EFFECT OF MECHANICAL HARVESTING ON CITRUS TREE YIELDS

By

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A THESIS PRESENTED TO THE GRADUATE SCHOOL
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To my Family

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Mechanical harvesting techniques have been a controversial topic of discussion in the Florida citrus industry over the last decade. Florida continues to be the number one citrus producing state in the United States. During the 2008–2009 season, over 9.5 million boxes and 35,600 acres were mechanically harvested. A total of 463,900 acres were both hand and mechanically harvested during 2008-2009, meaning 7.67% of the total number of acres harvested were mechanically harvested. The concern with mechanical harvesting has been its potential harm on tree health and a potential lag-effect on yield following the mechanical harvesting process. The purpose of this research was to determine if mechanical harvesting had an adverse effect on subsequent citrus yields based on the given factors of each commercial grove operation. A total of four growers located in Collier and Hendry County provided data on their commercial citrus groves including yield, variety, harvest method, tree age, rootstock, block size and tree count. A county yield variable and a hurricane variable were added to the model to incorporate environmental factors that may have influenced yield.

Prior research into the possible effects mechanical harvesting could have on citrus yields took place as controlled field trials. Generally occurring over a five-year time period, these trials concluded that mechanical harvesting did not have a significant effect on citrus yields over time on well-managed groves. The reason for furthering this research was to perform a study using data from commercial grove operations and to examine if mechanical harvesting had an effect over a period of ten years. This research is unique because there have been no other studies done on actual commercial grove operations for a time period of ten years.

The goal of this research is to determine if mechanical harvesting has a lagged-effect on citrus yields over a period of ten years. This study will also determine what other factors may significantly influence crop yields aside from harvesting method. The primary limitation to this research is the limited access to grower data. It would be beneficial to have data collected on more growers as well as to have data on their management practices, such as fertilization techniques and irrigation techniques, etc.

CHAPTER 1
INTRODUCTION

The Florida Citrus Industry

The Florida Citrus Industry contributes more than $9 billion annually to the Florida economy (Hodges and Rahmani, 2009). More than 67% of the United States citrus supply, including grapefruit, comes from Florida and approximately 95% of the Florida orange crop is used for juicing (Florida Department of Agriculture and Consumer Services 2004). Florida is a prime state for citrus production due to the sandy soil and subtropical climates. Ideal growing conditions for citrus are warm during the day and cooler during the nights. In Florida, 30 of the 67 counties grow citrus and more than 80% of the citrus grown is within 10 counties south of interstate I-4 (Figure 1-1). Since 2006, 25 of the 30 counties in Florida have seen a decline in citrus acreage. In total, southwest Florida[1] has lost nearly 11,000 acres and 2.0 million trees since 2006. The primary reason for tree loss is because of a lack of new tree availability. This is primarily due to the increase in citrus canker and citrus greening. Although bearing acreage has seen a decline, actual production has seen an increase in relative importance to Florida's total citrus production (Table 1-1) (FASS, 2009.). The hurricanes in 2004 and 2005 affected all citrus production regions in Florida and these effects have lasted through the 2006-2007 season. Three hurricanes in 2004 affected citrus production across the northern and central part of Florida's citrus belt. . In 2005, Hurricane Wilma significantly affected the southwest Florida citrus production region. Production rebounded in the 2007-2008 season with over 200 million boxes (Table 1-2) (FASS, 2009). Even with the significant loss in acreage and number of trees, citrus is

[1] Southwest Florida includes Charlotte, Collier, Glades, Hendry, and Lee counties.

still Florida's top horticultural crop (Table 1-3). In addition, Florida is the number one producer of citrus in the United States, as well as second in the world, only to Brazil (Roka et al., 2009).

One of the primary concerns in the citrus industry is rising harvesting costs. A majority of citrus acreage is hand harvested. Due to rising labor costs in the United States, competition from "low-cost" producing countries in the orange juice market, and higher costs associated with fighting diseases such as citrus canker and citrus greening, Florida need to identify and adopt new technologies that will lower costs and increase efficiency. One possible technology is mechanical harvesting. Mechanical harvesting systems were being developed in Florida as early as the 1950s. At that time, citrus acreage and production were steadily increasing and there was concern about the ability of labor to keep up with the growing amount of production. Due to lack of strong economic justification for commercial investment into the equipment, USDA policies discouraging "labor-saving" technologies, and devastating freezes, mechanical harvesting research came to a halt by the 1980s. During the early 1990s, citrus acreage and production were rapidly expanding across the state and particularly in southwest Florida, and interest in mechanical harvesting arose once again. At that time, fruit prices were low; so much of the attention was focused on lowering harvesting costs through mechanical harvesting systems. Acres harvested with mechanical harvesting equipment increased from 6,500 in 1999-2000 to more than 35,000 by 2006-07 (Figure 1-2). During the 2007-2008 season, mechanical harvested acreage decreased by 9%, but rebounded to more than 35,000 acres in the 2008-09 season (FDOC, 2010) There were a total of 463,900 acres both hand and mechanically harvested in the 2008-2009 season, meaning 7.67% of the total citrus acreage was mechanically harvested at 35,600 acres.

Researchable Problem

Mechanical harvesting has the potential to dramatically reduce a grower's harvesting cost (Roka et al., 2009). Citrus growers of oranges for juice processing, however, have been reluctant to embrace mechanized harvest of their orange crop. Of paramount concern to every commerical citrus producer is whether mechanical harvesting has an adverse effect on fruit yield and long-term tree productivity health. Growers tend to be discouraged following the mechanical harvesting process when they see "physical injuries" to the tree. These injuries include shedding of leaves, flowers and young fruit, broken branches, exposed roots, and scuffing of bark.

Many long-term studies revealed, however, that fruit yields and citrus tree mortality are not negatively affected by mechanical harvesting (Hedden, 1988). More recent studies on citrus tree physiology following mechanical harvesting showed that the visible injuries incurred during the process, with properly operated equipment, did not cause any significant physiological damage or "stresses in well-managed trees" (Roka at al. 2009). The physical damages visible to the eye are considered minimal and the citrus trees fully recover to the same status as the hand harvested trees.

Despite these research results, many growers remain unconvinced that mechanical harvesting can function without significant damage to their trees and resulting loss of future production. One possible reason for grower doubts is all of the prior research was designed as controlled field trials involving a limited number of trees. Could results from these trials be extrapolated to commercial production conditions?

The purpose of this research is to use data collected from commercial production operations and determine if there is in fact an effect from mechanical harvesting on short and long term production. Results from this study could be useful to commercial growers in the Florida Citrus Industry so they can see the results of research based on large actual commercial operations to include in their decisions about whether mechanical harvesting is or is not harmful.

Objective

The primary objective of this research is to determine if mechanical harvesting has an adverse effect on short term crop yield and tree health, which would negatively affect long term crop yields. The primary source of data used to test this research hypothesis will come from grower production records and supplemented with data on tree counts from the Florida Agriculture Statistics Service. The data collected will include grower yields, fruit varieties, tree rootstocks, tree age, tree density, harvest year, harvest method, prior harvest methods, county yields and a variable to incorporate the hurricanes that took place in 2004 and 2005 that could potentially have an effect on yield for the 2005-2008 seasons. Regression analysis will be used to determine what factors are statistically significant in determining yield.

Testable Hypotheses

Three hypotheses have been formed based off of the objective state above.

- It is predicted that mechanical harvesting will have no significant effect on yield compared to hand harvesting.
- It is predicted that yield will not be significantly affected by last year's method of harvest.
- It is predicted that the number of times a block was previously mechanically harvested will not significantly affect current yield.

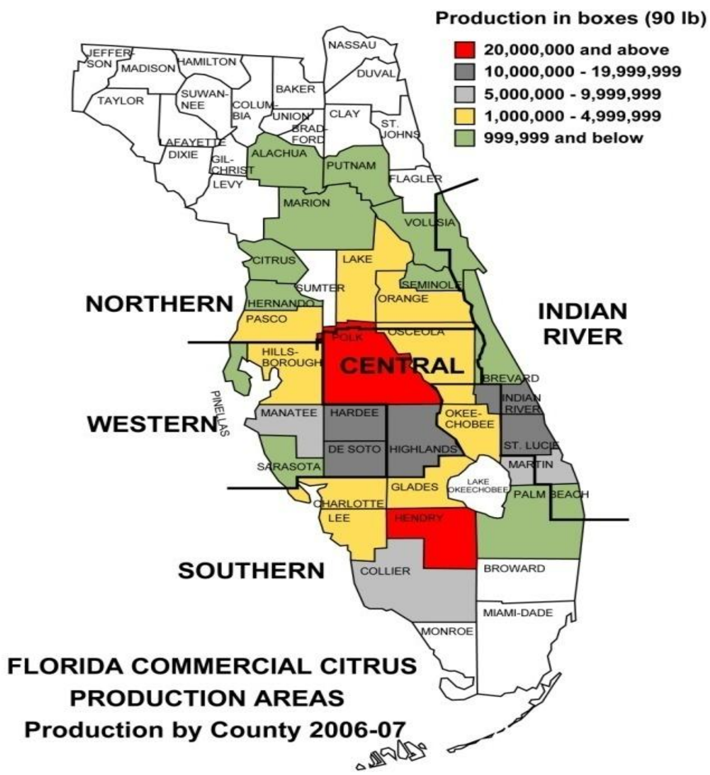

Figure 1-1. Florida Citrus Producing Regions and Counties 2006-2007 (Source: Roka et al. 2009, page 7)

Table 1-1. Citrus Production Values per Crop Year (Florida Department of Agriculture and Consumer Services, 2004)

Citrus Crop Year	**Value**
1995-96	$1,075,817,000
1996-97	$960,496,000
1997-98	$1,023,383,000
1998-99	$1,097,253,000
1999-00	$1,108,523,000
2000-01	$863,031,000
2001-02	$966,803,000
2002-03	$787,378,000
2003-04	$891,500,000
2004-05	$742,201,000

Table 1-2. Orange Production (millions of boxes), Boxes and Percentage of Total Orange Crop Processed Into Juice, and Total Value of On-Tree Production of Oranges (millions of dollars) (FASS, 2009)

Season	Total Orange Production (MM box)	Total Orange Processed (MM box)	Proportion of Total Orange Production - Processed (%)	Total Orange Value ($MM)
1996	226.2	215.5	96%	$801.3
1997	244.0	233.0	95%	$900.8
1998	186.0	175.1	94%	$900.0
1999	233.0	223.6	96%	$856.1
2000	223.3	213.6	96%	$716.1
2001	230.0	220.6	96%	$797.6
2002	203.0	193.3	95%	$643.8
2003	242.0	232.1	96%	$699.9
2004	149.8	142.4	95%	$522.9
2005	147.7	140.4	95%	$813.3
2006	129.0	122.6	95%	$1,310.8
2007 preliminary	170.2	164.3	96%	$1,057.4
2008 projected	195.0			

Table 1-3. 2004 Cash Receipts for All Commodities in Florida (Florida Department of Agriculture and Consumer Services, 2004)

Commodity	**2004 Receipts**	**Percent of Total**
All Commodities	$6,843,731,000	100.00
Citrus	$1,242,029,000	18.15
Other Fruits and Nuts	$236,728,000	3.94
Vegetables and Melons	$1,446,654,000	21.14
Field Crops	$704,711,000	10.30
Foliage and Floriculture	$825,672,000	12.06
Aquatic Plants	$20,000,000	0.29
Other Crops and Products	$850,801,000	12.43
Milk	$431,616,000	6.31
Cattle and Calves	$443,145,000	6.48
Poultry and Eggs	$399,108,000	5.44
Aquaculture	$68,539,000	1.00
Miscellaneous Livestock	$141,818,000	2.06

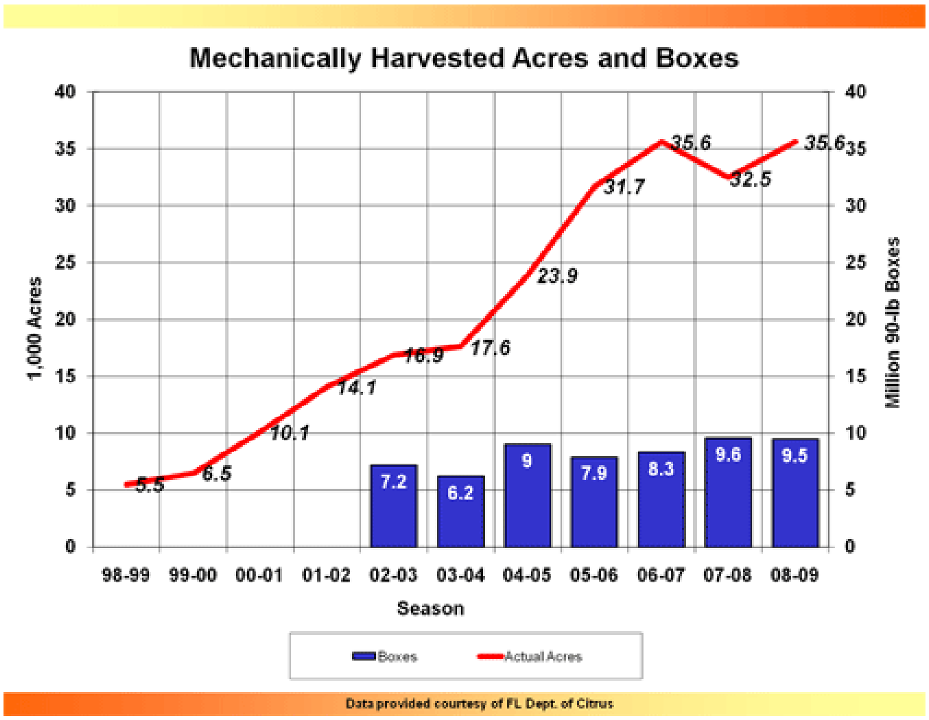

Figure 1-2. Total Acreage and Boxes Mechanically Harvested Since 1997 (FDOC, 2009)

CHAPTER 2
LITERATURE REVIEW

Mechanical harvesting of citrus has been researched for decades; however, hand harvesting continues to be the primary harvesting method for the majority of citrus acreage in Florida. In the 2008-09 season there were approximately 35,600 acres mechanically harvested. That number has plateaued (or leveled off) over the last few seasons as growers have yet to fully embrace mechanical harvesting technology. A question citrus growers continue to raise is whether mechanical harvesting has an adverse affect on tree health and long-term productivity. The following literature review examines several research studies which have attempted to evaluate the impacts of mechanical harvesting on tree productivity. Each study was controlled and focused on an array of possible effects of mechanical harvesting while also evaluating yields. The review of literature to follow will go into more detail about the studies and results that have developed over time to form these assumptions and conclusions.

One of the first studies to examine the impact of mechanical harvesting on tree productivity occurred over a three season period from 1968 to 1971 and looked at the effects of a limb shaker on the harvesting of Valencia oranges (Coppock, 1971). Valencia oranges complicate mechanical harvesting because Valencia trees carry two crops during the harvest season, this year's crop and next year's crop. The objective of Coppock's study was to determine the effect of harvest timing on maximum removal of the mature fruit with minimal removal of the young fruitlets and lessening the possibility of a decrease in the subsequent crop yields (Coppock, 1971). There were a total of four experiments that took place during the study. The purpose of the first three studies was to evaluate the relationship of young fruit diameter at harvest time to shaker selectivity, subsequent fruit yield and the natural young fruit drop. Study four was conducted to evaluate the relationship of shaker frequency and stroke to shaker selectivity, subsequent yield, mature fruit removal and actual shake time.

Experiment one progressed over three harvest seasons, (1968, 1969, 1970), and consisted of nine three-tree plots where three different treatments were applied at three dates of harvest, each coinciding with a specific young fruit diameter. Experiment two was conducted for the 1969 harvest season with nine two-tree plots where different harvesting treatments were replicated three times at three dates of harvest. Experiment three took place in 1970 involving three replications of two-tree plots where they were harvested approximately every two weeks during the season. Experiment four ran for only one year (1970) with nine four-tree plots and was used to determine the optimum shaker adjustment for selective harvest.

All of the experiments conducted were in the same overall grove area. The trees were around thirty-five years of age and spaced at approximately 18 x 24 feet (101 trees per acre). The overall height of the trees was around 18 feet. Some hedging took place to help control for crowding prior to harvest so all the trees would have a general shape suitable for shaker harvest.

The results Coppock (1971) found from all four experiments showed that there were no significant differences in fruit removal and subsequent yields between the minimum and maximum shaking intensities at the 95% confidence level. When the oranges were harvested before the end of the main drop period of the young fruit, there was a insignificant reduction in subsequent yields. The main drop period is the time period when the young Valencia fruitlets of next year's crop on the tree have not yet reached approximately 0.85 inches in diameter. Once the young fruit has reached this particular diameter they are more susceptible to being removed by mechanical harvesters, therefore, subsequent yield loss could reach as high as 50% due to mechanical harvesting with a shaker. After the main drop period of the young fruit, or during the late season, there was a 32% reduction in yields. This significant reduction in yield was due to time of harvest, not due to the shaking treatments that were applied. Therefore, it was concluded that Valencia oranges can be harvested with a limb shaker until close to the end of the young fruit drop period, which is when the young fruit is approximately 0.85 inches in diameter, without significant reduction in subsequent yields

Whitney and Wheaton (1987) performed more orange harvesting studies beginning in 1979 and continuing through the 1985 season. Their studies included air shakers, trunk shakers and hand harvesting methods. The purpose of their research was to compare yields and harvesting efficiency between the different harvesting methods. Severe freeze events occurred during four of the five seasons that were studied. The southern sites, where the Hamlin and Valencia studies were performed did not experience as much tree damage due to these freezes. A total of eight studies were performed, with only two of the studies evaluating trunk shaker equipment. A trunk shaker was used on the Hamlin and Valencia study. Shaking time with the trunk shaker was approximately three to seven seconds and was dependent upon the equipment operator's judgment. Any fruit that fell to the ground or was remaining on the tree was collected and weighed by hand.

There was some variation in tree size, however, those variations proved to be insignificant with respect to fruit removal percentages by the shaker equipment. When Whitney and Wheaton (1987) looked at initial season fruit yields of the Hamlin orange study, the yields were the same for hand harvesting and trunk shaker methods. Then they looked at subsequent fruit yields of the Hamlin study and the trunk shaker did not significantly reduce fruit yields in any of the five seasons studied. On average, trees that were harvested with a trunk shaker yielded up to 5% more boxes than trees that were handpicked.

Whitney and Wheaton (1987) did a second study, this time on Valencia oranges and the initial yields by the trunk shaker and, similar to the results with Hamlins, hand harvesting and mechanical harvesting results were not significantly different. Subsequent yields showed that trees harvested with a trunk shaker experienced significantly lower yields during the 1980-1981 season. However, when yields by all harvest methods were averaged over the five year study period, trunk shaker and hand harvesting methods resulted in very similar yields with no significant reductions in the Hamlin study. Similar to findings in the Coppock (1971) study, yield reductions were noticed in the Valencia study when mechanical harvesting took place during the late season, when the fruitlets were approximately 0.85” in diameter or larger. Another concern addressed in the Valencia study was the potential fruit production reduction due to bark damage from the shaker clamp pads. During the initial season, 1979-1980 there was bark damage on approximately half of the trees harvested with the trunk shaker. In the subsequent seasons, there was a large reduction in bark damage that occurred. Whitney and Wheaton (1987) found no supporting evidence as to whether or not the bark damage could have attributed to any part of the yield reduction.

Whitney and Wheaton (1987) concluded from this long-term study that a trunk shaker did not reduce yields in the Hamlin orange study; however, yields were reduced in late season in the Valencia study by an average of 10%, Once again, this is because late season harvest by mechanical methods, after the beginning of May, affect the fruitlets which would then be around 0.85" in diameter or larger, making them more susceptible to subsequent yield reduction.

Whitney et al. (1986) performed another five-year study with Hamlin and Valencia sweet oranges using four trunk shakers, two linear and two multidirectional. For each type of shaker and hand harvesting method one experiment used an abscission compound and one experiment did not. The purpose of this study was to evaluate the effects of the two different types of trunk shakers with and without abscission chemicals on tree growth, fruit removal, fruit yield and overall harvesting efficiency. The Hamlin and Valencia orange trees were eight and fifteen-year old trees that were approximately the same in size and density. The Valencia studies took place prior to May and before the young fruitlets had reached a diameter of 0.5". Whitney et al. (1986) stated that if shaking occurred when the fruitlets were larger, yields may have been reduced more than what was determined in their study. Tree growth results of the Hamlin orange experiments showed that there were no significant differences in trunk circumferences in the initial year between hand and mechanically harvested trees. All of the trees harvested with a trunk shaker grew approximately two inches between 1982 and 1986, again with no significant differences by harvest method. Measurements of tree growth in the Valencia experiments had similar results to the Hamlin study. There were no significant differences in trunk circumferences in the initial year between hand and mechanically harvested trees. Between 1982 and 1986, all of the trees harvested with a trunk shaker grew by approximately two inches in circumference with no significant differences by harvest method. By 1986, all the shaker trunks had grown approximately two inches; however, those shaken with the linear shaker with 133lbs unbalanced mass combined with the abscission chemical applied had smaller trunks. Even though the trees shaken with the 133-pounds of unbalanced mass combined with the abscission chemical had smaller trunks, the overall percentage increase in circumferences among all the trunk shook trees was not significantly different. Unfortunately, the article did not state the importance of the different masses on the different types of shakers.

Whitney et al. (1986) found there were no significant differences in fruit yields of Hamlin oranges for all treatments. The yields were higher in 1982 and from trees harvested by the multidirectional shaker with eccentric masses in same rotation without abscission chemicals applied produced significantly higher yields than hand harvesting methods. Due to damaging freezes during 1982, the 1983 yields were all significantly lower than usual. Overall, when averaging the yields for each method over the 1982-1986 seasons, there were no significant differences in yield. Abscission chemicals significantly increased removal and harvesting efficiencies.

Results from the Valencia trial were not as uniform initially as the Hamlin trial, however there were no significant differences noted among the harvest methods. Overall from 1982-1986, the multidirectional same rotation shaker with abscission chemicals applied was the only treatment that was significantly less than those hand harvested. The explanation for the significant difference is because that was the most aggressive form of shaker and with the abscission chemicals being applied the young fruit was more susceptible to being lost. When comparing all the different shaker treatment average yields with hand harvesting average yields, no significant differences were noted. Abscission chemicals significantly increased removal and harvesting efficiencies.

Whitney et al. (1986) concluded tree growth of both Hamlin and Valencia oranges was not affected by any of the shaker treatments or by the application of abscission chemicals. Bark damage, which can be a common problem with trunk shakers, was not an apparent problem over the five-year study. Valencia yields were only reduced significantly by the multidirectional shaker with the same direction mass rotation when abscission chemicals were applied. All other Valencia yields and all Hamlin yields were not affected by the trunk shakers or abscission chemicals.

Li et al. (2005) performed a study that began in 2003 and ran for approximately five years to look at the immediate and long term responses of trees to mechanical harvesting. The objective of this study was to look at tree physiological activity after mechanical harvesting and to evaluate return growth, tree vigor, and yields of Hamlin and Valencia trees. Their study measured tree water status, leaf gas exchange characteristics and return bloom after harvesting with a trunk shaker.

Li et al. (2005) found that between 10% and 15% of the leaves were removed due to mechanical harvesting when trees were shook for 10 seconds. As with the mature fruit removal, defoliation only increased slightly due to a longer shaking time (Li et al. 2005) All trees harvested with the trunk shaker maintained a water status similar to those trees that were hand harvested. Drought stress was not increased in those trees mechanically harvested versus those hand harvested. When irrigation was withheld, the drought stress incurred by the trees mechanically harvested quickly disappeared when the soil water was replenished with rainfall or irrigation. Leaf water use efficiency and leaf chlorophyll fluorescence were not affected by defoliation caused by mechanical harvesting or by root damage due to the trunk shaker. The return growth in 2004 crops was no different between those trees mechanically harvested and hand harvested. Overall, the results showed "well-managed" citrus trees can tolerate low levels of defoliation and possible root and bark damage from trunk shaking without any further physiological stresses being developed.

Li and Syvertsen (2005) published a second paper in 2005 based on a different study looking at physiological impacts by measuring the tree water status and leaf gas exchange of mature Hamlin and Valencia oranges following mechanical harvesting by a trunk shaker. The results were compared to the tree water status and leaf gas exchange from hand harvested mature Hamlin and Valencia oranges. There are several factors that can affect the physiological status of citrus trees such as the type of harvest equipment, operator skill, grove design and conditions as well as the weather. When looking at long term studies that have been performed, such as those discussed prior, fruit yield was not significantly affected by mechanical harvesting methods compared to hand harvesting methods. There have been some secondary type infections that arose after immediate injury following mechanical harvesting in cherry, almond and peach trees; however, physiological type reactions to these possible physical injuries have not actually been documented (or noted at all in citrus trees). In this case, three experiments were performed.

Results from Li and Syvertsen (2005) first experiment showed that trunk shaking can cause moderate drought stress, but once the trees were watered following harvest, they recovered immediately. For the trees shaken for 20 seconds, the mid-day water measurement was at a level similar to a continuous drought stressed tree. Irrigation and rainfall that followed harvesting, however, brought the trees back to full recovery immediately. In the second experiment, rainfall helped to ensure a high mid day water status. However, the temperature rose to above normal for harvesting time, exceeding 29º C, which caused the mid day water level of the hand harvested trees to actually be lower than that of the trees mechanically harvested. Lastly, in the third experiment initially soil water content was high, thus there were no drought induced symptoms that occurred regardless of irrigation, harvesting type or bark removal. Overall, Li and Syvertsen (2005) found there were no significant differences in leaf gas exchange measurements between hand harvested and mechanically harvested trees. There was also no significant effect on photosystem II efficiency as measured by the chlorophyll fluorescence.

Li and Syvertsen (2005) concluded that mechanically harvested trees did not develop significant water stress symptoms when the grove was well irrigated. When grove irrigation was withheld, mechanical harvesting induced slight drought stress symptoms. But trees recovered as soon as irrigation was resumed. Also, when the weather was hotter and dry, the mechanically harvested trees had a higher mid day water stem content than those trees hand harvested. Due to the rapid recovery of the trees following any drought stress type symptoms, there were no significant differences noted in water status between hand and mechanical harvesting. Leaf gas exchange was also unaffected by the defoliation and slight root damage that occurred due to trunk shaking methods. It has actually been reported that partial defoliation can help increase leaf photosynthesis in the remaining leaves of the trees. Overall, when harvesting “healthy, well-managed trees”, trunk shaking could cause leaf defoliation, root and bark damage without long lasting physiological stress on a citrus tree.

Since growers had expressed concerns over the potential effects of defoliation from mechanical harvesting, Li et al. (2006) initiated a second set of studies in 2003 to further examine the potential effects of leaf loss on tree health and fruit production. Trials were conducted on thirteen year old Hamlin and fourteen year old Valencia orange trees. Trees were both hand harvested and harvested with a linear type trunk shaker for 10 to 20 seconds. Then, from 2004 to 2006, individual trees were harvested with the same harvest treatment. Any leaves that were removed were collected and the leaf area was measured after harvest and the canopy area was estimated.

In the Hamlin study, when the trunk shaker was used, more than 12% of the leaf area was lost in 2004. By 2005, Li et al. (2006) determined the canopy light interception of the mechanically harvested trees was similar to those hand harvested. The trees intercepted almost 80% direct sunlight regardless of the harvest method used in 2004. The second year of trunk shaking only caused a 6% loss of leaf area, and once again, there were no significant changes in actual canopy light interception.

In the Valencia study, trunk shaking removed approximately 15% of the leaf area in 2004. By 2005, the canopy light interception was once again similar among all trees regardless of prior harvest treatment. Between 7% and 13% of the leaf area was removed the second year, but once again, there was no significant loss in canopy light interception.

Li et al. (2006) concluded that defoliation caused by the trunk shakers did not significantly reduce canopy light interception in well-developed citrus trees. It was actually shown that the partial removal of leaves due to mechanical harvesting could help to increase light penetration to the inner canopy which subsequently increases the gas exchange rate of the leaves inside the canopy. They determined that a healthy tree could sustain up to 25% defoliation without causing a reduction in next year’s yield. They also found that citrus trees can partially compensate for leaf loss by increasing photosynthesis of the remaining leaves. So while up to 15% of the canopy area was reduced, trees were able to maintain enough photosynthetic activity to maintain stable yields.

A common concern among growers in regard to mechanical harvesting is potential tree damage (Roka et al. 2009). A harvest machine can cause shedding of leaves, flowers and young fruit, broken branches, scuffing of bark and root exposure. Harvesting during the late-season will adversely affect next year’s Valencia crop yield. Throughout the literature reviewed above, there was no evidence that these visible “injuries” weaken the trees or affect tree health. These long-term studies have revealed that fruit yield and mortality of citrus trees were not affected by mechanical harvesting. There have been recent investigations that state “properly” operated equipment did not induce significant physiological stress in “well-managed” trees. It is believed by a majority of researchers that the physical damage seen by the eye is considered minimal and mechanically harvested trees fully recover to the same status as the hand harvested trees.

The studies discussed in this review have been “trial” studies under controlled conditions, and not studies based on commercial yields. These trials involved a limited number of trees per treatment and were designed by the researcher to control as many factors as possible, other than harvest method. A lingering concern among growers may stem from the uncertainty of extending results from “small-plots” to commercial blocks, involving hundreds of acres and thousands of trees. Furthermore, most of the studies reviewed above lasted less than five years. There needs to be a study performed on actual commercial groves in the industry with real-time factors playing a part such as weather and grove design of different groves, for example. Growers cannot control a lot of external factors like rain or drought and although some of the studies above simulated those conditions to measure potential affects, many growers still have their doubts.

I intend to build on prior research by analyzing production records from several commercial groves over a ten-year time period. My research will be based on several commercial groves in the state of Florida over a ten-year time period where many adverse conditions may have played a part, such as freezes, hurricanes and even drought. There are different grove designs and potential for equipment operators to play a part in potential yields. The data to be collected will include mechanical and hand harvesting yields, tree age, planting density, number of trees, rootstock and variety. The purpose of the study will answer the question “does mechanical harvesting have an affect on tree productivity?” and the answers will be based on commercial operating groves and not small-plot trials. Also, my study will be based on groves that were all harvested before the “late season”; therefore, the late season yield reductions in Valencia oranges that were reported in some of the studies above will not be a factor in my research. The “late season” problem is a large concern in itself and my study will not be looking at this issue, nor will it contain data collected during that time period. This study will hopefully give growers more confidence in the results that are found in determining tree productivity, yield and tree health in regards to harvesting methods. The results of this study will then be available to further help growers’ in making a decision on whether or not to mechanically harvest their citrus.

CHAPTER 3
DATA

The primary objective of this research was to determine if there was an immediate or lagged effect on yield and/or tree health caused by mechanical harvesting. It is important to remember this study was not a controlled experiment. Data were collected from four citrus growers in southwest Florida who used mechanical harvesting at some point in the past ten years. Also, we had to compare hand harvesting to mechanical harvesting, therefore, we needed growers who have performed both methods of harvest on their groves over the years. Yield data from commercial citrus blocks were. It is expected that this year's harvest method will not influence yield this year because generally it takes time for any potential physiological stress or damage to occur, therefore, it would not be evident in the immediate crop yields, but in the subsequent yields. It is also expected that there will be no lagged effect between harvest method and yield response. The data include both cross-sectional and times series data, meaning yield data were collected from several commercial blocks for a specific growing season as well as over ten growing seasons. The commercial blocks varied in size. Dividing annual yield values by the number of net tree acres standardized yield data as boxes per acre and allowed for comparison across all of the blocks. If a particular block was comprised of several tree age categories, a weighted average of yield was used to allocate a percent of the total yield reported by the grower to the tree age categories. The reason for using tree age as a production percent factor was because tree production varies with tree age. Tree density was then calculated by dividing the number of trees reported by the block size, in acres.

There are many other factors that may influence yield beyond harvest method. Grove management, fertilizer usage, irrigation, soil, and proficiency of equipment operators are all factors that may significantly affect yield for these commercial blocks; however we had no data to measure these factors. Data that was collected that could possibly affect yield beyond harvest method was tree age, tree density, variety, and rootstock. A county yield variable was used to incorporate some factors associated with weather and general growing conditions. A hurricane variable was used to incorporate the fact that there were several major hurricanes that affected the Florida citrus industry between 2004 and 2005.

A majority of the data collection took place at the United States Department of Agriculture (USDA), Florida Agriculture Statistics Service (FASS), office located in Orlando, Florida. The FASS office is a state branch under the National Agriculture Statistics Service office. The data collected at the FASS office was data that was reported by Florida citrus growers to the United States Department of Agriculture. It was easiest to obtain the data from the FASS office, as they had it in a spreadsheet laid out for ease of reading. The remainder of the data was collected by researchers at the University of Florida's Research and Education Center (SWFREC) located in Immokalee, Florida, from the growers. Data were collected on a total of four citrus growers, with multiple groves, located in both Hendry and Collier Counties. Each grower signed a release form enabling their grove information over the last decade to be used for the purpose of this research.

Each grower that participated in this research provided a list of their groves with section, township and range, as well as a grove map. The USDA uses Arc map, which is mapping software for computers. The grove blocks shown on the maps provided by the growers were matched with the blocks shown in the arc map system. A difficulty encountered during the data collection process arose when trying to match grower blocks with USDA designated blocks. At times, what a grower considered to be five different blocks, for example, the USDA would designate as one block. Other times the blocks were not able to be matched. Each block in the arc map system was assigned a FASS block number which was used to keep statistics on the block for a minimum of ten years. All the data collected for the research was hand-copied and later put into an excel spreadsheet. The data collected from the FASS spreadsheet included harvest year, company name, block ID, variety, rootstock, plant date, block size, tree count and net tree acres.

The data collected was on commercial sweet orange blocks located in southwest Florida. Data collected from the growers included total yield in boxes per acre by grower identified block and harvest method. A total of 572 observations were recorded with 25,553 net tree acres represented. From 1999-2008, over 11,109,214 boxes were both mechanically and hand harvested from the blocks analyzed in this study. Tree density was then calculated by dividing the number of trees FASS reported by the block size (in acres), which the researchers at the Southwest Florida Research and Education Center reported, (Table 3-1.), and ranged from 121 to 141.8 per block. The overall average tree density for all growers combined was 136.7 trees per block.

There were forty-seven blocks in the dataset, with the number of blocks per grower, varying from three to twenty per grower (Figure 3-1). These blocks were all located in Collier and Hendry County. The blocks represented a number of variety and rootstock combinations. There were four rootstocks and five varieties total (Table 3-2). The most frequent variety/rootstock combination was Hamlin/Carrizo followed by Rhode Red Valencia/Swingle. Overall, swingle was the most common rootstock and Hamlin was the most common variety planted. Block sizes also varied, with the average size per grower (Figure 3-2) ranging between 39 and 84 acres. Individual block size ranged from 17.90 to 152.4 acres.

There were two harvesting methods recorded in the data collected by SWFREC, hand and mechanical (Figure 3-3). Three variables were created from this data. The first is which harvesting method was used in the year the oranges were harvested. A total of 55% of all blocks harvested between 1999 and 2008 were hand harvested and 44% of all blocks harvested between 1999 and 2008 were mechanically harvested. A second variable was created to identify which harvesting method was used in the previous year. This was the method from the previous year, by block for years 2000-2008. Data from 1998 was not recorded, so the assumption was made that all trees were hand harvested in 1998, therefore the lag harvest variable for 1999 oranges is always hand harvest. Finally, a total mechanical harvest variable was created. This variable was the total number of times a specific grove had been mechanically harvested over the 1999-2008 period. The maximum number of times a block could be mechanically harvested over the ten-year period was ten times. A total of eight blocks throughout the study were mechanically harvested a total of ten times. A total of 14 blocks were never mechanically harvested over the ten year period. Grower one had three blocks that were never mechanically harvested, grower two had one block that was always hand harvested, grower three had six blocks that were always hand harvested and grower four had three blocks that were never mechanically harvested.

The average yield per grower was measured in boxes per acre per year (Figure 3-4). Growers 1 and 4 had the highest average yields until approximately 2004. They dropped off significantly, hitting their lowest yields in 2006. Grower 4 never recovered much but grower 1 improved significantly by 2008. Grower 2 averaged the lowest yields each year, also dropping off in 2006, but they also recovered improved by 2008. Grower 3 had the most consistent yields across the board, barely dropping any in 2006 and topping off a little over 500 boxes per acre in 2007. A factor with grower 2 that needs to be noted is that grower 2 only had three blocks worth of data compared to all of the other growers with quite a few more blocks. Tree age was then calculated by taking the data collection year and subtracting plant date. The dataset included trees ranging from two years to twenty-six years of age. A citrus tree typically will not produce fruit at two years of age, and if so they would not be harvested by machine. Citrus trees will generally not be harvested until it is at least three years of age. The majority of the trees in this data set were between the ages of twelve and twenty-one years (Figure 3-5). Typically as a citrus tree ages, production continues to increase. Previous studies performed in southwest Florida suggest that production in boxes per acre will increase up to a ten-year old tree and then remains fairly level (Roka et al. 1997). For the purpose of this research, percentage of production by age was a weighted average adjusted due to the range of tree ages we encountered. Any trees ages 14 and older were considered to be at 100% production. Trees between 9 and 13 years of age were at 78% production, those six to eight years of age were at 57% production and any trees between three and five years of age were at 43% production. In some cases, there were blocks with three different sets of data for one block; this was because there were new trees planted at different times within a block so they had to be separated from the original trees that were planted. Yield for each block was given as one overall total, so in order to determine true yield for the younger trees versus the older trees, we allocated the yield based off what percent production each tree should be producing at dependent upon their age, which was determined by harvest year minus plant date. The weighted percentages were determined by evaluating the tree age/productivity table in the Annual Citrus Summary for 2007-2008 (NASS, 2009). The total number of trees harvested per year has declined significantly since 2006 (Figure 3-6). This significant reduction in trees is primarily due to the lack of resetting after trees die or are removed. The tree inventory, as reported in the January 2004 census, (FASS, 2009), was 82,978.5 trees. In January 2006 that number fell to 70,849.4 and by January of 2008 it was down to 65,775.3 (FASS, 2009). The lack of resetting is due to new regulations imposed on citrus nursery operations. Citrus nurseries had to revamp their production facilities so that after January 1, 2008 all propagation of new citrus trees (from budwood to sold tree) occurred inside an enclosed structure.

County yield was collected from the annual Citrus Summaries, provided an estimate of season average yields (boxes per acre) by county for all orange varieties, early/mid season, and for late season varieties. Valencia oranges were listed in their own category due to being a late-season variety and typically exhibiting lower yields than the early and mid season varieties. Figure 3-7 shows both Collier and Hendry County yields in boxes per acre per year differentiating between early/mid varieties and late varieties. While Valencia yields followed a similar increasing and decreasing pattern as all other orange varieties combined, it was consistently less than all other oranges combined yields. The overall total yields per county, in boxes per acre, were compared. The average yields by early/mid and late season varieties for Hendry and Collier County were very similar each year. Both counties showed a substantial yield reduction in 2006, as expected due to Hurricane Wilma that hit south Florida in October 2005.

Lastly, data was collected to incorporate a hurricane variable. This variable was used to show the influence the hurricanes had on citrus yields across the state. The hurricane that significantly affected southwest Florida citrus yields was Hurricane Wilma and occurred on October 27, 2005. Therefore, the hurricane variable was assigned a zero for all harvest years prior to 2005, which included 1999-2004. A one was assigned to all harvest years after the 2004 season, which included years 2005-2008.

Data that wasn't included was the changes in the number of trees harvested annually. On average, a citrus block loses between two to three percent of its trees per year. Prior to 2005, growers would reset the open spaces in their groves with young trees. After 2005, growers were no longer resetting these open spaces due to the increasing problem of citrus canker and greening.

After the data collection was complete, the first step before analyzing the data was to clean the data once it was placed into an excel spreadsheet. Cleaning the data simply consisted of removing observations with missing data, doing some calculations using data collected to get other data measurements (for example, we had to calculate tree density based off of block size and tree counts) and making sure everything was placed in the correct columns and rows etc. The spreadsheet was organized with the harvest year as the first column followed by citrus company (grower) ID, block ID, variety, rootstock, plant date, block size in acres, FASS tree count, net tree acres, harvest method, lag harvest method, total mechanical, tree age, tree yield (in boxes per tree), tree density and the county location of the grove. Once the spreadsheet was organized with all the data, following the cleaning process, the regression could take place.

Table 3-1. Average Tree Density per Grower

Grower #	**Average Tree Density**
1	127
2	121
3	137.2
4	141.8
Overall	136.7

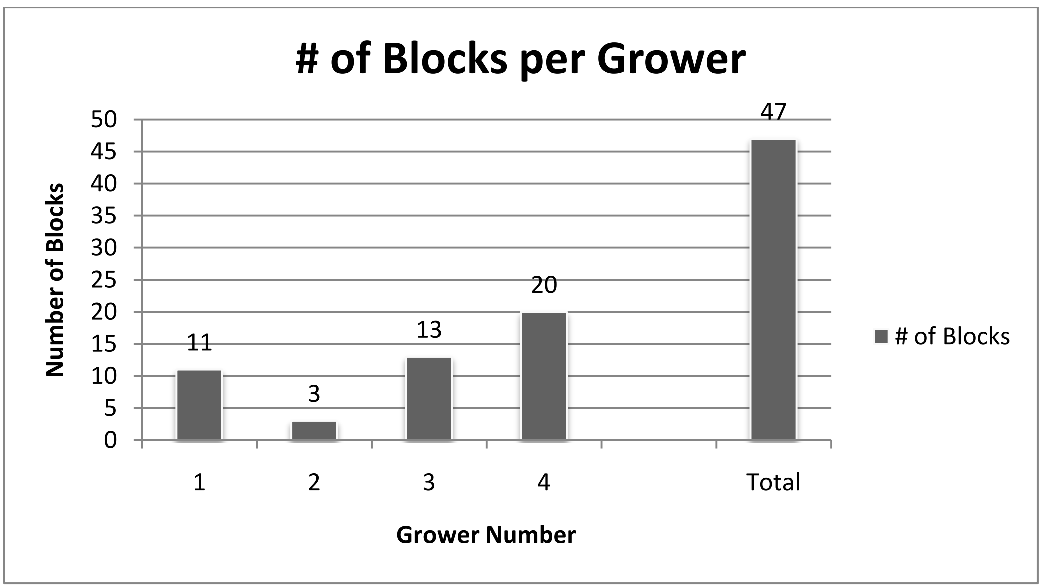

Figure 3-1. Number of Blocks per Grower

Table 3-2. Variety/Rootstock Combination Frequencies

	Swingle	Carrizo	Cleo	Cleo-Carrizo	Total by variety
Hamlin	111	135	10	20	276
Valenica	80	64	0	0	144
Parson Brown	0	10	0	0	10
Pineapple	0	20	10	0	30
Rhode Red Valencia	120	0	0	0	120
Total by rootstock	311	229	20	20	580

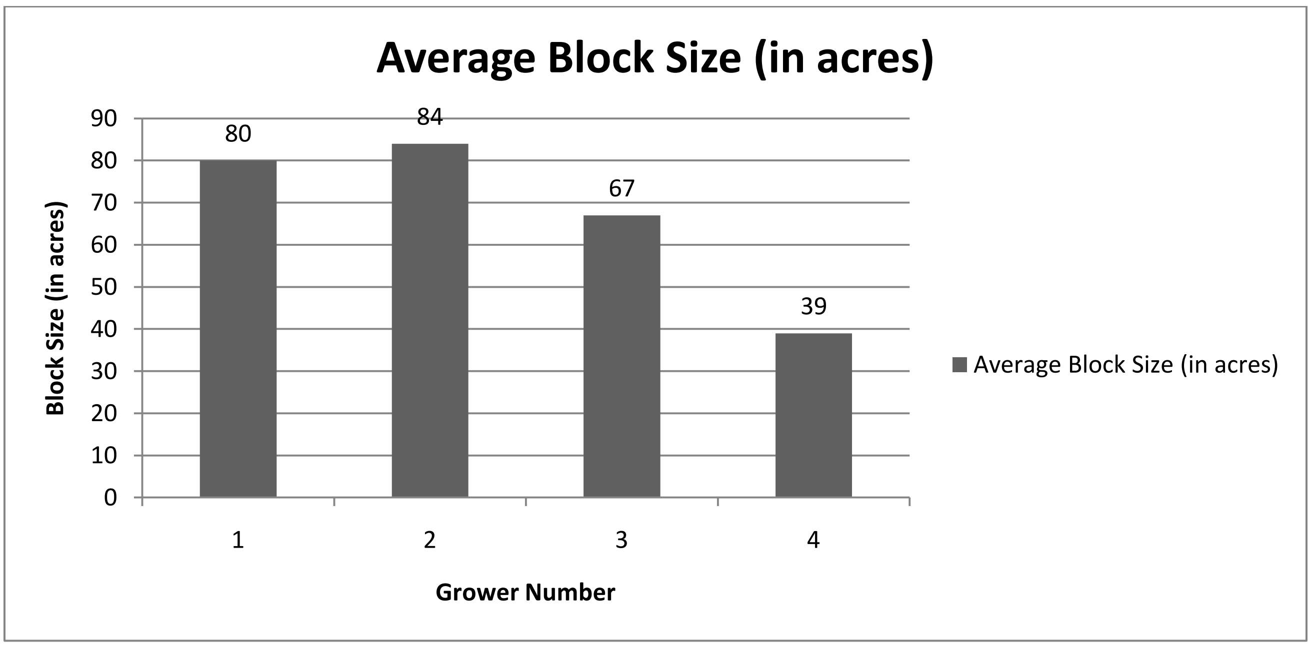

Figure 3-2. Average Block Size (in acres) per Grower

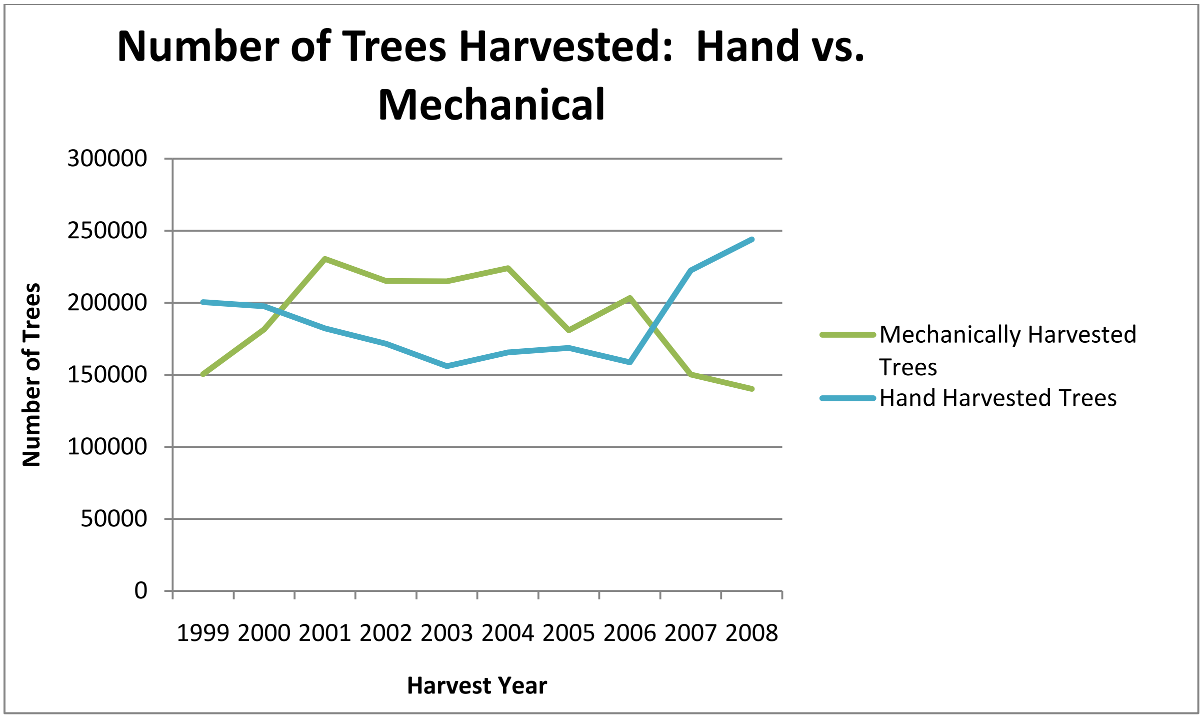

Figure 3-3. Number of Trees Harvested per Year: Hand vs. Mechanical

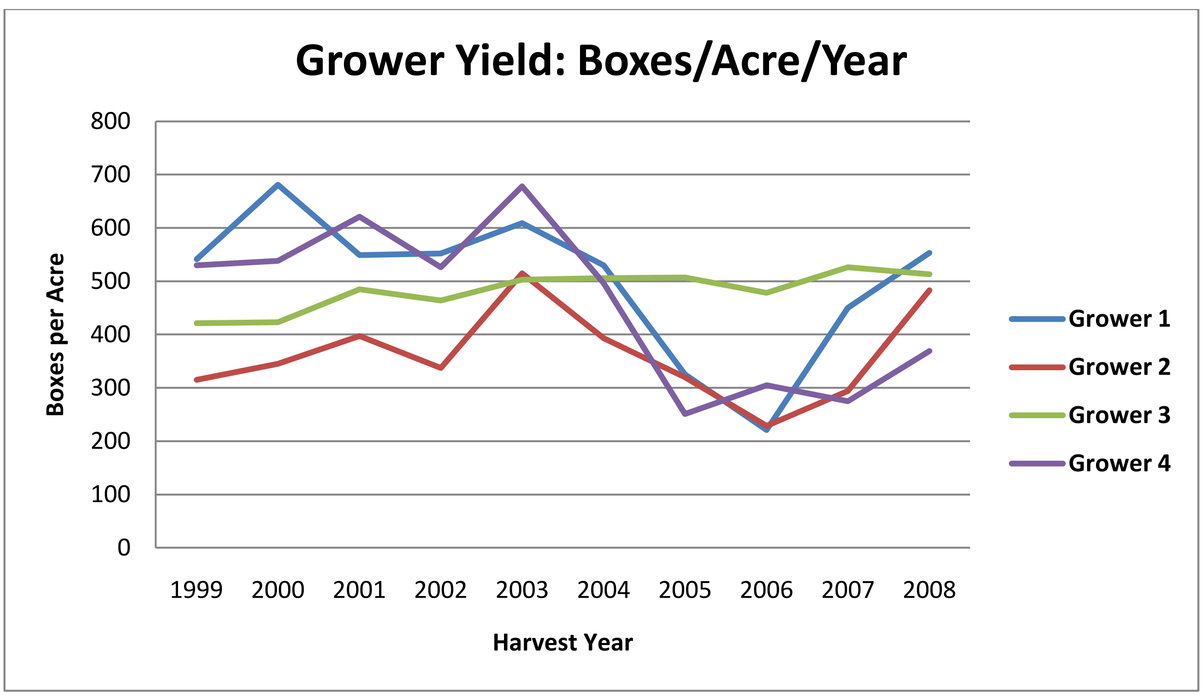

Figure 3-4. Average Grower Yield in Boxes per Acre per Year

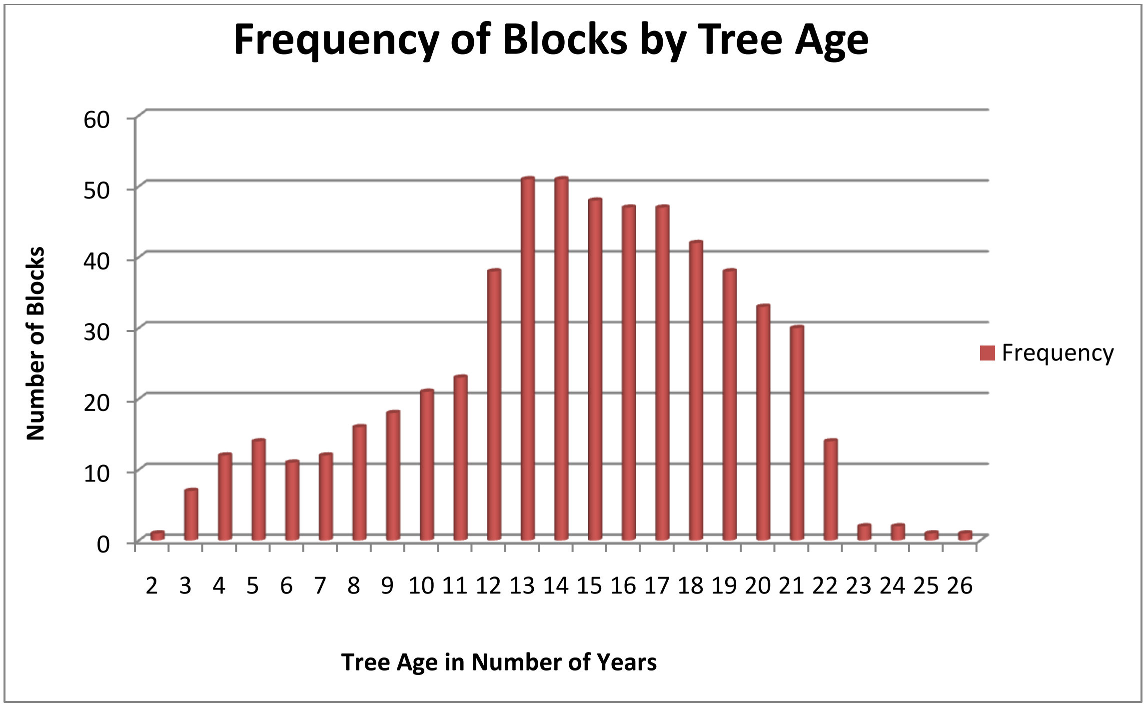

Figure 3-5. Tree Age Frequency and Percent Distribution

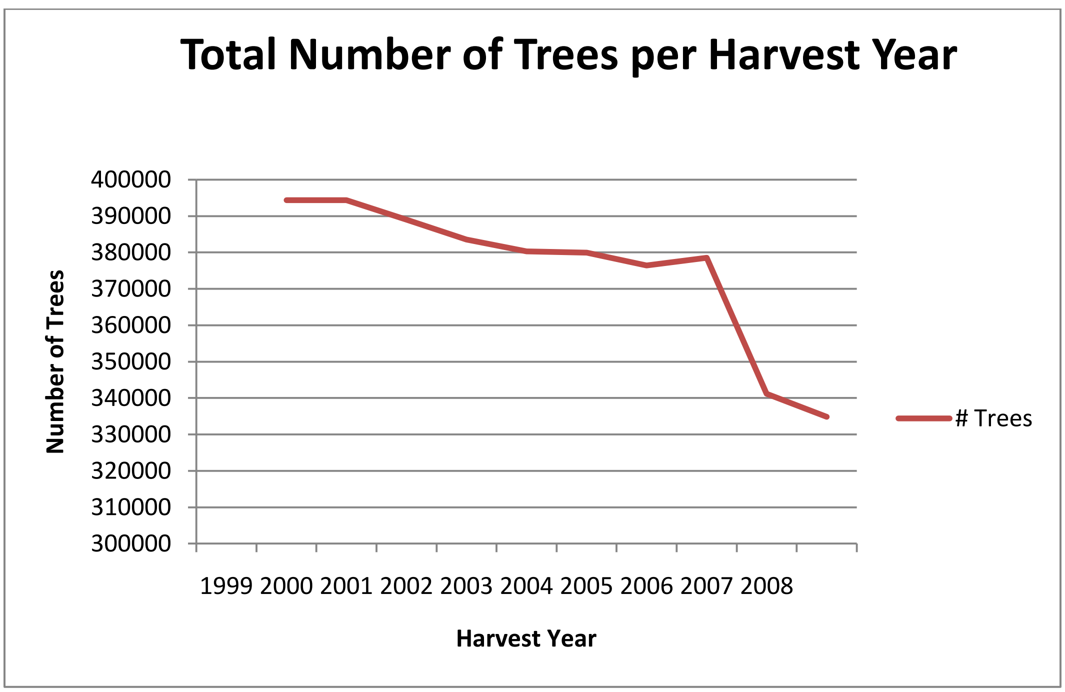

Figure 3-6. Total Number of Trees Harvested per Year

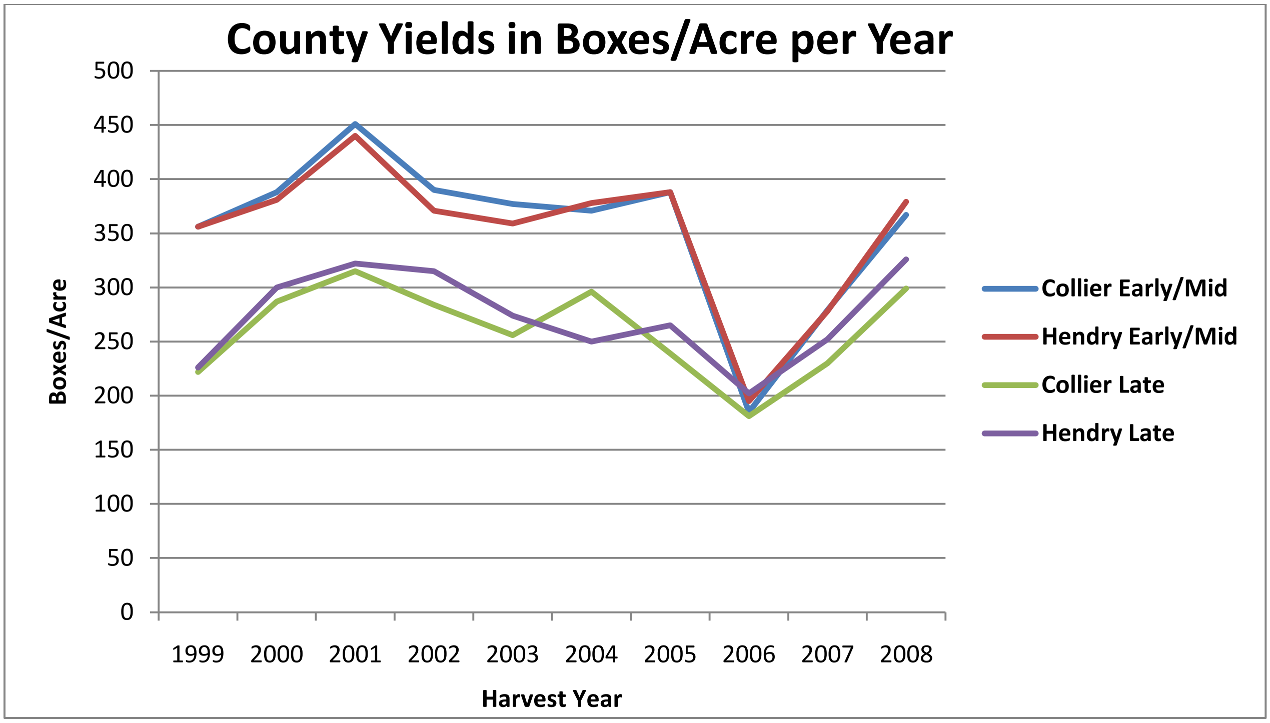

Figure 3-7. County Yields in Boxes/Acre per Year

CHAPTER 4
METHODOLOGY

Introduction

Following the collection, preparation, and organization of the data, a linear model was formed. Ordinary least squares, (OLS) were used to estimate a model with the data collected. This OLS model was used to determine which variables were significant when determining yield. It will also determine if there is a lagged affect on yield due to the number of times a tree has been mechanically harvested over the last ten years.

Theoretical Model: Ordinary Least Squares

An Ordinary Least Squares model (OLS) minimizes the sum of squared distances between the observed responses (data collected), and the fitted responses from the regression model. The simple linear regression determines if the independent variables used in the model are statistically significant in determining the variance in the dependent variable. A measure of goodness-of-fit for an OLS model is the R^2 value. The R^2 indicates how much of the variation in the dependent variable is explained by the independent variables. The closer the value is to one, the more variation that is explained. An R^2 of 1 would indicate 100% of the variation is explained, where an R^2 of zero would indicate none of the variation is explained.

The general OLS model is expressed as:

$$y_i = \alpha + \beta\chi_i + \varepsilon_i \text{ where } i = 1,\ldots,n,$$

where y is the dependent variable, χ is the independent variable and i indentifies each of the *n* sample observations. (Greene, 1990) The “least squares” coefficients in the model, α and β, are the values that minimize the closeness of the fitting criteria. Greene (1990) states that the least squares regression line passes through the point of means.

The fitting criterion, which is the sum of squared residuals, provides a measure of the fit of the regression line to the data. Ideally, the data should moderately fit the linear regression line and not be scattered across the graph.

Empirical Model

The empirical model for this study is

Yield = f (harvest method, past harvest methods, variety, rootstock, tree age, tree density, county yield, grower, and hurricane)

where the dependent variable is yield, measured in boxes per acre. The independent variables, which represent $\beta\chi_i$, were tested to determine if they were significantly different from zero. In order to be statistically significant from zero, the p-value for each independent variable had to be less than .05, preferably less than .01. This would indicate they are statistically different than zero with 95 or 99 % confidence, respectively.

While all coefficients are being interpreted, if the estimated coefficient of an independent variable is deemed statistically significant then it will be interpreted in regards to how it is significantly affecting yield. A positive coefficient indicates that as the independent variable increases by one, the dependent variable, yield, increases by the actual numerical value of the coefficient. For example, if tree age was statistically significant at the .01 level, with a positive coefficient of five, for every one year increase in tree age, yield would increase by five boxes per acre. If the coefficient was statistically significant but negative, the opposite would be true; for every one year increase in tree age, the yield would decrease by five boxes per acre. If an estimated coefficient is not statistically significant it is interpreted as being equal to zero and the particular variable has little or no influence on the dependent variable.

For regression purposes, some dummy variables were created. Dummy variables allow for the “comparison of means of a variable in two groups” (Greene, 1990, page 239). When evaluating harvest method, the only two options were hand harvest and mechanical harvest. Hand harvest equaled zero and mechanical harvest equaled one. This meant any block hand harvested was assigned a numerical value of zero and if the block was mechanically harvested it was assigned a value of one. Hurricane was the other dummy variable created. If harvest took place prior to 2005, it was assigned a zero and if harvest took place in 2005 or later, it was assigned a value of one.

There are several independent variables in the regression which may be highly correlated (Table 4-1). According to Greene (1990), one of the most frequently used solutions for highly correlated regressors is to drop one of the dummy variables from the regression itself. Therefore, we dropped one of the variables, in three cases, when running the regression so there would be no multicollinearity. The first group of variables that were highly correlated was the early, mid and late regressors. These variables were used to better group the citrus varieties. The late variable, which was Valencia and Rhode Red Valencia, was dropped in the regression. The results for the remaining variety variables will be interpreted compared to the late variable. For example, if early is significant and positive, it will mean that the early varieties have significantly higher yields than the late varieties. The next group of variables that were highly correlated was the group of variables representing the type of rootstock. The Carrizo rootstock was dropped. The results for the remaining rootstock variables will be interpreted compared to the Carrizo rootstock. For example, if Swingle is significant and negative, it will mean that Swingle produces significantly less boxes per acre than the Carrizo rootstock. Lastly, the four growers were considered highly correlated as well. Grower four was dropped in the regression meaning the remaining growers were then interpreted compared to grower four. For example, if grower two was significant and positive, it will mean that grower two produces significantly more yield than grower four.

Limitations

There are several limitations to the study on the affects of mechanical harvesting. A common fact of any research endeavor is that the research cannot be compared to the entire United States. A significant limitation to be considered is that there was limited access to data that could have possibly influenced and/or improved the overall regression model. One example of this is that the citrus growers did not keep accurate tree count data for their blocks, which would have been preferred over using FASS's tree inventory data. Another limitation is that this research is based on groves that are assumed to be properly managed and this assumption may not necessarily apply to all citrus producers in the state of Florida or the United States as a whole. Therefore, this research does not include information on production practices such as fertilizer usage and irrigation management for example. There have been new arguments suggesting that while stress from mechanical harvesting by itself may not adversely affect production, when stress from mechanical harvesting is added with other environmental stresses and poor management; there could be a cumulative and notable effect on tree health and crop yield. The data collected were not intended to be a representative sample of the entire citrus industry. The research objective was set up to determine whether or not with the given conditions found with the commercial blocks used in the study if mechanical harvesting caused any type of effect on production.

Table 4-1. Variable Names and Definitions

Variable Name	Definition
Harvest Method	Harvest method was an H if the entire block was hand harvested and M if the entire block was mechanically harvested.
Lagged harvest method	Lagged harvest method explained how the block was harvested the year prior. For example, we did not have data for 1998 and because mechanical harvesting was not widely used at that time, when evaluating the 1999 season, the lag variable was an H to indicate that particular block was hand harvested the year before.
Total Mechanical	Total mechanical provides a number that indicates how many times a block was mechanically harvested between 1999 – 2008. The maximum this number could be is 10 which would mean a grove was mechanically harvested every year from 1999 until 2008.
Early	Early encompasses the early season varieties, which included Hamlin and Parson Brown in this research.
Mid	Mid illustrates the mid season varieties, which was Pineapple in this study.
Late	Late encompasses the late season varieties, which were Rhode Red Valencia and Valencia in this research.
Swingle	Swingle is a type of rootstock.
Cleo	Cleo is a type of rootstock.
Cleo-Carrizo (CC)	Cleo-Carrizo is a mixture of two rootstock within one block.
Carrizo	Carrizo is a type of rootstock.
Tree Age	Tree age was calculated by subtracting the plant date from the 2008 season, which was the last season we had data collected on.

Table 4.1 Continued

Variable Name	**Definition**
Tree Density	Tree density was calculated by taking the number of trees FASS reported and dividing that by the block size (in acres). This illustrated how many trees there were planted per acre for each block.
County Yield	County yield indicates what the yield was, in boxes per acre, for each season from 1999 – 2008. We only collected this data for Hendry and Collier Counties, as they were the only counties data was collected on.
Grower	Grower was divided into grower 1, grower 2, grower 3, and grower 4. This represented each of the growers we collected data on.
Hurricane	Hurricane was a variable used to show the influence of Hurricane Wilma which affected southwest Florida in October 2005 and included as a variable to capture any hurricane related effects on production between the 2005-06 and 2008-09 seasons. Hurricane was assigned a zero for seasons 1999 – 2004 because those crops were not affected by H.Wilma. Hurricane was assigned a one for 2005 – 2008 to indicate that these seasons were subsequently affected.

CHAPTER 5
RESULTS

Introduction

This chapter will discuss the econometric results from the ordinary least squares regression that was run. The results will be used to test the hypotheses formed in the introduction of this thesis. The results for each regressor will be discussed and interpreted as to their effects on fruit yield. The results chapter will be followed by the conclusions chapter which will go back and review the objective of this paper and how the results affect the objectives and hypotheses.

Econometric Results

The objective of the empirical model was to determine if mechanical harvesting has an effect on yield. A number of additional variables were included in an attempt to isolate the effect from harvest methods on annual fruit yield. The model estimated was:

Yield (boxes per acre for a given year) = f(harvest method for the current year, lagged harvest method, total mechanical, variety, rootstock, tree age, tree density, county yield, grower, and hurricane)

Although we were trying to determine if the yield for next year is affected by this year’s harvest method, the current year’s harvest method was included simply to see if there was a significant yield difference between hand harvesting and mechanical harvesting for the current year. Lag harvest method captures the harvesting method of the year prior to the current year being studied and total mechanical is the number of times the block was mechanically harvested prior to the current year. Both of these past harvest method variables relate directly to our concern about prior harvesting methods affecting subsequent crop yields. Variety was broken up into three categories:

1) early (Hamlin and Parson Brown), 2) mid (Pineapple), and 3) late (Valencia and Rhode Red Valencia). There were a total of four rootstocks represented in the data analysis - Swingle, Carrizo, Cleo-Carrizo (mixture), and Cleo. Variety and rootstock combinations were included because according to prior research crop yields vary with variety and rootstocks. Tree age is important because as a tree ages, up to approximately ten years of age, production continually increases. Therefore, we must take into account how the age of the trees possibly affects crop yields. According to prior research, an increased tree density can reduce subsequent crop yields. That being said, it was included to determine if the densities of these commercial growers played a significant part on crop yield. Average annual "County" yield was included to help account for general differences in growing conditions among regions and across time. Counties may vary in a number of environmental ways and this variable was used to ensure that the locations of the groves were captured in the regression. Individual growers were included as explanatory variables to capture any significant differences in overall grove management practices. The regression results will address the differences in the growers by determining if any one grower was significantly more or less productive than the other. Lastly, a hurricane variable was incorporated into the regression to distinguish between those years of harvest prior to Hurricane Wilma and her affect on subsequent crop yields versus crop yields of those years prior to the storm

As stated in the Methods chapter, there are several dummy variables in the model. Included in the intercept term of the OLS model are hand harvesting, late varieties, Carrizo rootstock, grower four, and production between 1999 and 2004. The total number of observations included in the analysis was 572. The original data had

580 observations, but eight were excluded due to missing data. This model was estimated using SAS 9.2 statistical software and results are presented in Table 5-1.

The most important finding from this model is that the coefficients for harvest method, lagged harvest method and total mechanical were not statistically significant. This indicates there are no significant yield differences per acre for mechanical harvesting versus hand harvesting, whether the mechanical harvesting happened in the current or immediately past season. The coefficient for total mechanical, which measured the number of times a block was mechanically harvested before the current year, dating back to 1999, was also insignificant, indicating there is not cumulative damage from mechanical harvesting that impacts fruit yields.

The coefficient on the variable distinguishing orange varieties was significant, as would be expected. Early varieties, which included Hamlin and Parson Brown, yielded 124.47 more boxes per acre than for the late varieties (Valencias and the Rhode Red Valencias). The coefficient for early variety oranges was positive and significant at the 99% confidence level. The coefficient for the variable representing the mid-season variety (Pineapple) had a positive and significant coefficient at the 95% confidence level. Mid-season Pineapple oranges produced on average 86.91 more boxes per acre than the late season varieties.

Swingle, Cleo and CC (Carrizo-Cleo), are the three rootstocks included in the regression (Carrizo was dropped). Carrizo-Cleo is not an actual rootstock; it was used to identify blocks that were a mixture of Cleo and Carrizo rootstocks. The coefficient for Swingle is positive and significant, indicating for each additional tree with a Swingle rootstock 108.5 more boxes per acre were produced than those trees with a Carrizo rootstock. The coefficient for Cleo was negative and statistically significant at the 95% confidence level; demonstrating each additional tree with a Cleo rootstock produced 93.53 fewer boxes per acre than those planted on Carrizo rootstock. The coefficient for the Cleo-Carrizo mixture was not significant indicating no significant yield differences per acre when compared with trees on a Carrizo rootstock.

The coefficient of tree age was positive and statistically significant at the 99% confidence level, implying that as trees increase in age by one year, they increase productivity by 56.89 boxes per tree. The coefficient of tree density was negative and significant at the 99% confidence level, indicating that for each additional tree per acre yield decreased by 3.16 boxes per acre. One thing to remember is that tree density had a very narrow range for this study. County yield, which is a variable used to help incorporate county wide trends such as weather, soil and other environmental factors, had a positive coefficient of 0.51, which was statistically significant at the 99% confidence level. This indicates there is more variation in yield at the block level than at the county level. County yield captures overall growing conditions and the value of yield in any given year should vary directly with general growing conditions.

There were a total of four growers and grower four was dropped to avoid perfect multi-collinearity. The coefficients for growers one and two were not statistically significant, implying there were no significant yield differences between growers one or two and grower four. Grower three had a negative coefficient which was significant at the 99% confidence level, indicating that grower three produced 47.89 fewer boxes per acre than grower four. One possible explanation for this significant difference could be related to grove management practices. Finally, a variable was included to capture the impact of the October 2005 Hurricane Wilma on overall tree productivity. The coefficient for the hurricane variable was negative and statistically significant at the 99% confidence level, indicating that after the 2004-2005 season, yield decreased by 112.51 boxes per acre, per year.

The R^2 for this model is 0.4219. This means that 42.19% of the sample variation in our dependent variable, total yield in boxes per acre, is explained by all of the independent variables shown in the model equation above. This R^2 value corresponds favorably with a sugarcane study that utilized block-level yield data as well (Crane and Spreen, 1980). In general, cross-sectional studies incorporate more variability and thus tend not to produce a high R^2.

Table 5-1. Regression Results

Variable	Estimate/Coefficient	Error	Pr > ltl
Intercept	540.92	85.98	< .0001
Harvest Method	-15.62	20.08	0.44
Lagged Harvest Method	2.66	23.03	0.91
Total Mechanical	-0.29	4.16	0.95
Early	124.47	16.47	< .0001
Mid	86.90	38.31	0.02
Swingle	108.50	17.64	< .0001
Cleo	-93.53	41.27	0.024
Carrizo-Cleo (CC)	-115.67	66.60	0.08
Tree Age	56.89	8.16	< .0001
Tree Density	-3.16	0.51	< .0001
County Yield	0.51	0.12	< .0001
Grower 1	-25.93	23.92	0.28
Grower 2	-47.89	54.66	0.38
Grower 3	-98.72	19.35	< .0001
Hurricane	-112.51	17.06	< .0001

Note: Intercept term includes hand harvest, late varieties, Carrizo rootstocks, grower 4, and production prior to 2004.

CHAPTER 6
SUMMARY AND CONCLUSIONS

The goal of this research was to determine if mechanical harvesting causes an adverse effect on fruit yields in the current or future years. Mechanical harvesting and the possible negative impact on tree health has been a concern among growers for quite some time. Many people believe it makes a difference in yields both short and long term due to potential tree damage that may occur during the harvesting process. Previous scientific research indicated that mechanical harvesting equipment, which when properaly operated and not during the late-season Valencia harvest period, did not adversely affect crop yield or tree mortality. These studies, however, were conducted on a limited number of trees per field trials, and not under commercial production conditions. The data collected for this study were from four commercial grove operations in southwest Florida. Data were collected from a ten year time period in order to determine if lag effects exist in addition to short-term impacts. The results of the regression were used to determine if our hypotheses were correct and to see if mechanical harvesting truly does have an effect.

An ordinary lease squares regression was run with yield, in boxes per acre, as the dependent variable with harvest method, past harvest methods, variety, rootstock, tree age, tree density, county yield, grower and hurricane as the independent variables. The results from the ordinary least squares regression showed us what variables were significant in determining yield in boxes per acre. The coefficients for each of the significant variables indicated whether the variable would have a positive or negative influence on total yield. The significance level was also reported to indicate our level of confidence in whether a particular variable had an effect on fruit yields or not.

The results from the regression indicated there were a total of nine significant variables, seven of which were significant at the 99% confidence level and two of which were significant at the 95% level.

As found in other research, early varieties of oranges, which include Hamlin and Parson Brown, produced significantly higher yields than late season varieties, which were Rhode Red Valencia and Valencia. The variable representing mid-season varieties, Pineapple, was positive and significant at the 95% level. This once again indicates that the mid varieties produce higher yields than Valencia trees. According to NASS (2009), these findings are to be expected. From 2000-2008 mid season oranges, have yielded more than the late-season Valencia oranges.

Swingle rootstock produced significantly higher yields than the Carrizo rootstock. The Cleo rootstock, which was significant at the 95% level, exhibited a negative coefficient, meaning those trees with a Cleo rootstock, produced 93.53 fewer boxes per acre than those trees with a Carrizo rootstock. According to Castle (2003), different rootstocks are more productive in certain locations than others due to factors such as soil texture, depth, organic matter content, pH, nutrient status etc. The results from this study infer that the factors necessary for Swingle to be highly productive were present and some of the factors that may hinder the performance of the Carrizo were possibly present. A long-term study of yields in southwest Florida suggests that Carrizo is a more vigorous rootstock and provides higher production during the first ten years of production. Afterward, however, production from trees with Swingle rootstocks outperform the Carrizo trees.

Also, as tree age increased by one year, production increased by 56.89 boxes per acre. This was expected based off information found by FASS (2009). It is important to remember that percentage of production based off tree age was adjusted for this research due to the age range we had. All trees between three and five years of age were considered to be producing at 43%. Trees between six to eight years of age were producing at 57% and trees from nine to thirteen years of age were producing at 78% production. All trees over the age of 14 were considered to be producing at 100%. Therefore, it was expected that as trees aged they would produce more, which is what the regression results stated.

Harvest method, lagged harvest method, and total mechanical were not significant. The fact that harvest method and past harvest methods are not statistically significant is extremely important when looking back at our research objective. As found in the study conducted by Whitney and Wheaton (1987), yields were very similar between hand harvesting and mechanical harvesting over a period of at least five years. Results from this study suggest the same conclusion but for a ten-year period of time and based on commercial production data. Lag effect and total mechanical were both used to determine if previous harvest methods caused a long term effect in current yields.

Hypotheses

The results of the study and regression were used to determine if the hypotheses formed were accepted or not accepted. The first hypothesis predicted no significant yield differences between mechanical harvesting and hand harvesting for the year being studied. The coefficient for the variable harvest method was not statistically significant, indicating that we fail to reject the null hypothesis that mechanical harvesting is not significantly different from hand harvesting. This was expected because generally a change in harvest method would affect the subsequent crop yield, if any affect at all, as opposed to the original year it took place.

The second hypothesis predicted that yield would not be significantly affected by last year's method of harvest. The lag variable in the regression captured the method of harvest the year prior to the year being studied. The coefficient of lagged harvest method was not different from zero and it was not statistically significant. This indicates we fail to reject the null hypothesis, which predicted the harvest method of the prior year would not affect yield of the current year. Ultimately, this means the lag variable suggests no "short-term" effects on yield.

The final hypothesis predicted that the number of times a block was previously mechanically harvested would not significantly affect current yield. The total mechanical variable measured how many times a block was mechanically harvested prior to the year being evaluated. The coefficient for total mechanical was not different from zero, and it was not significant, indicating we fail to reject the null hypothesis that as the number of times a block was mechanically harvested increases, it did not affect yield. It can be concluded that the total mechanical variable seems to infer that mechanical harvesting has no "cumulative" effect on harvest yields.

Whitney et al. (1986) concluded that tree growth was not affected by shaker treatments and that Valencia yields and Hamlin yields were not affected either. The results of the regression model determined that lag effect and total mechanical were insignificant in determining yield, which means there appears to be no tree health or growth affects significant enough to reduce yields due to prior mechanical harvesting methods, just as Whitney et al. (1986) concluded. Li and Syvertsen (2005) published a paper looking at physiological impacts of mechanical harvesting and once again, they concluded fruit yields were not significant affected by mechanical harvesting methods compared to hand harvesting methods. As stated above, the results of the OLS regression performed on the data came to the same conclusion; yield was not significantly affected by current harvest method or prior harvest methods that go back up to ten years.

Further Research

There are many opportunities for further research on the effects of mechanical harvesting. One area that could be further built upon is grove management. No data were collected on fertilizers, irrigation techniques, and other grove management practices. These factors could have a large potential to affect fruit yields. Also, it is important that the operation of mechanical harvesting equipment is done properly. While that could be hard to measure it could potentially be a large factor in yield as well.

This study was limited to Collier and Hendry Counties, which are only two counties out of several that, have large commercial citrus groves. There is very little mechanical harvesting that occurs outside of Hendry and Collier Counties. It would be of benefit to increase the sample size throughout the state. The data that we were able to collect from the FASS office played a part in limiting the areas we could research because their system did not allow us to use Arc Map on any other counties. Location has the potential to influence citrus yields as well and therefore the sample size should be increased for future research.

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BIOGRAPHICAL SKETCH

Katrina Leonard was born and raised in Tampa, Florida and began at the University of Florida in the fall of 2004. She graduated with honors from Walter Sickles High School May 22, 2004. She graduated with her Bachelor of Science in food and resource economics with minors in Agricultural and Natural Resource Law and Leadership on May 2, 2008 Cum Laude. She received her Master of Science in food and resource economics on May 1, 2010.

While in high school Katrina was a member of the National Honor Society and FFA. She was Chaplain, President and Vice president of her FFA chapter throughout her high school career. She was also captain of their FFA horse judging team, where they placed fourth in the state and she was second high individual in the state. She was also a member of the Ag. Business team for the first year her high school competed.

Katrina was a teaching assistant for undergraduate Macroeconomics in the Food and Resource Economics Department from August 2008 through May 2010. She spent the summer of 2007 helping Dr. Lisa House with research through a summer internship program the Food and Resource Economics Department offered.

Most recently, Katrina was selected for a summer student position with the USDA Rural Development agency for the summer of 2009. Following the end of her student clerk position she was converted to an ARRA, America Recovery and Readjustment Act, student technician and then most recently she was converted to their Disaster Technician (non-student). Katrina has been blessed with many wonderful opportunities throughout her life which have helped to amplify her leadership skills over quite some time.