	$2,161.03
%change from previous season		2.99 %	2.74 %	-0.26 %	1.13 %
Ridge - Processed Valencia Oranges	97-98	98-99	99-00	00-01	01-02
per hectare cost of production	$1,891.98	$1,904.66	$1,935.89	$1,875.16	$1,897.20
%change from previous season		0.67 %	1.64 %	-3.14 %	1.18 %

--primary data have been converted from acres to hectares

Precision Agriculture

Production practices in agriculture are constantly changing. The introduction of site-specific crop management (SSCM), also known as precision farming, is among the newest advances in production agriculture and mechanization. The use of multiple technologies with traditional production practices has opened a new era of "high-tech" farming. The use of yield monitoring, variable-rate technology (VRT) applications of herbicide, pesticide and fertilizer, remote sensing, and soil sampling, are examples of precision agriculture. In addition, the application of the Global Positioning System (GPS) and geographic information systems (GIS) are major components of many precision farming technologies. The National Research Council (NRC, 1997) defines precision agriculture as *"a management strategy that uses information technologies to bring data from multiple sources to bear on decisions associated with crop production."* Morgan and Ess (2003) provided the following definition for precision agriculture *"managing each crop production input…on a site-specific basis to reduce waste, increase profits, and maintain the quality of the environment."*

The usefulness of precision agriculture or SSCM lies in the value of the information. The adoption of a precision farming technology comes at a cost, and often a high one. The efficiencies gained in production methods must outweigh the cost of adoption, or it is economically infeasible. Precision farming technologies provide information that is gathered from a series of interrelated components. As mentioned above, grid sampling and yield monitoring in conjunction with GPS technologies offer a bird's-eye view of the production area; the grove in this study. This information is then used to determine the spatial variability within the grove. The variability of soil conditions, weed and pest outbreaks, and yield are then transferred into the use of variable rate technologies to target that variability, and manage crop inputs on a site-specific basis (Khanna et al., 2000).

Precision agriculture technologies are currently being used in the production of cereal and grain crops; cotton, peanuts and soybean; potatoes, tomatoes, and sugar beets; forage and grass crops; sugarcane and citrus. SSCM offers the producer an alternative to enhancing input efficiencies over standardized production methods. These alternatives are provided by the acquisition of information, at a cost, about spatial variability within the production area, and then using that information to target those inputs at the locations of the variability (Khanna et al., 2000). The purpose of precision agriculture is multifold. First, growers seek to increase profits by maximizing yield, while simultaneously decreasing production costs by carefully tailoring soil and crop management. Second, producers are becoming more environmentally aware, and as a result of tailoring inputs, more environmentally friendly practices are implemented. Potentially growers can realize economic benefits by reducing their overall cost of production, likewise the environment benefits, and what appears to be a win-win situation is a result of simply being able to manage inputs site-specifically to production.

Daberkow and McBride (1998) in a survey study of farmers showed a low rate of adoption of precision farming technologies. This is in spite of the potential economic and environmental benefits. According to their results, by 1996, only 4 percent of farmers across the US had adopted variable rate technologies, and only 6 percent had adopted yield monitoring systems. A follow-up to the Daberkow and McBride study done in the Midwest identified adoption levels of 12 percent on VRT systems and 10 percent on yield monitoring (Khanna et al., 1999). The study went on to state that a number of these "adoptions" were producers who contracted services through custom hiring instead of purchasing the technologies outright. Farmers surveyed in their study indicated that the reason for non-adoption included uncertainty about the payback on the high cost investment. Last, their study indicated that farmers were intending and willing to wait on the adoption decision, and that the adoption rates of these technologies are likely to increase fourfold at the end of five years. The processes involved in technology diffusion and adoption will be discussed in further detail in Chapter 2.

The following chapters of this research study will investigate the current level of adoption of precision farming technologies in Florida citrus production. Second, the study will investigate the demographic characteristics and variables that determine the willingness to invest in these technologies. In an effort to expound upon the "who" and "how many" have adopted, a case study analysis will look at the "why", "what" and "how" a citrus farm made the adoption decision. The research questions posed above will try and determine what the current status is for precision farming in the Florida citrus industry, and what to expect with precision farming technologies in the future.

CHAPTER 2
TECHNOLOGY ADOPTION AND A CITRUS PRODUCER SURVEY

Objectives

This chapter of the study is going to discuss the technology adoption life cycle as well as the body of literature dedicated to the diffusion theory of new technologies and innovations. In addition, this chapter will address identifying the current level of adoption of precision farming technologies for citrus producers in the 10 largest citrus producing counties in the state of Florida. Additionally this chapter investigates the attitudes of adopters versus non-adopters towards technology in general. The specific objectives for this chapter are to quantify the adoption rate of precision farming technologies in Florida citrus production, and to determine where the industry is on the technology life-cycle curve.

Background

Diffusion Theory

Diffusion theory is the body of work that describes the process by which technological advances are discovered then distributed. Classical literature on the theory of diffusion field dates back to Rogers (1962; 2003), Ruttan (1959), and Katz (1961), as well as others even earlier. Rogers identifies four elements of the diffusion of innovations. The first element is the “innovation” itself; the discovery of an idea, technology, or social movement. Element two is the process by which the innovation spreads or disseminates, hence “diffusion”. The third element is the “social system”; the collective body or population that is encountered by this innovation. The members of the social system can be individuals, firms or collective groups of either. The last element is "time". The diffusion of an innovation has temporal aspects that must be considered. The innovation must travel a process of diffusion through some social system, and it must travel the process over a period of time. Diffusion is not instantaneous and can occur within the population by different channels of communication of the innovation (Grubler, 1998). Rogers describes the adoption process as a "…mental process through which an individual passes from first hearing about an innovation to final adoption." This definition implies the affect of time on the diffusion of innovations. Geroski (2000) also states that the diffusion process can occur rapidly, but inherently more time is spent on the adoption of the innovation.

The diffusion of innovation is a topic that is studied by a wide variety of disciplines. Most often economics and sociology are the fields that provide the most attention to the subject (Fisher et al., 2000). The diffusion of innovation and the adoption decision process, although linked, are separate and distinct processes. Diffusion is differentiated from adoption, in that diffusion is the process by which a new product is distributed amongst the population; adoption is the internal decision making process that an individual or firm must go through. Many researchers, especially in the field of economics, use binomial models to investigate technology adoption. An example of one of the binomial models is found in Chapter 3 of this study. The life cycle of adoption and the adoption process will be discussed in the next section of this chapter.

Technology Adoption Life Cycle

The technology adoption life cycle refers to cycle and process that an innovation travels through to the point of adoption by some population. The population can be individuals or firms; this study's emphasis was on the adoption life cycle of precision farming technologies and their acceptance within the Florida citrus industry.

In the literature, the technology adoption life cycle has been illustrated in several forms. A common representation of the life cycle is illustrated as a normal bell-curve (Rogers, 1962, and Moore, 1991). See Figure 2-1 below. This representation of the technology adoption life cycle is measured over time and is continuous.

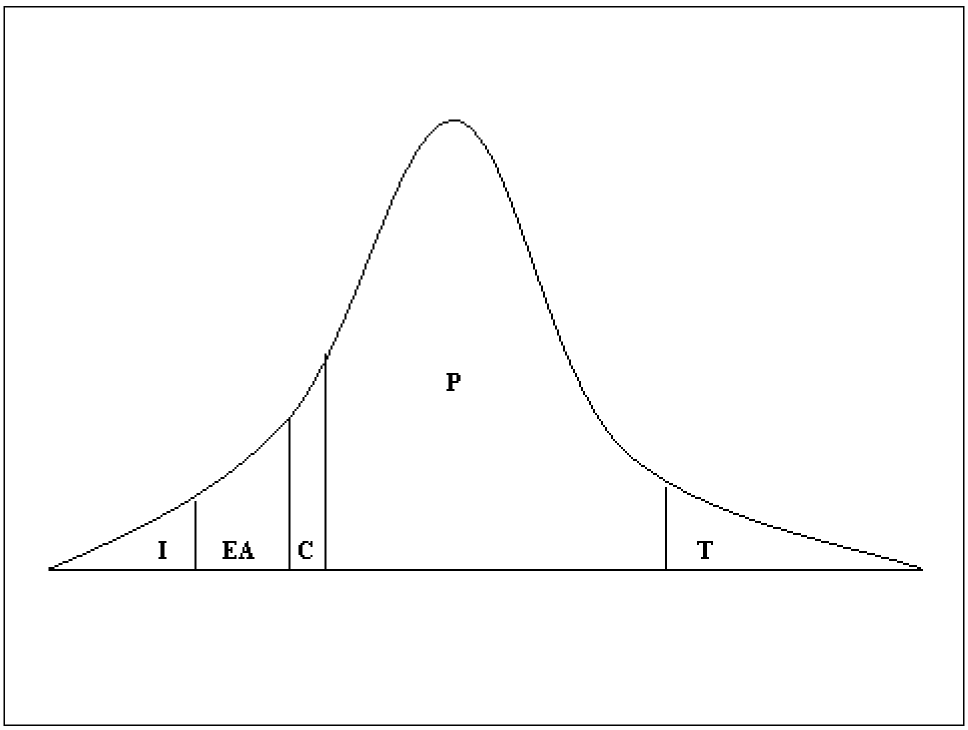

Figure 2-1. Bell-curve technology adoption life cycle.

The area under the curve is broken into adopter categories as seen above (Moore, 1991):

- Innovators (I): technology enthusiasts who adopt technology for its own sake.
- Early adopters (EA): firms or individuals whom adopt new technologies to take an opportunity that benefits them.
- The Chasm (C): Moore refers to this as a "time gap" between the EA category and the P category.

- Pragmatists (P): Moore differentiates this section into both the "Early Majority" and "Late Majority". The "Early Majority" is risk averse, yet is ready to adopt tested technologies. The "Late Majority" dislike innovation, and believe in standard traditional practices rather than technological advancement; usually adopting reluctantly.

- Traditionalists (T): described by both Moore and Rogers as laggards. They do not engage with high tech innovations.

Other literature has chosen to represent the technology adoption life cycle as a series of S-curves, or logistic curves (Easterling et al., 2003, and Geroski, 2000). The justification being that the normal bell curve representation does not reflect the aggregate adoption of a technology over time. The bell-curve representation of the technology adoption life-cycle does measure adoption temporally, but it does not show the fraction of adopters, at each point in time, which makes the S-curve representation more favorable.

The use of the S-curve allows for the representation of each adopter category, similar to those of Rogers and Moore, but as a fraction of total adoption over time. The pattern of adoption begins with a period of slow growth, followed by a period of time in which accelerated acceptance is observed, and finally growth tapering off until saturation is reached. The Easterling et al. study (2003) was in the context of climatic change affecting agronomic production practices. The study equated climatic change to a technology innovation, in order to model changes in agronomic practices. Although climatic change occurs during a much longer time period than most technological advances, the concept of measuring adaptation and adoption to climate is synonymous with identifying adopters of an unfamiliar management strategy as seen in precision farming technologies.

Rogers (2003) reviews both the S-curve and the normal distribution curve of adoption based on a study by Ryan and Gross (1943) on hybrid corn adoption in two

Iowa communities. In the figure below, both curves are produced from the same data set collected by Ryan and Gross (1943), but the bell-shaped curve shows the number of new adopters at each time frequency, where as the S-Shaped curve shows cumulative adoption at each frequency frequencies. Both curves are normally distributed, but each provides a different illustration of the data.

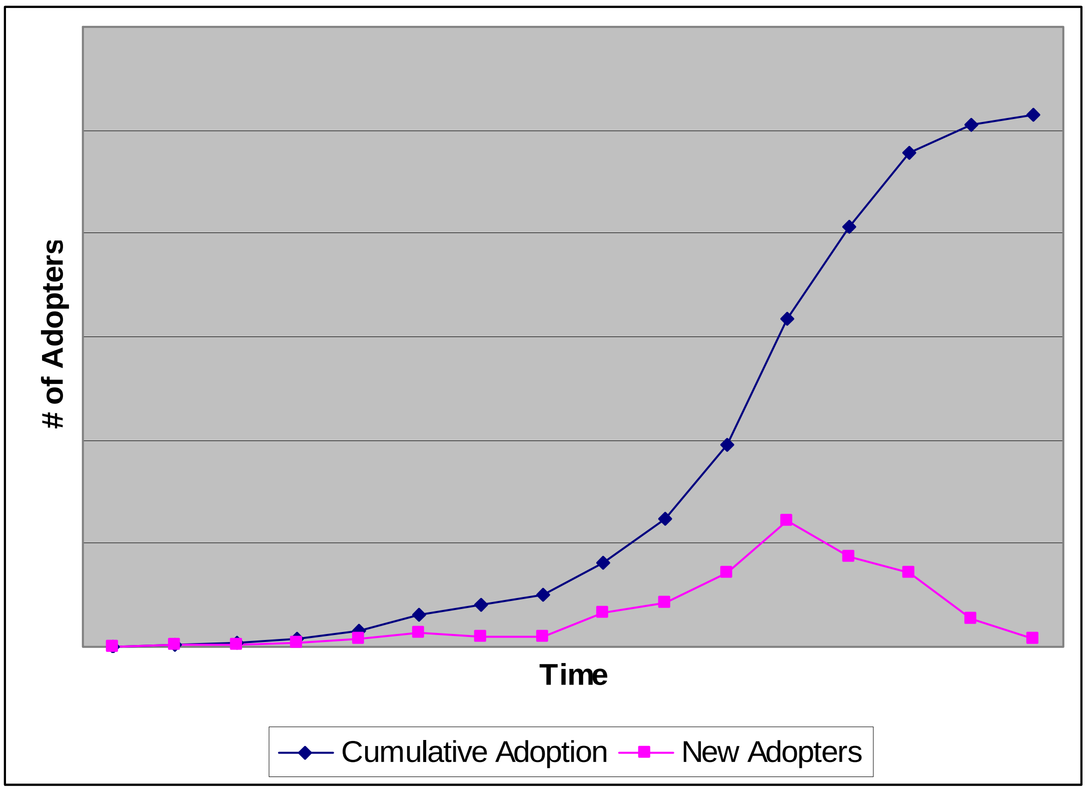

Figure 2-2: S-Curve Adoption vs. Normal Distribution Curve

Precision farming technologies in citrus have not reached the level of acceptance as in traditional row crops, and are still in the infant stages of adoption. Although the manufacture and distribution of these technologies has been going on since the late 1990’s and early 2000’s, they have yet to become a generally accepted tool in production management. These site-specific technologies are still undergoing rapid improvements, causing many early adopters to feel "penalized". As witnessed in the information technology industry, obsolescence occurs very rapidly. Early adopters are willing to be the first to buy-in; yet they have undoubtedly paid a premium for technology that will still undergo many evolutions of technological change and perfection. In addition, current prices for these technologies will decrease as demand grows; allowing manufacturers allocate more economies of scale to their production (Khanna et al, 2000). Early adopters essentially forfeit their ability to invest in the "new and improved" next generation of their adopted technology, at least not until their original investment has been fully depreciated.

Methodology

Survey and Data Collection

The primary instrument used to carry out this research to determine the current technology adoption levels was a mail survey questionnaire. The self-administered questionnaire is an efficient and cost-effective way to collect data from a large and often geographically disbursed group (Fowler, 2002). The first step in any survey-based research is to identify a sample, and then a sample frame. The population of interest is citrus producers in the state of Florida.

Sample Selection

In previous research (D'Souza et al., 1993; Daberkow and McBride, 1998; Khanna, 2001), it was determined that one of the primary barriers to adoption of alternative production practices was the scale of the operation. In citrus production, scale can be defined in two ways. First, scale can simply be the production area (acres or hectares) of planted commercial citrus. Second, scale can be stated in the number of trees (total area multiplied by the tree density). Tree density (trees planted per ha), is not a static variable in the Florida citrus industry, so it is difficult to determine tree counts accurately. For example, in the early 1970's, average tree density for oranges and grapefruits was approximately 198 trees per ha and 180 trees per ha, respectively. As of 2002, tree density was approximately 326 trees per ha for citrus and 267 trees per ha for grapefruit (FASS, 2002). Since tree density can vary so greatly, the scale was determined to be the production area of planted commercial citrus in hectares.

In identifying a sample, the top 10 citrus producing counties in the state were selected based on area in citrus production. Table 2-1 itemizes each county and its respective percentage of the total citrus production area in the state. Counties eleven through thirteen counties were omitted from the survey sample due to the nature of the ownership in those counties. In Lake County alone, there was an estimated 2,000 growers with relatively small groves (fewer than 4 ha per owner). This clientele would inherently be the last group expected to adopt precision technologies based on the assumption of scale as a barrier. A map of the geographic areas that were sampled is provided in Appendix C.

By assuming scale to be a barrier to adoption, the focus was on growers who had been identified in the industry as having at least 40 ha of area dedicated to citrus production. The state's main growers association, Florida Citrus Mutual (FCM), provided information on growers' scales of operation. By using FCM membership records, small growers were segregated from large growers.

Table 2-1. Top 13 citrus producing counties in Florida (FASS, 2002).

Rank	County	All Citrus Production Area (ha)	percent of Total		
1	Polk	40,550	12.6 percent		
2	Hendry	38,097	11.8 percent		
3	St. Lucie	37,429	11.6 percent		
4	Highlands	31,319	9.7 percent		
5	Desoto	28,476	8.8 percent		
6	Indian River	22,667	7.0 percent		
7	Hardee	22,242	6.9 percent		
8	Martin	17,081	5.3 percent		
9	Collier	13,584	4.2 percent	percent Hectares by:	
10	Hillsborough	9,605	2.9 percent	80.9 percent	Top 10 Counties
11	Manatee	8,872	2.8 percent	83.7 percent	Top 11 Counties
12	Charlotte	8,293	2.6 percent	86.2 percent	Top 12 Counties
13	Lake	7,622	2.4 percent	88.6 percent	Top 13 Counties
14	All Others	36,820	11.4 percent		
	Total (ha)	322,658	100.00 percent		

The sampling technique used was a systematic random sample. This allows for the use of a predefined characteristic, which influenced the selection for sampling, for example, geographic location or a demographic characteristic (Fowler, 2002). In this case, all FCM members who had reported or were known to own/operate a citrus operation in excess of 40 ha were chosen.

In identifying the sample frame, 2,391 growers were identified in the 10 county sample. By using the membership records, 84 growers were segregated from the total sample that had been identified as having greater than 40.5 hectares. Each one of these 84 growers was selected to receive the questionnaire. The remaining 2,307 growers were randomly chosen by a coin flip. These growers were given a unique numeric identifier a “head” on the coin flip meant the selection of odd-numbered growers, and vice versa “tail” on the coin flip meant even-numbered. The coin flip resulted in a “tail” so all even-numbered growers were then selected to receive the questionnaire. The final sample frame was narrowed down to all of the 84 "large" growers and the remaining even-numbered growers. This resulted in a mail survey of 1,232 growers. The use of production area as a segregation tool and then following with a coin flip to randomize the remaining sample resulted in what is referred to as a "systematic random sample" (Fowler, 2002). The sample frame resulted in selecting more than 50 percent of the member growers available in the 10 county sample.

Survey Techniques

After the randomization exercise, a unique numeric identifier was assigned to each of the survey participants; this is a common market-research practice in order to track respondent participation. This numeric identifier was affixed as a control number using a self-adhesive label to all correspondence going to the respective participants. As responses were received, the identifier was used not for data association, but simply to remove the participant from future mailings.

Using a mail survey methodology established by D. A. Dillman (Fowler, 2002), selected participants received a questionnaire in the mail in late March 2003. A reminder card was sent to all of the non-respondents within 7-10 days in early April 2003. Last, another 7-10 days after the reminder card was sent, a complete second packet was also sent in an attempt to collect a response. Survey questionnaires were accepted for approximately six months.

Questionnaire Topics

The primary research question was to identify the rate of technology adoption in Florida citrus production. In order to determine this adoption rate, a response matrix was provided to the participants (the survey instrument is included in Appendix A). The adoption matrix was used to determine by a simple yes or no answer whether the technology was currently in use, and on what total area of production. The matrix included information about future plans for adoption, or whether or not current usage was to be increased onto additional hectares. Lastly, if additional acreage was to be placed into precision farming production or a planned adoption was to occur, the respondent was asked to indicate the time frame for that adoption.

The technologies investigated in this matrix were the following:

- Sensor-based variable rate applicators (e.g. – "Tree See")
- Prescription map based variable rate applicators (e.g. – "Legacy 6000")
- Pest scouting and mapping (e.g. – "EntoNet")
- Weed scouting and mapping
- Remote sensing (e.g. – aerial or satellite imagery)
- GPS receiver (e.g. – boundary mapping)
- Soil variability mapping
- Water table monitoring (e.g. – automated irrigation scheduling)
- Harvesting logistics (e.g. – mapping brix, acid and sugar levels to determine peak harvest time)
- Yield monitoring (e.g. – GOAT yield monitoring system)

A second matrix was used to compile the cause of negative responses to adoption. Respondents were asked to place a checkmark in fields to identify their attitudes toward each of the respective technologies. The selections provided to the respondents for "Not Adopting" or "No Plan To Adopt" were the following:

- Not enough information
- Not profitable

- Lack of capital
- Process/equipment not reliable
- Process/equipment too complex for laborers
- Satisfied with current practices
- Other (please specify)

Additional information was collected for the purpose of establishing demographic profiles for adopters versus non-adopters. These questions also provided information pertaining to the cost of production estimates for these growers for future research in connection with the profile that is built.

These questions included the following:

- Grower demographic information (age, highest education level achieved, and grove management experience)
- Size and type of operation (hectares of fresh oranges or grapefruit, processed oranges or grapefruit, or "other" citrus)
- Counties and Water Management Districts of operation
- Types of irrigation used
- Rootstocks of respective citrus varieties as well as average age of the grove
- Personal willingness to adopt technology
- Current use of computer applications (email, internet, financial record keeping, weather networks, GIS, expert decision systems for production management, or none)
- Ability to identify the current level of in-grove variability

Results

Survey Response Rate

The analysis of the response rates followed guidelines discussed by Fowler (2002). The raw response rate was simply the number of returned questionnaires as a percent of the total questionnaires mailed out. Table 2-2 below illustrates the survey response rate data. The modified response rate accounted for questionnaires that were returned incomplete for various reasons. Exclusions from the response rate were allowable under certain conditions. These conditions included questionnaires that could not be forwarded, and respondents that refused or declined participation. Responses were also excluded from surveys that were returned by a third party marking the respondent as deceased. Last surveys from growers were omitted if they had either sold their property or had gone out of business.

Among those mailed out, 304 questionnaires (24.7 percent of total mailed) were received, 211 of those returned were completed. The completed responses accounted for 17.1 percent of the total mailed. The modified response rate accounting for the exclusions was calculated to be 18.5 percent. This response rate is fair at best, but the expectation was that the second mailing would obtain additional responses, making the modified response rate more favorable.

Table 2-2. Survey response rates.

Mailed questionnaires	1232	
	Rcvd	**Rate**
Raw response rate	304	24.7 %
(Total received/Total mailed)		
	Rcvd	**Rate**
Completed questionnaires	211	17.1 %
	Rcvd	**Rate**
Returned (no-forwarding)	12	0.9 %
Refused-return to sender	5	0.4 %
Referred to 2nd party	6	0.5 %
Declined participation	4	0.3 %
Out-of-business/Sold property	52	4.2 %
Deceased	14	1.1 %
	Rcvd	**Rate**
Modified response rate	211	18.5 %
(Completed/(Total mailed-Exclusions))		

Survey Responses

Adopted Technology Percentages

A response matrix was provided in the questionnaire to identify which technologies were currently being used, as well as planned future adoptions. Table 2-3 provides the results from this response matrix. The respondents were permitted to provide only yes or no responses in this matrix, as well as integer data regarding current or planned production areas using precision technologies.

Table 2-3. Results from the technology adoption matrix (data represent a percent of total value based on 211 completed survey questionnaires).**

Precision Technology	Currently Use	Do Not Use	Plan to Use	Did Not Answer
Sensor-based variable rate applicator	17.5 %	66.4 %	9.9 %	16.1 %
"Prescription map" variable rate applicator	3.3 %	77.7 %	5.2 %	18.9 %
Pest scouting and mapping	14.2 %	69.2 %	2.8 %	16.6 %
Weed scouting and mapping	10.4 %	73.5 %	3.8 %	16.1 %
Remote sensing	4.7 %	77.3 %	5.2 %	18.0 %
GPS receiver	16.1 %	66.8 %	5.2 %	17.1 %
Soil variability mapping	16.1 %	67.8 %	7.6 %	16.1 %
Water table monitoring	12.3 %	70.1 %	10.9 %	17.5 %
Harvesting logistics	11.4 %	71.1 %	5.7 %	17.5 %
Yield monitoring	8.5 %	74.4 %	6.7 %	17.1 %

** - The reported response frequencies in Table 2-3 for each technology can exceed 100 %. The “Plan to Use” category includes individuals who are either in the “Currently Use” category and plan to add additional acres, or are in the “Do Not Use” category and plan to adopt precision technology management.

The data are presented as a percent of total from the 211 completed questionnaires. Currently, the most commonly used precision agriculture technologies are the sensor-based variable rate applicators (17.5 percent of the completed surveys indicated use), soil variability mapping (16.1 percent), and GPS boundary mapping (16.1 percent). The least commonly used technologies are remote sensing (e.g., aerial or satellite imagery) with its current level of adoption at 4.7 percent and "prescription map" variable rate controllers at 3.3 percent.

Responses for Non-Adoption

A second response matrix was used to determine reasons for "Not Adopting" precision farming technologies. The results from this matrix can be seen in table 2-4. The respondent was permitted to make multiple selections so the data is represented as frequency data, not a percent of total. By far, the most common response

Table 2-4. Reasons indicated for "Not Adopting" precision agriculture technologies.

Precision Technology	A	B	C	D	E	F
Sensor-based variable rate applicator	36	17	40	9	6	65
"Prescription map" variable rate applicator	48	16	40	8	7	68
Pest scouting and mapping	45	14	33	2	5	68
Weed scouting and mapping	39	18	33	1	1	77
Remote sensing	51	19	38	3	3	60
GPS receiver	33	17	37	1	1	64
Soil variability mapping	40	13	34	3	1	61
Water table monitoring	31	13	36	7	2	69
Harvesting logistics	42	16	33	4	2	68
Yield monitoring	48	17	35	11	7	60

A – Not Enough Information
B – Not Profitable
C – Lack of Capital
D – Process/Equipment not Reliable
E – Process/Equipment too Complex for Laborers
F – Satisfied with Current Practices

in this matrix was that producers were satisfied with their current production practices, for all of the investigated technologies. The next most common responses were lack of information regarding the respective technologies, and lack of capital in order to make the investment in new technologies.

Self-Perceived Adoption Attitude

Respondents were also questioned on their "adoption attitude". This was their self-perceived willingness to adopt new technologies. The participants were given the opportunity to select only one of the following responses, seen in table 2-5. The responses are represented as a percent of total from the 211 completed questionnaires.

The largest category, representing 62.1 percent of the respondents indicated that, "I normally wait to see other's success with new technologies and production methods." This group of respondents would be categorized as "coat-tailers". Approximately 18-percent of the respondents were in the top two adoption attitude categories. They would be classified as "early-adopters". Roughly fourteen percent of the respondents would be classified as "slow-to-adopt". Lastly, approximately six percent of the respondents omitted responses to this question.

Table 2-5. Self-perceived adoption attitude.

Adoption Attitude	Responses	%of Total
I am always the first to try new technologies	4	1.9 %
I am one of the first…	34	16.1 %
I normally wait to see other's success	131	62.1 %
I am one of the last…	21	9.9 %
I never try new technologies	7	3.3 %
No Answer from Respondent	14	6.6 %

Grower Demographics

The last section of the questionnaire was dedicated to the demographic profiles of the respondents. These questions investigated the respondents' age, years of experience in the citrus industry, and highest level of education achieved.

The highest educational level achieved is represented as a percent of total in table 2-6. The respondent was asked to select only one maximum level. If multiple entries were chosen, inherently the highest level was chosen during the data entry process as the question had requested. These results are based on 211 completed questionnaires. Approximately 81 percent of the respondents reported having had some college education. Sixteen percent of the respondents reported a high school education or lower. Approximately three percent of the responses were unanswered for this question.

Table 2-6. Highest education level achieved.

Education Level	Responses	%of Total
High school or below	34	16.1 %
Some college	52	24.6 %
College graduate	88	41.7 %
Graduate or professional degree	31	14.7 %
No answer from respondent	6	2.8 %

Experience in the citrus industry was another variable analyzed to determine if it influenced the technology adoption decision. The average reported years of experience by the 211 respondents, was 31.4 years with a standard deviation of 15.3. The maximum and minimum responses to this question were 85 years and 0 years of experience, respectively. Hence there is a great deal of variability in the owners and managers of citrus production areas, with regard to their experience in citrus production. Likewise, the average age of the respondent was 61.1 years old with a standard deviation of 13.8.

The youngest respondent was 24 years old and the oldest was 92. The resulting central tendencies for both age and years of experience are listed in table 2-7 below.

Table 2-7. Average age and years of experience.

	Age (yrs)	Experience (yrs)
Mean	61.1	31.4
Min	24	0
Max	92	85
St. Dev.	13.8	15.3

Discussion

The survey instrument was created in order to determine the current level of adoption of precision farming technologies in Florida citrus. Based on the results from the survey, the most commonly used precision technologies in Florida citrus production were the sensor-based variable rate applicators and the soil variability mapping. The least commonly used technology was remote sensing, and as indicated in open-ended responses, this was as a result of the value of the information being far less than the cost to acquire the information.

The most prevalent reason for not adopting new technologies was quite simply that the respondents were satisfied with their current production practices. Anecdotally, “why change it if it already works”.

Additionally in the survey, open-ended responses were provided for respondents to provide additional insight as to reasons for non-adoption. Although not many growers used this response field in the questionnaire matrix, approximately 20 respondents indicated that the Cooperative Extension Service needed to play a larger role in disseminating more information regarding the effectiveness and profitability of precision farming technologies for Florida citrus producers. However, Daberkow and McBride

(2003) in a recent study identified that the awareness of precision agriculture technologies has no impact on the willingness to adopt them for production management.

The Technology Adoption Outlook in Florida Citrus Production

As the survey results indicate, the adoption of precision farming technologies and strategies have been slow at best in Florida citrus production. Research and development by both the University of Florida and private industry continue to adapt precision farming technologies for use in citrus production (Wei and Salyani, 2004; Annamalai and Lee, 2003; Brown, 2002; Whitney et al., 2001; Annamalai et al., 2004; Miller and Whitney, 2003; Townsend, 2004).

Citrus, being a perennial tree, is managed quite differently than the crops which most precision farming technologies are tailored to. Although grid soil sampling and mapping, boundary mapping using GPS technologies, and variable rate applicators using prescription maps were conceptually easy to transition into citrus production, yield monitoring and on-the-go sensor variable rate applicators have been slow in acceptance.

Yield monitoring, a technology that is the most widely accepted and adopted technology in conventional row crops, has yet to be perfected in citrus. Yield monitoring methods have been developed and tested, but primarily as a result of errors by grove laborers the yield data has some inconsistencies (Schueller et al., 1999). The concept established in that study should work if the issues related to grove worker operation could be overcome.

The next step towards developing a yield monitoring system in citrus relies heavily on the development and production of reliable mechanical harvesters. There are several generations of mechanical harvesters in operation in Florida, but each has their own issues before the majority of citrus producers are willing to accept them. On the other hand, once the mechanical harvesting issues have been resolved, equipping these harvesters with yield monitoring system, should overcome the grove worker issues that Schueller et al., experienced.

CHAPTER 3
FLORIDA CITRUS GROWER TECHNOLOGY ADOPTION SURVEY – PROBIT MODEL ANAYLSIS

Objectives

The survey research covered in the previous chapter simply identified the current level of adoption of various precision farming technologies in Florida citrus production. This section of the study will analyze the responses from the earlier survey, in order to identify grower's characteristics that influence the adoption of precision farming technology. This analysis is performed by estimating a probit model to measure the significance and correlation of the explanatory variables that influence precision farming technology adoption.

The Probit Model Defined

Linear regression assumes that the dependent variable being tested is both continuous and measured for all of the observations within the sample. In this survey, the dependent variable is not continuous; instead it is a dichotomous binary variable. The dependent variables were the 10 respective technologies, and each had 2 choices. The choices were designed to measure current adoption and then planned adoption of the 10 technologies. Data was collected from surveys and recorded using a binary 0/1 response. The respondent was scored a one (1) for a "yes" response to either "currently using" or "planning to use" a technology. Alternatively, a negative response was assigned a zero (0). Additionally, some survey respondents did not indicate a positive or negative response; hence there is an incomplete measurement for that case. Given these circumstances, linear regression is not appropriate, and an alternative means was used to run a regression analysis on the survey data.

Linear regression models have other assumptions that are violated by the data in this survey. Linearity is assumed, in that the dependent variable is linearly related to the independent variables through the beta parameters. A theoretical illustration of a linear regression model is shown in equation (1).

$$y_i = \beta_0 + \beta_1 xi_1 + \ldots + \beta_k xi_k + \varepsilon_i \qquad (1)$$

where - xi_1, ..., xi_k are explanatory variables thought to influence the dependent variable such as age, years of experience, and total production area. The complete list of variables is provided in table 3-1

- β_0, β_1, ..., β_k are parameters to be estimated

- ε_i is the error term

The matrix formed by the observations on the x's is assumed to be of full rank so that the inverse of x'x exists. This assumption means there is no collinearity among the explanatory variables. Homoscedastic and uncorrelated errors also require the errors to have a constant variance and a randomly distributed error term (Greene, 1990).

In working with data that represent binary outcomes, there are several possible methods to perform regression analysis. The linear probability model (LPM) is one of such methods, but it also has shortcomings in dealing with heteroscedasticity and normality. An LPM illustration can be seen in equation (2), where x_i is an explanatory variable thought to influence the dependent variable, denoted by y_i ; the parameters to be estimated β , and ε_i is the error term.

$$y_i = \beta x_i + \varepsilon_i \qquad (2)$$

where - x_i is the explanatory variable thought to influence the dependent variable denoted by y_i

- β is the parameter to be estimated

- ε_i is the error term

Since the expected value of the dependent variable y given the independent variable x is βx, the variance of y depends on x_i, which implies that the variance of the errors depends on x and is not constant, therefore not homoscedastic. In addition, binary values (0/1) result in errors not being normally distributed, hence violating the normality assumption as well. This results in the LPM not being appropriate for the analysis of this study (Long, 1997).

The probit model is an acceptable alternative approach to analyze the binary data collected in this study (Maddala, 1983). This model assumes that there is a response variable of y_i* with the following regression relationship seen in equation (3).

$$y_i^* = \beta' x_i + \varepsilon_i \tag{3}$$

Normally, y_i* is not observable, so a dummy variable (y) must be defined where:

$y = 1$ if $y_i^* > 0$

$y = 0$ otherwise

In the probit model, $\beta' x_i$ is not defined by $F(y_i \mid x_i)$ as traditionally seen in the linear probability model (LPM), but instead it is defined by $F(y_i^* \mid x_i)$. From equation (3) and the underlying dummy variable (y) we have

$$\text{Prob}(y_i = 1) = \text{Prob}(\varepsilon_i > -\beta' x_i)$$

$$\text{Prob}(y_i = 1) = 1 - F(-\beta' x_i) \tag{4}$$

where F is the cumulative density function for ε_i

The observed values for (y) are as a result of the binomial process with probabilities given by equation (4) and can vary from trial to trial depending on the value given by x_i. This results in a likelihood function (*L*) of

$$L = \prod_{yi=0} F(-\beta' x_i) \prod_{yi=1} [1 - F(-\beta' x_i) \qquad (5)$$

In equation (5) the functional form of *F* will depend on the assumptions made about the distribution of errors (ε_i) from equation (3). In this case we assume that the errors have a normal distribution, making this a normit or probit model. However, if the cumulative distribution of the errors was logistic, than it would be referred to as the logit model. In this case the probit model assumption of a normally distributed ε_i was applied resulting in

$$F(-\beta' x_i) = \int_{-\infty}^{-\beta' x_i / \sigma} \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{t^2}{2}\right) dt \qquad (6)$$

Scientific literature, especially within the area of econometrics, commonly illustrates the probit model in the following form, shown in equation (7):

$$\Pr(\mathrm{y} = 1 \mid \mathrm{x}) = \beta_0 + \beta_1 x_1 + \ldots + \beta_n x_n + \varepsilon \qquad (7)$$

Equation (8) represents the probit model used in this study. The variable definitions are shown in table 3-1. The dependent variable is USETECH. USETECH is the variable name that represents the aggregation of all responses from the survey questioning current use of precision farming technology in Florida citrus production. The justification for aggregating the adoption of precision farming technologies is that whether the grower uses one technology or multiple technologies, there is theoretically only one adoption of a non-traditional production method.

$$\Pr(y=1\,|\,x)=\beta_0+\beta_1 x_{own}+\beta_2 x_{age}+\beta_3 x_{\exp}+\beta_4 x_{adt1}+\beta_5 x_{adt2}+ \\ \beta_6 x_{ed2}+\beta_7 x_{ed3}+\beta_8 x_{ed4}+\beta_9 x_{\mathrm{mod\,var}}+\beta_{10} x_{\max\mathrm{var}}+\varepsilon \quad (8)$$

where - y denotes the dependent variable, USETECH, whether or not the grower uses the technology.

- β is the parameter to be estimated.

- x represents the independent variables that can influence a producer's willingness to adopt.

- x_{own} is the total production area owned by the respondent in hectares.

- x_{age} is the age in years of the respondent.

- x_{exp} is the amount of experience the respondent has in the citrus industry in years.

- $x_{adt1, 2, 3}$ denote the self-perceived willingness by the grower to adopt new technology for production management. Level 1 indicates they are always willing to adopt; 2 indicates they will wait to see others success; 3 indicates that they will likely never adopt. See below for the explanation about why x_{adt3} being omitted from the model.

- $x_{ed1, 2, 3, 4}$ denote the maximum level of education achieved by the respondent. Level 1 is a high school education or less; 2 is some college education; level 3 indicates a 4-year degree having been achieved; 4 represents that the respondent received a graduate or professional degree; x_{ed1} was omitted from the model, see the explanation below.

- $x_{minvar, modvar, maxvar}$ represents the respondents self-perceived in-grove spatial variability; x_{minvar} was omitted from the model see the explanation below.

- ε denotes the error term of the regression model

Probit Model Variables

In table 3-1, there are several multi-level variables that were present in the probit model. The variables for the respondent's self-perceived adoption attitude, their maximum education achieved, and the in-grove variability are multi-level variables. These variables were presented on a likert-scale for response, and each was scored using a binary response system, yes (1) if that level was answered or no (0) if that level was not indicated in the response.

Table 3-1. Independent variables containing multiple levels used in the probit model analysis.

Multilevel Variables	Description
ADT1	Respondent is likely to adopt
ADT2	Respondent will wait to adopt
ADT3	Respondent will likely never adopt
ED1	A high school education or less was received
ED2	Some college education received
ED3	A college degree achieved
ED4	A graduate or professional degree achieved
MINVAR	Minimum in-grove variability
MODVAR	Moderate in-grove variability
MAXVAR	Maximum in-grove variability

When multi-level variables are used as explanatory variables in a probit analysis, one level of the variable is excluded. Results are then interpreted by using the omitted level as the point of comparison for the other levels. The omitted variables are shown in table 3-2, in addition to the variable DKVAR. DKVAR was collected to allow respondents to indicate that they were uncertain of their in-grove variability. This variable was omitted entirely from the analysis, since less than one percent of the respondents chose this response.

Table 3-2. Omitted variables from the probit model analysis.

Variable Name	Description
ADT3	Respondent never adopts
ED1	A high school education or less
MINVAR	Minimal in-grove variability
DKVAR	Don't know in-grove variability

The probit model in equation (8) was estimated using the statistical software package LIMDEP, version 7.0 (Greene, 1995). Note that 1,232 surveys were distributed by mail. Respondents returned more than 300 surveys, 211 were considered to be completed and contain usable data. The estimation of the model determined that 135 observations had all of the responses completed in its entirety.

Results and Discussion

The probit model can only make estimates for responses in which every variable measured contained a response. This being the case, the probit model could only be used for 135 observations. The estimated model (provided in Appendix B in full detail) indicated that three of the independent variables were statistically significant in influencing the decision to adopt precision farming technologies, see the figure below.

The variable for the grower's age was significant and negatively correlated to USETECH, indicating that as the grower's age increases, the likelihood of adopting precision farming technologies decreased. The variables associated with the in-grove variability resulted in two significant independent variables. The variables representing maximum variability and moderate variability were significant and positively related to likelihood to adopt. The positive correlation indicates that a level of variability higher than minimum in-grove variability influenced the decision to adopt precision farming technologies. Marginal probabilities indicate the degree to which farmers with maximum and moderate variability are more likely to adopt the technology compared to those in the minimum variability group.

```
                +--------------------------------------------+
                | Binomial Probit Model                      |
                | Maximum Likelihood Estimates               |
                | Dependent variable               USETECH   |
                | Weighting variable                   ONE   |
                | Number of observations               135   |
                | Iterations completed                   8   |
                | Log likelihood function        -71.23216   |
                | Restricted log likelihood      -92.50165   |
                | Chi-squared                     42.53899   |
                | Degrees of freedom                     9   |
                | Significance level           .2618101E-05  |
                +--------------------------------------------+
+---------+--------------+----------------+--------+---------+----------+
|Variable | Coefficient  | Standard Error |b/St.Er.|P[|Z|>z] | Mean of X|
+---------+--------------+----------------+--------+---------+----------+
         Index function for probability
 TC_OWN    .4390390174E-03  .26705878E-03    1.644   .1002    837.61296
 AGE      -.1642453096E-01  .79138701E-02   -2.075   .0379     58.696296
 YRS_EXP  -.7439444811E-02  .11309781E-01    -.658   .5107     29.733333
 LIKEADT   .5686880888      .41653625        1.365   .1722       .185185
 WAITADT  -.1338363165      .34040528        -.393   .6942       .651851
 SOMEED    .6193040949      .39873538        1.553   .1204       .237037
 BSED      .5153843892      .37667667        1.368   .1712       .481481
 GRADED    .7517915387      .47205160        1.593   .1112       .148148
 MODVAR    .4308330425      .25950603        1.660   .0969       .414814
 MAXVAR    .8486323138      .39455804        2.151   .0315       .170370
```

Figure 3-1. Parameter estimates for probit model.

In the survey discussed in Chapter 2, scale was used as a determinant to segregate growers for sampling purposes. However, the production area of the grower was not found to be significant. The significance level used for this study was 90 percent (alpha=0.1), and the probability of total production area influencing the decision to adopt was 0.8998. This resulted in scale not being reported as a significant factor in the decision to adopt, however it was worth reporting.

Table 3-3 below illustrates the predicted outcomes versus the actual outcomes measured in the survey results. Note that respondents were asked to identify from a list of ten technologies if they were currently using or planning to use any of the technologies. For the sake of the probit model in this study, current usage was only taken into consideration (referred to as USETECH above). Those survey responses were measured against the predicted outcomes of the binary probit model.

Table 3-3. Frequencies of actual and predicted outcomes matrix.

Actual	Predicted		Total
	0	1	
0	64	12	76
1	24	35	59
Total	88	47	135

The benefit of the predicted outcomes matrix is in identifying the percentage of correct guesses versus naïve predictions by the probit model. Table 3-3 shows that 99, or 73 percent, correct predictions were made (64 "no" responses and 35 "yes" responses). A correct prediction is when the model guesses a "no" (0) and it actually was, and likewise when it predicts a "yes" (1). The naïve prediction is calculated by always guessing either "no" (0) or "yes" (1). In this case, the naïve prediction would always guess "no" (0), as it would be correct more frequently; the naïve prediction rate would be 76, or 56 percent. Therefore, the probit model is better at predicting the dependent variable (73 percent correct prediction) compared to the naïve prediction (56 percent).

There are two types of incorrect predictions in a probit model – Type I errors and Type II errors. With a Type I error, the model incorrectly predicts a "no" when it should have predicted "yes" (in the predicted outcomes for the model, this occurred 24 times). A Type II error occurs when the model predicts a "yes" when it should predict a "no" (this occurred 12 times). Both error types are based on the model providing an adoption prediction for a grower as compared to other growers with a similar profile. The Type I error would predict the grower to “not adopt”, when actually growers of similar profiles did adopt. Alternately, the Type II error would predict that a grower “adopt” when other growers of a similar profile did not.

The probit model accurately predicted adoption decisions 73.3 percent of the time. In addition, Type II error predictions only occurred 8.9 percent of the time. If this model were to be used as a grower decision tool, more data would need to be collected in order to validate the predictions. Although 8.9 percent is relatively low, that represents approximately 1 in 10 incorrect predictions about whether a grower should adopt precision farming technologies.

CHAPTER 4
GROVE XYZ – A CASE STUDY ON TECHNOLOGY ADOPTION

Introduction

The case study is a research strategy employed when the questions of “how” and “why” are the goals of the investigator. Case studies are appropriate in situations where the investigator has limited control over behavioral events and the topic focuses on a contemporary issue versus a historical one (Yin, 2003). Case studies can assist in answering the why question, after theoretical and statistical experimentation has determined “what”, they do not replace these forms of experimentation, but case studies can be used to complement them (Kennedy and Luzar, 1999). The survey discussed in Chapter 2 of this dissertation answered the questions of “who,” “what,” “how many” and “how much.” The goal of case study provided herein is to extend that research and to determine the “why” related to the adoption of precision farming technologies by Grove XYZ. Secondly, emphasis is placed on determining “how” they went about investigating and investing in the precision technologies they chose.

Similar analyses to this case study were performed by Batte and Arnholt (2003), where six cutting-edge farms in Ohio, who had adopted precision farming technologies. That study used a multiple case study approach to cross-compare the six farms. Yin (2003) indicates that the use of a single case does not decrease its validity versus multiple case studies, as long as the single-case meets at least one of four rationales. This case fits the third rationale that the caretaking organization at the center of this single-case or holistic study is considered *typical*, or *representative*. The caretaking organization, other than their decision to adopt precision farming technologies, is not set apart in anyway from other caretakers. Prior to this technology adoption, their methods of managing clients' groves and production areas were similar to those of other caretakers who were using traditional crop management practices without precision technologies.

Objectives

In this case study the adoption process and investment decision made by an existing citrus caretaking organization is analyzed. Their identification has been withheld for reasons of anonymity for their clientele. The case identifies their production practices prior to considering the investment in precision farming technologies. In the discussion the alternatives that were considered and the final technology adoption decision is presented. The specific objective of this case study is to determine if the grower achieved break even (BE) status on their investment across several precision farming technologies.

Case Background

Grove XYZ is a citrus production management company in the "Ridge" production area of Central Florida. As a caretaker organization, their primary objective is to manage the production, harvesting, and marketing of their clients' citrus products. The majority of their clients' production capacity was targeted towards the processed orange juice industry, however a small segment of their business, specifically tangerines, tangelos, red grapefruit, and some oranges are sold through fresh fruit marketing channels.

The company directly controls approximately 500 hectares of citrus property that it manages, in addition to another 1,800 hectares that it manages for its clientele. Grove XYZ has maintained a caretaking business for fifty years. With a staff of 30 employees, many having been with the company in excess of 15-20 years, there is quite a large amount of tenure within this organization with regards to citrus production management, and long-standing relationships with their clients.

Production Strategies Prior to Adoption

Prior to considering the adoption of precision farming technologies, XYZ followed what most in the citrus industry consider fairly standard production practices. The grove production manager determines, based on variety, rootstock, soil type and tree age, how to proceed with soil amendments, tree nutrition, irrigation and necessary pesticide applications. These production decisions were made on a grove-by-grove basis and carry over from year to year. Production strategies change in situations of lower than expected yield from the previous year's harvest, future production expectations or in the case of some weed/pest outbreak, and inclement weather such as freezes or hurricanes. Production decisions conformed to a template that made production similar and consistent for the entire grove, not on a site-specific basis.

Business Decision Strategy

The Problem

Grove XYZ came to a point in their organization, where the need arose to purchase a new dry fertilizer spreader to replace a worn and obsolete spreader system. With this purchasing decision came the opportunity to consider a variable-rate fertilizer application spreader. Variable-rate technology (VRT) refers to the machine's ability to vary the applied amount of chemical while traveling through the grove. Variable-rate application can be implemented in real-time using electronic sensors which determine tree size, or it can be predetermined by soil sampling and then placed into a prescription map using GPS locations to apply the predetermined rate. In this specific decision, XYZ was more interested in considering a dry fertilizer spreader versus a VRT liquid applicator. With possibly purchasing a VRT applicator, XYZ was interested in solving several production problems:

- Resolve fertilizer application issues regarding variations in tree age.
- Realize a cost-savings by not applying a single-rate of fertilizer to immature trees in resets and also avoid applying fertilizer to skips.
- To decrease weed pressure on resets.
- Comply with Ridge Area best management practice (BMP) guidelines while still applying adequate fertilizer to high producing areas of the grove.

Secondly, XYZ was interested with better managing water resources for irrigation. This involved both the decision to irrigate and how much irrigation to apply. Irrigation decisions had been made by utilizing rain gauges and tensiometers located within managed groves in conjunction with historical evapotranspiration rates, as well as physical attributes of the trees within the grove to determine when and how much to irrigate. In pursuing a soil monitoring system XYZ was interested in resolving the following issues:

- Moisture monitoring for accurate irrigation scheduling.
- A tool to monitor winter stress to enhance bloom induction.
- Resolve quality concerns for fruit grown on different rootstock.
- Establish accurate measurements regarding proper irrigation management.

The Alternatives

VRT Fertilizer Application

Grove XYZ considered VRT applicators versus a standardized fixed-rate applicator. With the use of a fixed-rate applicator, XYZ had been well aware of the waste that was created by applying a single rate of materials across an entire grove. As in many groves across the state, XYZ manages groves that contain a noticeable number of resets or skips. Citrus trees are planted in rows, and in a mature grove that contains no resets or skips, there are no breaks between the trees as one travels down a row with an implement or applicator. In other words, there is a consistent string of trees in a row that are of similar age, canopy size, tree height, and the trees have a tendency to have similar yields from season to season.

Resets refer to a location where a tree as a result of age, disease, weather or pest damage, or it has surpassed its optimal maturity and can no longer produce an acceptable yield, has been replaced by a young tree. Skips refer to the location where the tree has not been replaced and there is a “blank” spot in the row. In the scenario where a fixed-rate applicator is being used in a grove that has a substantial number of skips or resets, the applicator may not have the ability to stop an application where there might be a skip (no tree at all) or a reset (a tree not needing the same application amount as a mature tree). Hence the waste was observed by XYZ by having used a single-rate applicator in the past.

Considering possible alternatives with regard to the VRT applicator, the decision involved the purchase of a real-time VRT system or a prescription map-based system. The real-time VRT system uses a system of “eyes”, and depending on the brand, this “eye” can be based on laser, infrared or optical sensors. As the implement, in this case a dry fertilizer spreader, travels down the rows of a grove, in “real-time” the sensors determine the size of the next tree or even if there is a tree in the next space. If the “eye” sees a mature tree, it applies the full amount to the location of the tree. Likewise if it sees a tree of smaller size, it decreases the application amount appropriately. Lastly, if it senses no tree at all, no material is applied to that location.

The second VRT applicator option is based on the premise of establishing a prescription map in order to vary the rates of application. The prescription map-based systems require the grove owner or caretaker to establish a grid sampling regime in order to determine what materials are needed. By various methods of interpolation, a map can be created to identify regions of variability within the grove that may need varying rates of material. This map is then fed into a VRT applicator that is GPS controlled, and it travels through the grove applying the prescribed rate of material to the grove based on its location in correspondence to the prescription map.

Irrigation and Moisture Control System

The second issue that Grove XYZ needed to resolve was the irrigation and moisture monitoring control system. XYZ began the investigation of a soil moisture sensor system to assist with irrigation management issues. A system had recently been developed that required the installation of soil moisture probes to monitor, log, and transmit data. These probes measured soil capacitance to determine the moisture levels at varying depths of the soil. The soil probes were connected to a data logger system, which was equipped with the ability to relay data from within the grove to a centralized data storage system. This would then allow for the grove owner or caretaker to retrieve the data pertaining to their specific grove. Immediately XYZ recognized that not only was this going to give them access to better data than just rainfall events and physical observation, but it was likely going to realize a cost savings to them as well as the grove owner. For example, in the past if a grove manager were to observe an afternoon wilt, they would have likely irrigated. If the afternoon wilt were as a result of hot weather and excessive transpiration, yet there was still sufficient moisture in the soil column, then this would have been a false alarm and irrigation would have been applied unnecessarily. This would have resulting wastes in pump time, pump fuel, labor requirements, and drive-time. Admittedly, if this could be avoided the secondary benefit was that this would save water. From a management perspective, XYZ was aware of the benefits of a system to better inform their grove production managers in making more sound irrigation decisions.

Adoption Decisions and Analysis

What Technology Adoptions Were Made

Although XYZ was not in a position to say which VRT system was "better", they did feel more comfortable in determining that the real-time VRT system was a better solution for their organization. They were more concerned with the waste associated with materials being applied to resets and skips, where it was not needed

Grove XYZ proceeded with the decision to purchase a VRT dry fertilizer applicator. They adopted a variable rate controller (Legacy Control System, MidTech, Inc.) with an optic tree size sensor (CCI Eye System, Chemical Containers, Inc.). The purchase was made in 2003 at a cost of approximately $16,000, and was placed into production for the first fertilizer application of 2004. Since that time five (5) VRT fertilizer applications have been made, including the January application of 2005. An analysis on application efficiency of this adoption is presented in the following sections of this chapter.

XYZ, with the cooperation with one of its clients, proceeded with the adoption of an irrigation and moisture monitoring control system. The decision to purchase a soil moisture monitoring and control system was made in April of 2003. The system is manufactured and distributed by Agrilink Holdings Pty Ltd of Australia, and the data services are maintained by AgWISE.net. The C-Probe soil moisture capacitance monitor is manufactured and distributed by C-Probe Corporation. Both AgWISE.net and C-Probe Corporation are subsidiaries of Agrilink International. This system was installed and placed into operation by May of 2003, and was used to monitor soil moisture during a "training" phase. It was placed into full production and assisting the grove manager in irrigation scheduling and decision making in September, 2003.

The Adoption Analysis

VRT Fertilizer System

Grove XYZ provided production data from two separate groves for this portion of the analysis. The first (Plot A) was a 70 hectare grove in the Highlands/Polk County region of Florida. The grove is planted with early and mid varieties and *Valencias*. The VRT system was implemented for two applications during the 2004 growing season from October/2003 through September/2004. The two applications occurred on January of 2004 and March of 2004, and it was used to apply a fertilizer application. The analysis performed and presented in Tables 4-1 and 4-2 assume that there was no change for the costs related to equipment setup, use, time and labor. All costs were set constant to determine the breakeven cost of the investment in the VRT spreader system.

In Table 4-1 the application data provided from XYZ is reported. In adhering to their normal practices, for the January and March applications of 2003, the grove manager made fertilizer recommendations of 0.44 MT/ha and 0.29 MT/ha respectively. Having no other means to vary the application at that time, the fixed-rate applicator applied the full amount established for that grove, on those two applications.

In 2004, the grove manager made his recommendations for the fertilizer application, which was 0.43 MT/ha for the January fertilization. This application was then made using the VRT applicator. Because the VRT system could vary the application based on identifying resets and skips, as well as other tree age variations as seen in the size of the tree, the full recommended application was not made. There was a savings of 0.09 MT/ha of fertilizer applied in January 2004 from the previous year's January application. Likewise in 2004, there was a cost savings of approximately 20 percent from the recommended application to what was actually applied, based on the sensor readings from the VRT. The savings of 20 percent in January 2004 related to a cost savings of $19.94 in production costs per hectare.

In March of 2004, the grove manager's recommendation was 0.29 MT/ha of fertilizer. The VRT system only made an application of 0.23 MT/ha. This resulted in 0.06 MT savings of fertilizer from that same application in 2003. The savings realized from the grove manager's recommendation during 2004 was approximately 22 percent, giving the grove a savings of $14.33 per hectare for fertilizer application in March of 2004.

Grove XYZ invested $15,685.00 in the MidTech Legacy Control System (with a CCI Eye System) for their variable-rate fertilizer spreader. This investment was scheduled for financing over seven years (or 84 months) and assumed the loan was taken with terms of 8.00% interest per year, and loan amount equaling the full cost of the investment. The annual financed cost of the VRT system adoption was (12 months at $244.47/month) $2,933.64.. The cost for fertilizer was $230/MT averaged across 2003 and 2004. The average cost savings per hectare for the two fertilizer applications was $17.14 per hectare, but XYZ was able to save a total of $34.27/ha for the entire season. In order to recover the costs of the investment and break even (BE) on the VRT system, XYZ would need to use the VRT system on 85.6 hectares to break even based on the production costs for Plot A. This does not mean that XYZ lost money on this investment, recall they have the ability to spread the costs of this investment over a possible 2,300 ha.

In addition, if the cost of fertilizer were to decrease to roughly $200 /MT, it would require XYZ to implement the VRT system on approximately 98.4 ha to recover their investment cost during that year. On the other hand if fertilizer costs were to increase to $260 /MT, then XYZ would only need to implement its use on 75.73 ha to recover their annual costs. The sensitivity analysis shows that the cost of adoption can be more easily absorbed in a situation where input costs are high, because fewer hectares are required to recover the investment cost in conjunction with higher input costs.

The analysis for Grove XYZ, Plot A assumed that this grove was the total production area owned by a citrus producer in order to formulate the BE analysis. If this were a grower with a production area of only 70 ha, than this grower would not have the capacity or scale to spread the costs solely across their own production area. However, they would have the opportunity to spread some excess capacity to other producers who may be in a similar situation of being “too small” to afford the investment. This may be an ideal scenario for a small to medium-sized grower to initiate a custom fertilizer service to other small to medium-sized producers in order to breakeven on the investment.

In Table 4-2 data from another plot that is managed by XYZ is shown. This plot is a four hectare (Plot B), planted solely in *Valencias*. Again for the purpose of this case study, it is being analyzed independently from the previous plot. The data provided by XYZ cover a four year time period. For the applications made in 2001, 2002 and 2003, a fixed-rate application was made. Following their standard production methods, at the rates recommended by the grove manager, fertilizer was applied.

Table 4-1: Grove XYZ, Plot A

Production Area (hectares-ha)	70.00	
Average Cost per MT of fertilizer between 2003-04 ($)	$ 230.00	
	2003-FRA	**2004-VRT**
Recommended Jan Application (MT of fertilizer)	30.96	30.29
Recommended MT of fertilizer per ha	0.44	0.43
Actual Jan Application (MT of fertilizer)	30.96	24.89
Actual MT of fertilizer per ha	0.44	0.36
Fertilizer savings per ha in Jan 2004 (MT)		0.09
Cost to fertilize per ha ($)	$ 101.73	$ 81.78
Fertilizer cost savings per ha in Jan 2004 ($)		$ 19.94
Fertilizer cost savings per ha in Jan 2004 (%)		19.6%
Recommended Mar Application (MT of fertilizer)	20.13	20.20
Recommended MT of fertilizer per ha	0.29	0.29
Actual Mar Application (MT of fertilizer)	20.13	15.77
Actual MT of fertilizer per ha	0.29	0.23
Fertilizer savings per ha in Mar 2004 (MT)		0.06
Cost to fertilize per ha ($)	$ 66.14	$ 51.82
Fertilizer cost savings per ha in Mar 2004 ($)		$ 14.33
Fertilizer cost savings per ha in Mar 2004 (%)		21.7%

Break Even (BE) Analysis for Grove A	
Equipment Description	Mid Tech Legacy System with CCI Eye System
Equipment Cost ($)	$15,685.00
Scheduled Financing Period (years)	7.00
Monthly Cost to Finance the Adoption ($/month)	$ 244.47
Annualized Cost of VRT ($/year)	$ 2,933.64
Average savings per ha for Jan/Mar applications ($)	$ 34.27
Production area to BE on annual cost of VRT (ha)	85.60
Sensitivity Analysis for Grove A data	
Scenario 1: Fertilizer cost decreases to… ($/MT)	$ 200.00
Production area to BE on annual cost of VRT (ha)	98.44
Scenario 2: Fertilizer cost increases to… ($/MT)	$ 260.00
Production area to BE on annual cost of VRT (ha)	75.73

In 2004, there were four applications made using the VRT system. During the years 2001 and 2002, only three fertilizer applications were made for those seasons. In order to properly compare VRT savings to the fixed-rate applicator, the comparison in Table 4-2 will focus on the four applications made in 2003 to the four applications made in 2004.

In January 2004, there was a savings of 0.12 MT/ha in fertilizer applied as compared to the fertilization recommendation made by the grove manager, resulting in a cost savings of $26.45/ha from the previous year. The applications for March and May were quite similar, resulting in savings of 0.05 MT/ha and 0.04 MT/ha of fertilizer applied from the 2004 recommendation, respectively. The March 2004 fertilization saved the grower approximately $11.00/ha in production costs. Likewise, the May 2004 fertilizer application saved an additional $8.00/ha in production costs.

The final application in 2004, during September, broke away from the savings trend as seen in the previous months. Although the application was ultimately lower than the previous year's application (0.89 metric tons in 2004, down from 1.06 metric tons in 2003), it was higher than the recommended application amount identified by the grove manager. The grove manager prescribed an application of fertilizer for this grove at 0.79 MT, and the VRT system applied 0.89 MT instead, but it was still a savings of 0.04 MT/ha from the previous season's application. The reason for this overage in application was because the anticipated savings by the VRT system was calculated into that application recommendation. The anticipated savings calculated by the grove manager was not exact; however a savings was still realized. The analysis for break even was performed on Plot B, assuming the adoption of the technology to be independent of Plot A due to the variation in the scale of the two plots. Productions costs are spread across the area being managed so in order to accurately reflect the cost of adoption and the return on investment, Plot B breakeven estimates are shown in Table 4-2.

Table 4-2: Grove XYZ, Plot B

Production Area (hectares-ha)	4.00	
Average Cost per MT of fertilizer between 2003-04 ($)	$ 230.00	
	2003-FRA	**2004-VRT**
Recommended Jan Application (MT of fertilizer)	1.84	1.84
Recommended MT of fertilizer per ha	0.46	0.46
Actual Jan Application (MT of fertilizer)	1.84	1.38
Actual MT of fertilizer per ha	0.46	0.35
Fertilizer savings per ha in Jan 2004 (MT)		0.12
Cost to fertilize per ha ($)	$ 105.80	$ 79.35
Fertilizer cost savings per ha in Jan 2004 ($)		$ 26.45
Fertilizer cost savings per ha in Jan 2004 (%)		25.0%
Recommended Mar Application (MT of fertilizer)	1.13	1.13
Recommended MT of fertilizer per ha	0.28	0.28
Actual Mar Application (MT of fertilizer)	1.13	0.94
Actual MT of fertilizer per ha	0.28	0.24
Fertilizer savings per ha in Mar 2004 (MT)		0.05
Cost to fertilize per ha ($)	$ 64.98	$ 54.05
Fertilizer cost savings per ha in Mar 2004 ($)		$ 10.93
Fertilizer cost savings per ha in Mar 2004 (%)		16.8%
Recommended May Application (MT of fertilizer)	1.71	1.71
Recommended MT of fertilizer per ha	0.43	0.43
Actual Mar Application (MT of fertilzer)	1.71	1.57
Actual MT of fertilizer per ha	0.43	0.39
Fertilizer savings per ha in May 2004 (MT)		0.04
Cost to fertilize per ha ($)	$ 98.33	$ 90.28
Fertilizer cost savings per ha in May 2004 ($)		$ 8.05
Fertilizer cost savings per ha in May 2004 (%)		8.2%
Recommended Sept Application (MT of fertilizer)	1.06	0.79
Recommended MT of fertilizer per ha	0.27	0.20
Actual Mar Application (MT of fertilzer)	1.06	0.89
Actual MT of fertilizer per ha	0.27	0.22
Fertilizer savings per ha in Sept 2004 (MT)		0.04
Cost to fertilize per ha ($)	$ 60.95	$ 51.18
Fertilizer cost savings per ha in Sept 2004 ($)		$ 9.78
Fertilizer cost savings per ha in Sept 2004 (%)		16.0%

Break Even (BE) Analysis for Grove B

Equipment Description	Mid Tech Legacy System with CCI Eye System
Equipment Cost ($)	$15,685.00
Scheduled Financing Period (years)	7.00
Monthly Cost to Finance the Adoption ($/month)	$ 244.47
Annualized Cost of VRT (Straight Line Depreciation)	$ 2,933.64
Average savings per ha for Jan/Mar applications ($)	$ 55.20
Production area to BE on annual cost of VRT (ha)	53.15

Sensitivity Analysis for Grove B data		
Scenario 1: Fertilizer cost decreases to… ($/MT)	$	200.00
Production area to BE on annual cost of VRT (ha)		61.12
Scenario 2: Fertilizer cost increases to… ($/MT)	$	260.00
Production area to BE on annual cost of VRT (ha)		47.01

Grove XYZ made a $15,685.00 investment by adopting a MidTech Legacy Control System, (with CCI Eye System) for their fertilizer spreader system. Using the same assumptions as in the Plot A analysis, a loan was acquired to cover the full cost of the adoption. This loan was issued for seven years, with an annual interest rate of 8.00%. The annual financed cost of the adoption was $2,933.64. The average costs savings per hectare over the January through September fertilizer applications in 2004, was approximately $14.00/ha, and a total savings for the season of $55.20/ha. In order to recover the annualized cost of the investment, XYZ would need to implement the use of the VRT system on 53.2 hectares in order to recover their costs through fertilizer application savings. In addition, if the cost of fertilizer were to decrease to $200 /MT, then XYZ would need to use the VRT system on a total of 61 ha to recover their investment costs for that year. On the other hand, if fertilizer costs were to increase to $260/MT, XYZ would only need to implement the VRT system on 47 hectares.

Finally, in comparing the fertilizer applications over the fours years of production data provided by XYZ, there were only three applications of fertilizer made in 2001 and 2002. There were four applications each in 2003 and 2004. To compare the four production seasons against each other, the September application has been removed from 2003 and 2004.

As shown in Figure 4-1, for the January through May fertilizer applications over the four years, there were similar recommendations and applications made in 2001 and 2002, 5.56 and 5.43 metric tons, respectively. There was a slight decrease in the application recommendation in 2003 to 4.68 metric tons, which was the same recommendation also for 2004. In 2004, the VRT system for these three comparable applications applied a total of 3.89 metric tons.

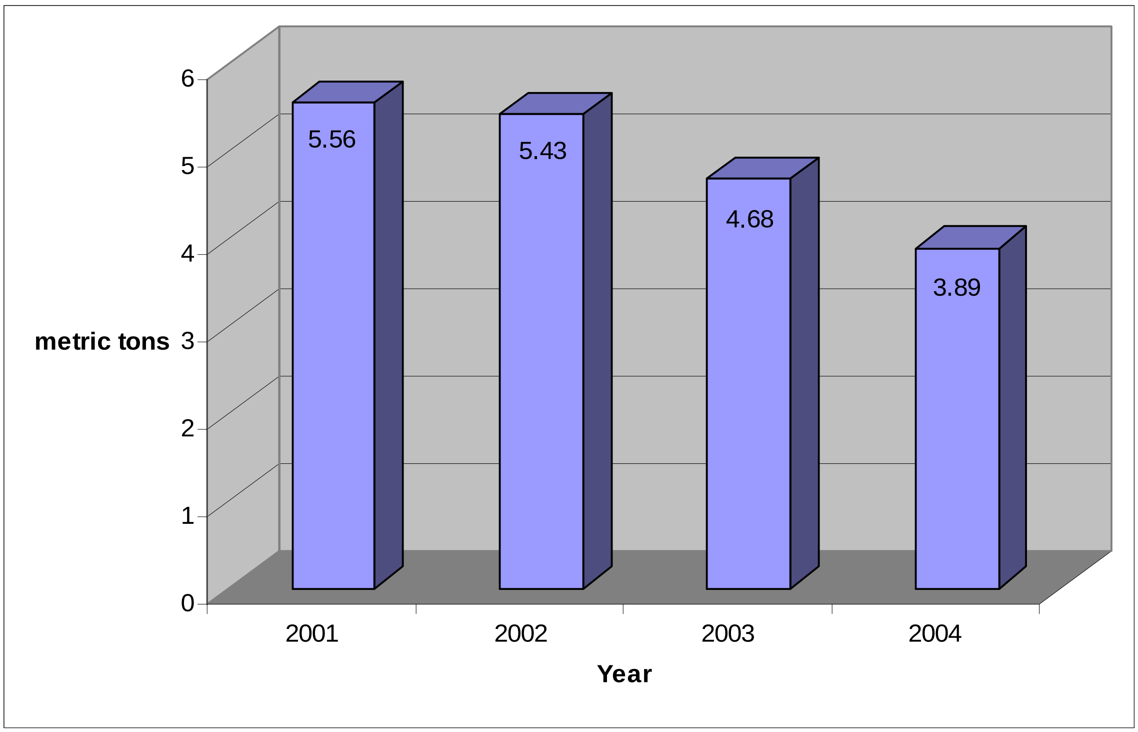

Figure 4-1: Plot B - Comparison of Total Applied Fertilizer from 2001-2003 FRA and 2004 VRT (September applications omitted)

In Figure 4-2, the comparison is between the 2003 and 2004 seasons, where 4 full fertlizer applications were made. In this chart, it is evident that even with the 13-percent overage, the VRT system still has a positive net savings of applied fertilizer in 2004 over the same four fertilizer applications made in 2003. There were 5.74 metric tons applied in 2003, versus a savings of nearly one metric ton to 4.78 MT applied in 2004.

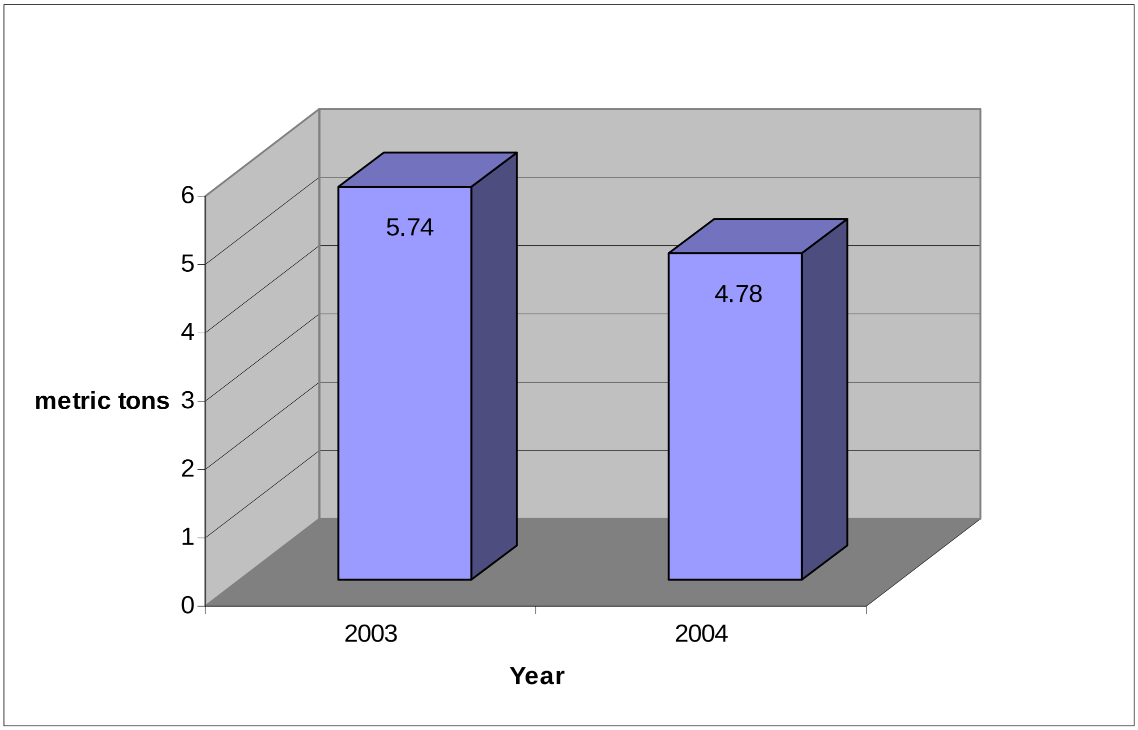

Figure 4-2: Plot B - 2003 FRA vs. 2004 VRT Total Fertilizer Applied (September application included)

Irrigation Monitoring and Control System

Grove XYZ invested in the C-Probe and Weather Station system manufactured and distributed by Agrilink Holdings Pty Ltd of Australia and its subsidiaries. The investment was made by the grove owner and had a total cost installed of approximately $6,800 in 2003. The moisture monitoring system is comprised of a series of C-Probe ™ soil moisture probes. They measure soil capacitance through a series of sensors within each probe at multiple depths in the soil column. These sensors measure the volumetric soil moisture content and then transfer the data using both analog and digital telemetry, where it is then uploaded into the AgWISE ™ software system, which can be accessed online (AgWISE ™, 2005).

The AgWISE ™ software package then allows the data from the C-Probes ™ to be graphed and displayed. Depending on the geographic region of the grower, in this case in Central Florida, the grove manager can establish irrigation templates that are best suited for the soil types of the grove. Since the sensors measure soil moisture as a consistent value over time, it can be displayed as a trend line graph. The value of the information lies in the trend line itself. The trend of soil moisture shows daytime and nighttime differentials, as well as rainfall and irrigation events.

The software can then be manipulated to allow for irrigation templates to be established, based on how the grove manager observes water uptake by the tree, as well as what the fill capacity is at certain depths within the root zone. This utility is not only helpful with the management of irrigation during summer months, but also during winter months where the grower can "stress" the citrus tree by limiting moisture availability, which can then assist in bud induction during the late winter (Townsend, 2004).

XYZ and the grove owner had the system installed in April of 2003. The system was in place and used to monitor their existing irrigation strategies, during a "training phase". For the 2004 season beginning in October 2003, the system was used for all irrigation decisions. This training phase allowed the grove manager to determine fill capacities for their specific soils at the various, as well as fine tune the navigation and manipulations that the AgWISE.net ™ software would permit.

In Figure 4-3 one can see the rainfall and irrigation data from this grove for the time period from 2001 through 2004. The rainfall data were collected by a FAWN remote weather station (FAWN, 2005). The Florida Automated Weather Network (FAWN) system was developed by the University of Florida, IFAS Extension Service. It provides up-to-date weather data from a series of remote weather stations across the state of Florida. This system also provides archived data that has been collected and catalogued since the installation of each weather station. The irrigation data provided in the chart is based on irrigation amounts measured directly from the grove.

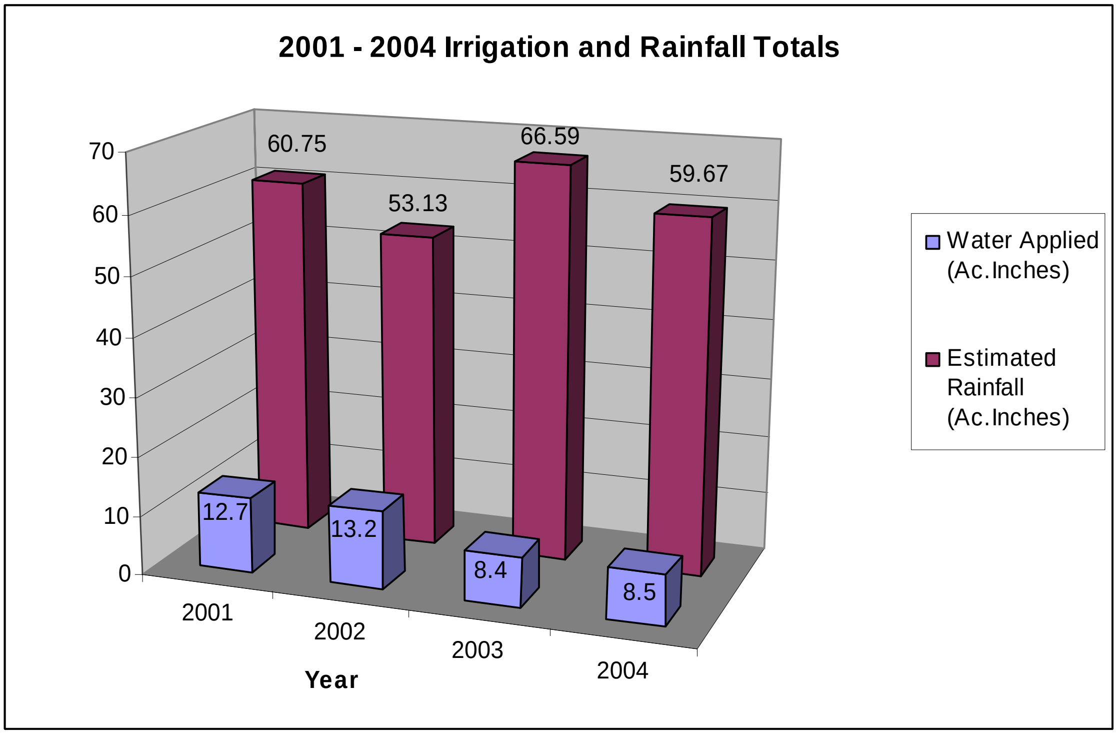

Figure 4-3: Rainfall and Irrigation Amounts

In Figure 4-3, there was a noticeable variation in the rainfall amounts from year to year. Observe that from 2001 to 2002 there was a decrease in total rainfall by almost 7.5 inches, and irrigation only increased by 0.5 inch. Similarly from 2002 to 2003, there was an increase in rainfall of approximately 13.5 inches, yet irrigation only decreased by 5 inches. It was during the 2001 through 2003 seasons that XYZ managed the irrigation decisions by rainfall estimates and grove observations. During 2004, the C-Probe ™ system was used to monitor moisture levels in the soil, and the AgWISE ™ software managed the data in irrigation templates. In 2004, there was a decline in rainfall by roughly 7 inches from the previous year, yet irrigation remained constant. Recall in 2002, with a marked decrease in rainfall, the irrigation system was turned on more frequently to make-up for the lack of rain. In 2004, this same scenario occurred but there was not an “irrigate reaction” on the part of the grove manager. Ultimately since the grove manager could now visualize the moisture levels in the soil column, there were little to no unnecessary irrigations. This ability to monitor the moisture levels in the soil allowed the grove manager to make more effective decisions about when and how much to irrigate this grove.

Coinciding with the ability to make more effective decisions regarding the timeliness of irrigations, XYZ was able to eliminate some expenses related to irrigation control. From 2003 to 2004, there was a decrease by 5.5-percent in the amount of labor required to manage the irrigation system, providing a cost savings of approximately $200. Likewise, there was a savings of approximately $4,200 in fuel expenses related to running the irrigation pumps. Not only was there a cost savings realized by the grove owner, but the ability to more effectively irrigate resulted in a marked increase in crop yield from that grove. The analysis on the irrigation system adoption differed greatly from the VRT adoption due to the nature of the equipment. The irrigation and moisture control system is composed of both fixed equipment costs as well as variable equipment costs related to the number of C-Probes ™ required to operate effectively. This being the case, per hectare cost of production is not as easily reported as seen in the VRT adoption analysis previously in this chapter.

Discussion

The VRT fertilizer system is now being used on approximately 550 hectares of total managed production area of approximately 2,300 hectares. They have not moved their entire management area into VRT application at this time. From a management perspective they feel that this would not be a wise decision since not all of their managed groves have the tree size variability issues. They still maintain fixed-rate applications on their properties that have consistent tree size and ages. It is also worth noting that XYZ has encountered a decrease in VRT spreader effectiveness of properties and groves that have an increased topographic profile. The less hills and inclines are better suited for the effectiveness of the VRT in distributing the fertilizer.

In Chapter 2, there was a discussion related to the scale of the grove being a determinant in the adoption of precision farming technologies. Data for Plot B provided in Table 4-2 was only a 4 hectare (10 acre) grove. This scenario of contracting services from a caretaker who utilizes precision farming technologies, allows the smaller grove owners to now “adopt” a once unachievable level of technology. The costs of a VRT system are quite high when compared to the holdings of a relatively small grove owner.

With regard to the irrigation and moisture control system, there are still some fine-tuning concerns that the grove manager is focusing on, yet they are equally pleased with the cost savings and water savings related to its installation. The grower made the investment in this technology adoption, but providing greater irrigation control to XYZ resulted in a single year improvement in internal fruit quality.

References made to Agrilink, C-Probe ™and AgWISE ™ were used only to identify technology adoptions made by the grower/caretaker in this case study. There are in no way a positive referral by the investigator in this study.

CHAPTER 5
CONCLUSIONS

Survey Analysis and Probit Model Results

This study investigated the current level of adoption of precision farming technologies in Florida citrus production. To date, no study had been done on adoption levels in Florida citrus. Secondly the study identified the demographic characteristics and variables that determined the willingness to make the investment decision in these technologies, by Florida citrus producers.

The most frequently adopted technologies were the sensor-based variable rate applicators, soil variability mapping, and GPS boundary mapping. The least commonly used technologies were remote sensing (e. g., aerial or satellite imagery) with its current level of adoption and "prescription map" variable rate controllers. With regard to reasons for non-adoption, the most common response was that producers were satisfied with their current production practices, for all of the investigated technologies. The next most common responses were lack of information regarding the respective technologies, and lack of capital in order to make the investment in new technologies. The largest percentage of the respondents indicated that, “I normally wait to see other's success with new technologies and production methods.”

The probit model analysis determined that the variables most likely to influence the willingness to adopt precision farming technologies were:

- Grower age: a negative correlation to the willingness to adopt

- Maximum and moderate variability: marginal probabilities indicate that farmers are more likely to adopt the technology compared to those in the minimum variability group.

Lastly, the probit model accurately predicted adoption decisions 73.3 percent of the time. In addition, Type II error predictions resulting in a mistaken decision to invest only occurred 8.9 percent of the time.

Case Study Analysis

In an effort to expound upon the "who" and "how many" have adopted, a case study analysis investigated the "why" and "how" an individual firm in the citrus production industry made the adoption decision. Citrus Caretakers, Inc. has a VRT fertilizer system that is now being used on approximately 550 hectares (1,350 acres) of their total managed production area. Collectively they manage approximately 2,300 hectares (5,600 acres) of groves that they both own and/or manage through direct partnerships and contracts. They have not moved their entire management area into VRT application at this time, and have only implemented its use on groves that have tree size and density variability issues.

The breakeven analyses performed on Plot A and B were treated as though they were owned by separate independent growers. This allowed for the analyses to determine what the breakeven production area would need to be in order for the cost of the investment to be recovered during each production year. In addition it is worth noting that a small to medium-sized grower with an entrepreneurial spirit could use this investment opportunity to create a custom application service in order to fill the excess capacity required to breakeven on the investment by hiring themselves out to other small growers.

With regard to the irrigation and moisture control system, CCI feels that there are still some fine-tuning concerns that the grove manager is focusing on, yet they are equally pleased with the cost savings and water savings related to its installation. The grove owner made the investment in this technology adoption, but providing greater irrigation control to CCI resulted in a single year improvement in fruit quality. This positive change in fruit quality netted an immediate return on that investment by doubling the total marketable yield.

Discussion and Closing Remarks

There are three criteria that must be met in order to justify the investment and adoption of site-specific technologies. First, there must be a significant in-grove level of variability, which affects crop yield. Second, this in-grove variability must be identified and quantified. Lastly, the variability measured must be handled by the modification of production practices and strategies in order to increase profit and decrease environmental impacts (Plant, 2001).

In citrus, depending on the production region, in-grove variability may be rather minimal. The case study analyzed in Chapter 4 of this study, identified a grove for irrigation moisture control analysis, in which there were nine differentiable soil types, yet all were various types of sand. As far as management practices were concerned for the caretaker in that study, they were all managed as a single consistent soil type. There are regions within the state's production areas that do encounter varying soil types that must be managed separately. This soil variability would be one qualifying criterion for technology adoption, as long as the caretaker can measure and quantify the variability. The third criterion for adoption seems to be problematic though. As indicated from the survey results in Chapter 2 of this study, more than 60-percent of the respondents for each of the ten technologies investigated, indicated that they were “satisfied with their current practices”. This nullifies the third criterion identified by Plant (2001), that in order to adopt, you must be willing to adapt and modify production management strategies.

Referring back to the case study analysis in Chapter 4, Grove XYZ decided to adopt a variable rate fertilizer spreader for the sole purpose of resolving tree size and density issues. They encountered an issue that may be representative of a large production area of the state. With the onslaught of hurricanes that Florida faced in 2004, there was a significant amount of tree damage seen across the state. As a result, many grove owners and caretakers began removing damaged trees and placing resets into those damaged groves. As XYZ realized, a VRT fertilizer system using an “eye” sensor system became an immediate solution to handling the fertilization of properties having inconsistent tree sizes and densities. This adoption did however coincide with the need to replace a worn and obsolete single-rate fertilizer applicator, so there was an economic consideration and need before the adoption was made. Likewise as noted in the case study, XYZ only uses this VRT fertilizer system on groves that “need” the varied application rates.

The adoption of precision farming technologies is still in the “Early Adopter” category with regard to Florida citrus production. As indicated in Chapter 2, the survey results from the citrus producer survey show that only 18-percent of the respondents were using one of the ten investigated precision farming technologies. On the other hand, 62-percent of those respondents report their willingness to wait on other growers’ success with the ten technologies. It is believed that the development of more generally accepted mechanical harvesting systems (with yield monitoring capabilities) will induce a higher willingness to adopt precision farming technologies. Yield monitoring has been the highest percentage of adoption in the production of conventional cropping systems. Identifying areas of high or low yield can assist in the measurement and observation of in-grove variability. This in turn would assist in the adoption of VRT fertilization systems.

Further investigation needs to be performed on the geographic distribution of precision farming adopters. There may be some correlation between the growers' location and their willingness to adopt, especially where certain SSCM equipment cannot be used on very hilly terrain. In addition to the study on the geographic distribution of adopters, research needs to be done on comparing fresh fruit producers versus processed fruit producers. It is unlikely that there is a large percentage of precision farming adopters associated with citrus production moving through fresh fruit marketing channels.

In addition, follow-up case studies should be performed on more precision technology adopters, in order to cross-compare the success of the adoption decision between those growers. Getting this information into publication outlets in the citrus industry may assist in future adoptions by other growers.

The largest potential for immediate options appears to be the VRT sensor-based fertilizer systems and chemical sprayers. In real-time, they have the ability to apply varying levels of chemical inputs on trees of varied size and density. This in turn results in an immediate savings with regard to inputs and the cost of total production per acre. The technology with the second greatest potential for adoption would likely be mechanized harvesters with on board yield monitoring capabilities. In production areas where soil type is the least favorable for optimal moisture control, joint systems such as C-Probe ™ and AgWISE ™, are an additional technologies that should be considered for adoption.

APPENDIX A
FLORIDA CITRUS GROWER TECHNOLOGY ADOPTION SURVEY

The following six pages represent the actual survey questionnaire that was distributed and used to collect data for this study.

Figure A-1: Citrus Producer Survey (page 1)

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Precision Agriculture – Citrus Owner/Manager Survey

The University of Florida is interested in helping the citrus industry evaluate new production technologies to improve profitability.

Your experiences with these new technologies can influence agricultural lending policies as well as research, extension and education efforts. Your responses to the following questions will be used for aggregate analyses only, and will remain strictly confidential.

1. How many total acres of land do you own in Florida? ______________ acres (include both citrus and non-citrus properties)
2. How many acres of the following types of citrus production do you own or manage? (Use the table below)
3. In what counties and Water Management Districts are these production sites located? (Use the table below)

Categories	Acres Owned	Acres Managed	Counties (list)	Water Management District (circle all that apply)
Fresh Oranges				SJRWMD SFWMD SWFWMD
Fresh Grapefruit				SJRWMD SFWMD SWFWMD
Processed Oranges				SJRWMD SFWMD SWFWMD
Processed Grapefruit				SJRWMD SFWMD SWFWMD
Other Citrus (e.g.-tangelo, tangerine, etc.)				SJRWMD SFWMD SWFWMD
Total Citrus Acreage				

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Figure A-2: Citrus Producer Survey (page 2)

UNIVERSITY OF FLORIDA

4. For the various types of grove you **own** or **manage**, what is the predominant age of the grove(s)? (Use the table below)

5. What predominant rootstock(s) is used? (Use the table below)

6. What type or types of irrigation systems do you have in place? (List micro jet, drip, overhead, water cannon or flood.) (Use the table below)

Categories	Age	Rootstocks (list)	Types of Irrigation Used (list)
Fresh Oranges			
Fresh Grapefruit			
Processed Oranges			
Processed Grapefruit			
Other Citrus (e.g.-tangelo, tangerine, etc)			

7. Please select the statement below that best describes the level of variability in your grove(s). (please check **one** only)

_____ Minimal Variability - single soil type, homogenous soil chemistry, similar topography.

_____ Moderate Variability - several (2-3) soil types, some variation in soil chemistry, differing topography.

_____ Maximum Variability - more then 3 soil types, high variation in soil chemistry, significant topographic variety.

_____ Don't know.

Figure A-3: Citrus Producer Survey (page 3)

8. Which of the following technologies, if any, do you currently use or plan to use in citrus production? Please fill in the appropriate information below:

Technology	Currently Use		If yes, # of acres you are currently using it on?	Plan to adopt or increase current acreage?		If yes, on how many additional or start-up acres?	If yes, when do you plan to adopt? (please circle one)		
Sensor-based variable rate applicator (e.g. - "Tree See")	Yes	No		Yes	No		1-2 yrs	3-5 yrs	6+ yrs
"Prescription Map"-based variable rate applicator	Yes	No		Yes	No		1-2 yrs	3-5 yrs	6+ yrs
Pest Scouting and mapping (e.g. - "EntoNet")	Yes	No		Yes	No		1-2 yrs	3-5 yrs	6+ yrs
Weed Scouting and Mapping	Yes	No		Yes	No		1-2 yrs	3-5 yrs	6+ yrs
Remote Sensing (e.g. – aerial or satellite imagery)	Yes	No		Yes	No		1-2 yrs	3-5 yrs	6+ yrs
GPS Receiver (e.g. – boundary mapping)	Yes	No		Yes	No		1-2 yrs	3-5 yrs	6+ yrs
Soil Variability Mapping	Yes	No		Yes	No		1-2 yrs	3-5 yrs	6+ yrs
Water Table Monitoring (e.g. - moisture sensors used to automate irrigation scheduling)	Yes	No		Yes	No		1-2 yrs	3-5 yrs	6+ yrs
Harvesting Logistics (e.g. - mapping brix, acid and sugar levels to determine peak harvest time)	Yes	No		Yes	No		1-2 yrs	3-5 yrs	6+ yrs
Yield Monitoring (e.g. - GOAT yield monitoring system)	Yes	No		Yes	No		1-2 yrs	3-5 yrs	6+ yrs

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Figure A-4: Citrus Producer Survey (page 4)

UNIVERSITY OF FLORIDA

9. If you have NOT adopted and DO NOT PLAN to adopt the following technologies, what are the main reasons why?

Please check the appropriate column(s):

Technology	Not enough information	Not Profitable	Lack of Capital	Process / equipment not reliable	Process / equipment too complex for laborers	Satisfied with current practices	Other (please specify)
Sensor-based variable rate applicator (e.g. - "Tree See")							
"Prescription Map"-based variable rate applicator							
Pest Scouting and mapping (e.g. - "EntoNet")							
Weed Scouting and Mapping							
Remote Sensing (e.g. – aerial or satellite imagery)							
GPS Receiver (e.g. – boundary mapping)							
Soil Variability Mapping							
Water Table Monitoring (e.g. - moisture sensors used to automate irrigation scheduling)							
Harvesting Logistics (e.g. - mapping brix, acid and sugar levels to determine peak harvest time)							
Yield Monitoring (e.g. - GOAT yield monitoring system)							

Figure A-5: Citrus Producer Survey (page 5)

UNIVERSITY OF FLORIDA

Precision Agriculture – Citrus Owner/Manager Survey

10. Please select the statement below that best describes your attitude towards new technology and production methods. (Please check **one** only)

_____ I am always the first to try new technologies and production methods.

_____ I am one of the first to try new technologies and production methods.

_____ I normally wait to see other's success with new technologies and production methods.

_____ I am one of the last to try new technologies and production methods.

_____ I never try new technologies or production methods.

11. Which of the following computer applications, if any, do you use? (Check **all** that apply)

_____ Email

_____ Internet

_____ Financial/Accounting Record Keeping Software

_____ Computer-based Weather Network

_____ GIS – Geographic Information System

_____ Expert Decision System (e.g. – DISC, Copper Scheduling Tool, Reset Analysis Tool)

_____ None

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Figure A-6: Citrus Producer Survey (page 6)

UNIVERSITY OF FLORIDA

Precision Agriculture – Citrus Owner/Manager Survey

For classification purposes only, please answer the following questions. Your responses will remain confidential.

12. How many years of experience do you have in the citrus industry? ____________ years

13. In what year were you born? ____________

14. What is the highest level of education achieved? (Please check **one** only)

_____ High School diploma or below

_____ Some College

_____ College Graduate

_____ Graduate or Professional Degree

Please return this in the postage paid envelope provided with this packet.

Thank you very much for your help!

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APPENDIX B
PROBIT MODEL ANALYSIS RESULTS

The probit model analysis was performed using the statistical software package LIMDEP, version 7.0 (Greene, 1995).

```
+-----------------------------------------------------------------------+
| Dependent variable is binary, y=0 or y not equal 0                    |
| Ordinary    least squares regression    Weighting variable = none     |
| Dep. var. = USETECH  Mean=   .4370370370    , S.D.=   .4978672035     |
| Model size: Observations =     135, Parameters =  10, Deg.Fr.=    125 |
| Residuals:  Sum of squares= 26.19664518    , Std.Dev.=         .45779 |
| Fit:        R-squared=  .211296, Adjusted R-squared =          .15451 |
| Model test: F[  9,    125] =    3.72,    Prob value =          .00036 |
| Diagnostic: Log-L =    -80.8808, Restricted(b=0) Log-L =     -96.9029 |
|             LogAmemiyaPrCrt.=   -1.491, Akaike Info. Crt.=      1.346 |
+-----------------------------------------------------------------------+
```

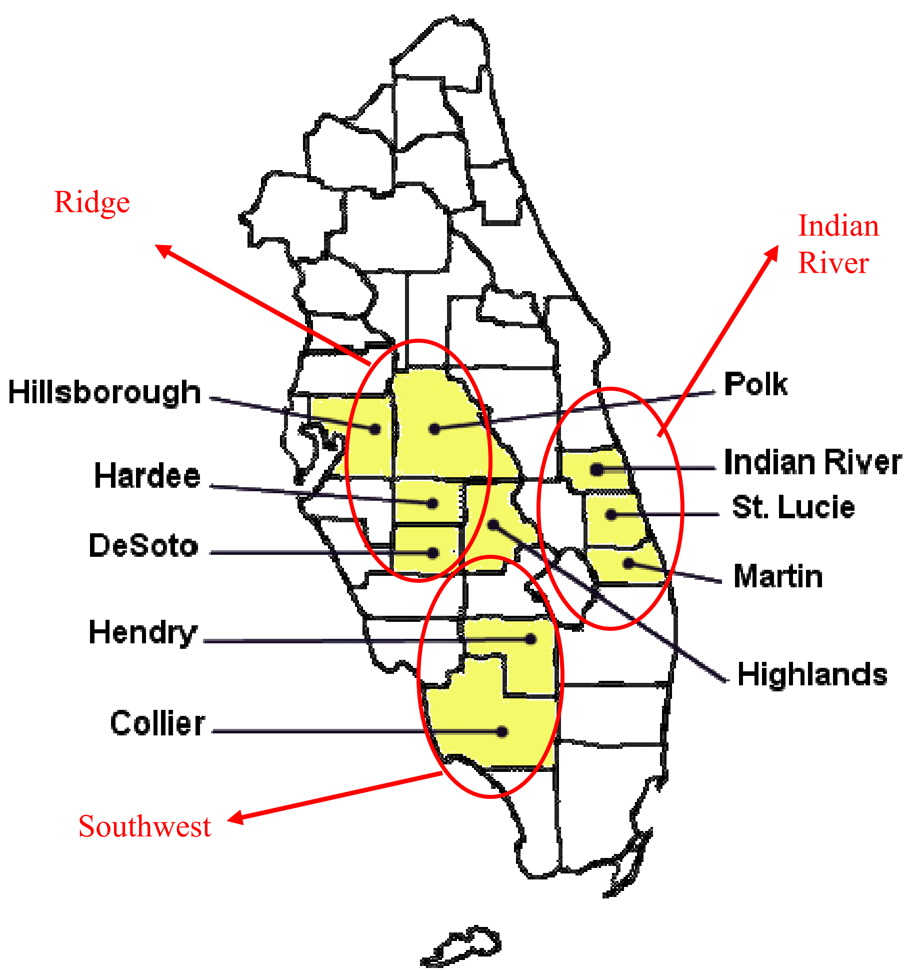
Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]	Mean of X
TC_OWN	.1611888556E-04	.11095516E-04	1.453	.1463	837.61296
AGE	.2975581064E-03	.24367421E-02	.122	.9028	58.696296
YRS_EXP	-.3942252586E-02	.36000163E-02	-1.095	.2735	29.733333
LIKEADT	.3048825378	.13132816	2.322	.0203	.185185
WAITADT	.2893071501E-01	.10880994	.266	.7903	.651851
SOMEED	.3212441544	.12816781	2.506	.0122	.237037
BSED	.3302916708	.11808518	2.797	.0052	.481481
GRADED	.3544126782	.14818655	2.392	.0168	.148148
MODVAR	.2004367428	.85718669E-01	2.338	.0194	.414814
MAXVAR	.3588914937	.12008715	2.989	.0028	.170370

Binomial Probit Model	
Maximum Likelihood Estimates	
Dependent variable	USETECH
Weighting variable	ONE
Number of observations	135
Iterations completed	8
Log likelihood function	**-71.23216**
Restricted log likelihood	-92.50165
Chi-squared	**42.53899**
Degrees of freedom	9
Significance level	.2618101E-05

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]	Mean of X
Index function for probability					
TC_OWN	.4390390174E-03	.26705878E-03	1.644	**.1002**	837.61296
AGE	-.1642453096E-01	.79138701E-02	-2.075	**.0379**	58.696296
YRS_EXP	-.7439444811E-02	.11309781E-01	-.658	.5107	29.733333
LIKEADT	.5686880888	.41653625	1.365	.1722	.185185
WAITADT	-.1338363165	.34040528	-.393	.6942	.651851
SOMEED	.6193040949	.39873538	1.553	.1204	.237037
BSED	.5153843892	.37667667	1.368	.1712	.481481
GRADED	.7517915387	.47205160	1.593	.1112	.148148
MODVAR	.4308330425	.25950603	1.660	**.0969**	.414814
MAXVAR	.8486323138	.39455804	2.151	**.0315**	.170370

APPENDIX C
CITRUS PRODUCING AREAS OF FLORIDA

Figure C-1: The citrus producing areas of Florida.



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BIOGRAPHICAL SKETCH

Brian James Sevier, born September 1974, in Salisbury, Maryland, is seeking the degree of Doctor of Philosophy in the College of Agriculture and Life Sciences, agricultural operations management, in the Agricultural and Biological Engineering Department.

Brian completed his Masters of Agribusiness (MAB) from the University of Florida, Food & Resource Economics Department in 2000. Brian also received his Bachelor of Science (BS) in food and resource economics specializing in agribusiness management, as well as a minor in business administration from the University of Florida in 1999.

Brian currently is employed by the University of Florida, Food and Resource Economics Department as a Coordinator, Economic Analysis. In this position he serves as the Department's Business and Operations Manager.

Brian was married to wife Danielle in 1997, and they have a son Tristan, who was born in 2002.