12-2022

An Economic Impact and Investment Analysis of Armillaria Root Rot in the United States Peach Industry

Gracie Herrin
geherri@g.clemson.edu

AN ECONOMIC IMPACT AND INVESTMENT ANALYSIS OF ARMILLARIA ROOT ROT IN THE UNITED STATES PEACH INDUSTRY

A Thesis
Presented to
the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science
Applied Economics and Statistics

---

by
Gracie Herrin
December 2022

Accepted by:
Dr. Michael Vassalos, Committee Chair
Dr. Felipe Silva
Dr. Nathan Smith
Dr. Anastasia Thayer

ABSTRACT

Peach production in the United States has decreased over the last decade due to an increase in disease prevalence. Armillaria root rot (ARR) is a lethal root fungus that affects many stone fruits, including peaches, often leading to rapid decline/death of trees and abandonment of orchards. This thesis is divided into four chapters which focus on answering four key questions that, to the best of my knowledge, have not been addressed in previous industry research.

The second chapter determines the magnitude of ARR disease prevalence in the United States and producers' maximum willingness to pay (WTP) for a theoretical ARR-resistant rootstock. Results from a nationwide survey of peach producers indicate that 100% of participants reported having crop loss due to ARR over the past two years. Producers also have an average premium WTP of $2.16 per tree for a rootstock that shows high disease resistance. With an assumed tree price of $6.00 per tree, this implied that producers were willing to pay 36% more for the large increase in ARR resistance.

The third chapter examines the economic impact of ARR on the national peach industry and an investment analysis of implementing the root collar excavation (RCE) method in peach orchards. Data was obtained from California, Florida, and South Carolina enterprise budgets and analyzed using a net present value (NPV) method paired with stochastic variables of disease impact year and impact rate. Findings suggest that ARR can decrease the national profitability of growing peaches by an average of $3,740 per acre. Additional findings indicate that implementing the RCE method on ARR-infected sites could increase profits per acre by an average of $657 nationwide.

ACKNOWLEDGMENTS

I would like to thank everyone who was directly and indirectly involved in aiding me through the process of completing my Master of Science in Applied Economics and Statistics. I could not have been successful in completion without the help of many involved parties.

Specifically, I would like to thank my graduate advisor and committee chair, Dr. Michael Vassalos. His trust and faith in me allowed me to have the opportunity as a graduate assistant for research and teaching, for which I am grateful. I would not be where I am today if it were not for his support and guidance along the way. I would also like to thank Dr. Felipe Silva, Dr. Nathan Smith, and Dr. Anastasia Thayer for serving on my graduate committee and answering the many questions I had throughout this process. I would further like to thank Dr. Thayer for believing in me enough to recommend me for a future career opportunity.

Continuing, I want to thank my friends and family for their support and words of encouragement. Particularly, I want to express my gratitude to my mom, Robin Herrin, and to Kevin Walker for their hours of help in the final stages of proofing and formatting and for their constant reassurance. I would also like to acknowledge all of the professors I had at Clemson in undergraduate and graduate school for nurturing my education and growth over the past four years. Lastly, I would like to thank Mr. Chalmers Carr, owner of Titan Farms, for his expertise and leadership. My first high school internship was at Titan Farms, which gave me background knowledge into the peach industry that proved crucial in the process of completing my thesis.

TABLE OF CONTENTS

Table of Contents (Continued) Page

LIST OF TABLES

List of Tables (Continued)

LIST OF FIGURES

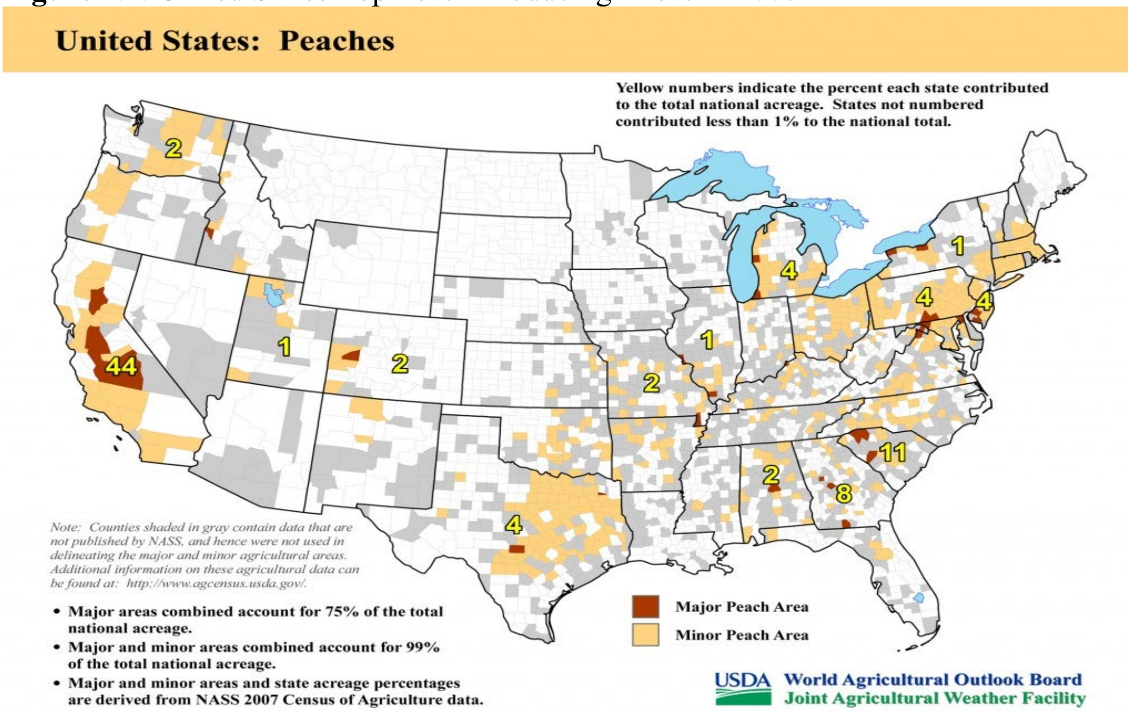
CHAPTER 1

INTRODUCTION OF THE UNITED STATES PEACH INDUSTRY AND ARMILLARIA ROOT ROT

Overview of the United States Peach Industry

According to the United States Department of Agriculture (USDA), in 2020 the peach industry in the United States produced more than 1.2 billion pounds of peaches valued at over $570 million in utilized fruit production. Peaches are grown commercially on over 76,000 acres in 20 states (NASS, 2022). California leads the US industry, producing over 75% of the nation’s peaches annually. Following California, the top producing states are South Carolina, Georgia, Pennsylvania, New Jersey, and Colorado respectively (AMRC, 2021; Shahbandeh, 2022). A depiction of the distribution of peaches across the United States is shown in Figure 1.1 (NASS, 2007). As seen on the map, the top three contributors of the national total peach acreage in 2007 were California (44%), South Carolina (11%), and Georgia (8%), respectively.

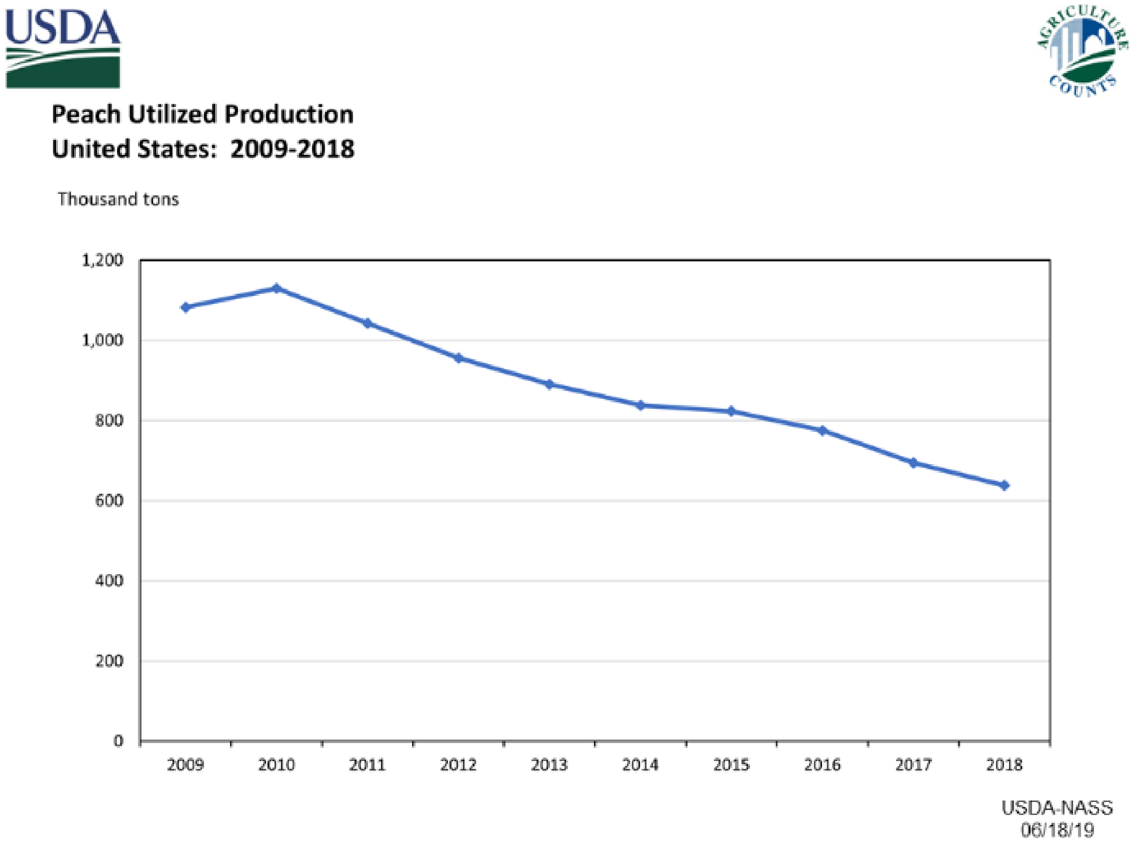
Figure 1.1. United States Top Peach Producing Areas in 2007



Source: USDA-NASS-World Agricultural Outlook Board-Charts and Maps-United States Top Peach Producing Areas and Growing Season, 2007.

However, production in the industry has consistently decreased over the last decade (see Figure 1.2), for a variety of reasons (NASS, 2019). A critical factor among these is an increase in disease prevalence (Miller et al., 2020; Johnson et al., 2021; Schnabel et al., 2021; Luo et al., 2022). Numerous diseases can impact peach orchards, including peach leaf curl, Phytophthora root and crown rot, peach tree short life, and Armillaria root rot (or oak root rot). Peach leaf curl causes leaves on the tree to fall off, and eventually can decrease the viability of the plant and diminish fruit quality, but infection can be managed by using preventative fungicides. Phytophthora root and crown rot causes affected trees to have decreased shoot growth, leaves, and sizes in fruit, but the disease can be prevented by ensuring adequate soil drainage (Shane, 2019).

Figure 1.2. Annual United States Peach Utilized Production from 2009–2018



Source: USDA-National Agricultural Statistics Service-Charts and Maps-Peaches: Utilized Production, US, 2019.

Peach tree short life (PTSL) causes rapid decay in branches and new blooms, resulting in death of the tree within weeks (Shane, 2019; Doubrava et al., 2021). In the 1990s, PTSL was the leading cause of premature peach tree mortality, causing almost 50% of early peach tree deaths in the United States (Beckman, 1998; Beckman & Chaparro, 2015). During this time, lifetime production losses due to PTSL in South Carolina alone were estimated to be over $6 million (Beckman et al., 1997). Many pre- and post-plant control options have since been discovered to increase tolerance to PTSL in peach orchards. The options include chemical nematicides, bacteria-based biological controls, biofumigation, crop rotation, and resistant rootstocks (Liu, 2009).

Armillaria root rot (ARR) was the second most lethal peach tree disease in the 1990s, causing early mortality of 35% of trees (Beckman, 1998; Beckman & Chaparro, 2015). At the time, PTSL and ARR combined reduced the average tree life from 12–15 years to only 7–9 years in South Carolina and Georgia, creating a substantial risk to the economic feasibility of peach production in the area (Beckman & Chaparro, 2015). In 1993, a new peach rootstock, Guardian®, was released jointly by the USDA-Agricultural Research Service (ARS) and Clemson University to combat both root-knot nematodes and PTSL in a single rootstock. This root cultivar has since been vastly adopted in the peach industry and the losses of trees due to PTSL have substantially declined (Beckman & Chaparro, 2015; Beckman et al., 2019). However, Guardian® is still highly vulnerable to ARR, which replaced PTSL as the dominant cause of early mortality in trees (Schnabel et al., 2012; Beckman & Chaparro, 2015).

ARR is caused by soil-borne basidiomycete fungi (*Desarmillaria tabescens* and *Armillaria mellea*) which spreads by root-to-root contact. The disease attacks woody roots, which then slowly decompose, causing yield and growth restrictions, and eventually total death of the tree (Baumgartner et al., 2018). Unlike other root diseases that leave bacteria in the soil (e.g., Phytophthora root and crown rot), ARR spreads through the woody roots that remain in the soil after removal of the infected trees as it is difficult for producers to ensure all roots are extracted. The disease then uses the dead roots as a nutrient source to remain alive in the soil. Depending on the size of the root affected, the distance of the root from the surface, soil type, and soil moisture, the fungus can survive in remaining roots from years to decades (Miller et al., 2020).

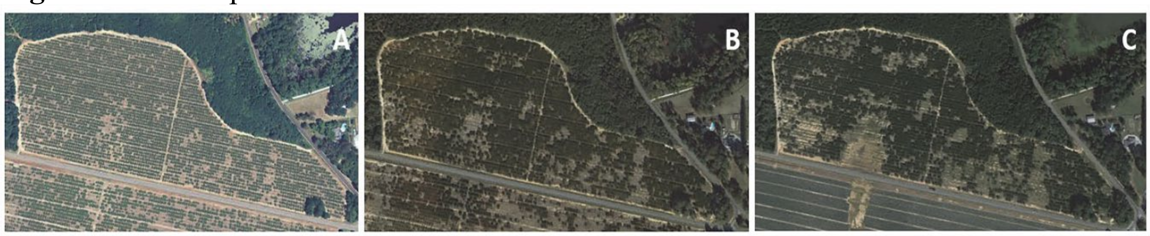
Peaches are categorized as “extremely susceptible” to ARR, as it can kill even the strongest trees (Miller et al., 2020). From 1980 to 1992, ARR was estimated to have caused $3.86 million in direct annual losses in South Carolina (Cox, 2004). In 2020, conservative estimates of tree mortality due to ARR in the southeast ranged from 3% to 4% of trees annually. Georgia and South Carolina Peach Councils reported this as an estimated annual loss of $8 million (Miller et al., 2020).

Chemical control options using sodium tetrathiocarbonate, propiconazole, methyl bromide, and cyproconazole, have been explored for ARR management. Nevertheless, all chemical options have all been deemed ineffective due to high costs or low efficacy. A biological control method of drenching *Trichoderma* spp. on seeds and soil has also been investigated. This option also proved to be nonviable as it did not diminish ARR presence in peach orchards over a 4-year study conducted by Schnabel et al. in 2011 (Scroggs, 2022).

Genetic solutions have also had minimal success as the only developed ARR-resistant rootstock is horticulturally difficult to reproduce (Adelberg et al., 2021). One frequently implemented cultural solution is root raking, which involves removing the roots from the orchard after trees removal with the goal of eradicating the microorganisms that cause ARR. While this does decrease the fungus presence, pieces of roots are unavoidably left behind as it is nearly impossible to achieve complete root removal. The remaining pieces then become hosts for the fungus to thrive on in the orchard (Scroggs, 2022).

Because of the length of time ARR can live in the roots, peach producers are recommended not to replant orchards on ARR-infested sites to prevent losses. However, ARR can also be present in soil where hardwood forests (e.g., pine-oaks) have recently been cleared, as it is also common in the forestry industry. This limits producers tremendously due to land scarcity, so growers are often forced to replant on infected land (Layne, 2005; Ivey; 2015). Figure 1.3 depicts an extreme example of the disease effects in a replanted peach orchard in South Carolina.

Figure 1.3. Example of Peach Tree Loss Due to ARR in an Orchard in South Carolina



Note. Orchard in 6 (A), 8 (B), and 12 (C) years of age. Photos courtesy of Chalmers Carr, President of Titan Farms, Ridge Spring, SC.

Purpose and Objectives

There have been numerous studies investigating potential solutions to ARR for producers (e.g., Baumgartner et al., 2018; Beckman, 1998; Miller et al., 2020). There are also multiple studies examining the economic impact of the fungus in the forestry industry (e.g., Filip & Ganio, 2004; Filip et al., 2009; Shaw et al., 2012). However, to the best of my knowledge, there have been very few studies analyzing the economic impact of the pathogen on the peach industry, in conjunction with potential profitability of specific management practices.

The second chapter of this thesis aims to cover this gap in literature by estimating the impact of ARR on the United States peach industry through a survey. The purpose of determining the effect caused by ARR in the peach industry is to assist research institutions in defining the magnitude of the ARR issue. Institutions will be able to use this information to decide if it is worth further research into new technologies to mitigate ARR losses. This information will also aid producers in being able to push for new technological development and would allow consumers to understand how much is lost in the economy due to this disease. An analysis was also conducted to determine producers' maximum WTP for a potential ARR-resistant rootstock. This information could be useful to nurseries and research institutions to determine if there is a demand for rootstock development. An examination of peach producers' risk tolerance was also included, which could help determine a potential adoption rate for a new ARR-resistant rootstock.

Chapter 3 of this thesis aims to estimate the economic impact and the potential gains to peach producers if the root collar excavation (RCE) method was implemented into their preplant management practices. The RCE method has been shown to provide a 2-year delay in ARR disease progression in peach orchards (Miller et al., 2020). A previous profitability analysis has been conducted by Miller et al. (2020) using the Florida peach enterprise budget. This chapter aims to build upon the previous estimates by including data from Florida, California, and South Carolina, and incorporating stochastic variables of disease impact year and rate.

The purpose of assessing the economic impact is to allow research institutions and producers to understand the effects of the disease on peach profitability in the United States. The purpose of determining the value of the RCE method is to aid producers in determining the net potential benefits from implementing the method. Producers nationwide will be able to use this research to determine if the benefits of the method outweigh the costs of implementation.

The last chapter of this thesis provides an overall conclusion on the results found in Chapters 2 and 3. Future research potential and recommendations are also noted.

CHAPTER 2

AN ESTIMATION OF THE IMPACT OF ARMILLARIA ROOT ROT IN THE UNITED STATES PEACH INDUSTRY

Objective

The purpose of this chapter is three-fold: i) to evaluate the impact of Armillaria root rot in the United States peach industry, ii) to estimate producers' maximum willingness to pay (WTP) for an ARR-resistant rootstock, and iii) to assess the overall risk-level of peach producers. The data for this study was collected from a phone survey of peach producers across the United States, conducted by Qualtrics.

Estimating the influence of the disease will provide critical data for research institutes, crop insurance agencies, consumers, and producers alike to assess the impact of the issue and how vital it is for a solution to be found for the economy. Analyzing producers' maximum WTP for a disease-resistant rootstock would give greenhouse producers insight into how much they could charge per tree. This could also incentivize new technological development because the nurseries will be able to analyze the potential demand and profitability. Estimating producers' risk-level has not been analyzed in the peach industry and can help determine a potential adoption rate if an ARR-rootstock is developed.

Sections in this chapter are organized as follows; a) relevant literature review on previous peach rootstock research, estimating willingness to pay, and potential peach adoption rate; b) summary of data collection; c) survey data summary; d) description of the methodology used; e) results from the survey and ordered logistic regressions; and f) conclusion, limitations, and potential future research.

Literature Review

Previous Rootstock Research in the United States Peach Industry

A variety of rootstock and cultivar combinations have been researched and implemented in the peach industry to adapt to various growing conditions. Studies have shown that the performance of the cultivar can be significantly impacted by the rootstock that it is grafted on. Rootstocks can impact leaf gas exchange, mineral and water uptake, tree size, tree vigor, bloom time, bud hardiness, fruit ripening time, and yield efficiency. Aside from relationship with grafted cultivars, rootstocks can also affect fruit size, harvest maturity, and concentration of sugars and organic acids, making the selection a critical production decision (Minas et al., 2018).

A fruit rootstock program in Byron, Georgia began targeted research into ARR and found that native North American plum species were significantly less susceptible to ARR than peaches. They began to develop an interspecific hybrid between the plum and peach species to combat PTSL, ARR, and nematodes in the same rootstock (Beckman & Chaparro, 2015). In 2007, a cooperation between the UDSA-ARS and the University of Florida led to the release of a new rootstock called ‘Sharpe’. This rootstock was a semi-dwarf plum hybrid and was based on the Byron program research (Beckman et al., 2008, 2019). ‘Sharpe’ became the first rootstock on the market that demonstrated resistance to all significant soil-borne diseases that producers likely faced. Nevertheless, ‘Sharpe’ showed insufficiency in production efficiency and fruit size and was quickly ruled unsuitable for extensive commercialization (Beckman & Chaparro, 2015; Beckman et al., 2019).

In 2011, another semi-dwarf plum × peach hybrid called 'MP-29' was jointly released by the USDA-ARS and the Florida Agricultural Experiment Station for trial (Beckman et al., 2012). The new hybrid offered extensive disease and nematode resistance, including resistance to ARR, while maintaining productivity. Due to its semi-dwarf characteristic, vigor was lower than standard peach trees in field testing as expected, but an unexpected outcome of smaller fruit also presented itself (Shahkoomahally, 2021). There are also issues with the availability of the rootstock as it is difficult to horticulturally reproduce, leaving producers without accessibility to it (Adelberg et al., 2021; personal communication). The Byron program is continuing their development in rootstocks and is targeting a variety of vigor options that will be more accessible to producers while maintaining the extensive disease resistance (Beckman et al., 2019).

Estimating Willingness-to-Pay

While research institutions are currently investigating new peach rootstocks, the research and development costs can be substantial, and adoption of the rootstock once developed is not guaranteed. To determine whether adoption will occur, it is crucial to be able to assess producers' desirable traits, demand, and willingness to pay for rootstock development (Kassie et al., 2017). WTP is a tool used to measure the maximum amount an individual would be willing to pay for a change in quality or price for some good (Kilduff & Tregeagle, 2022).

Stated preference valuation methods are often used to estimate WTP by asking individuals how they would respond to a change in a good if they were faced with a choice (Kilduff & Tregeagle, 2022). Two of the most used stated preference techniques are discrete choice experiments (DCE) and contingent valuation (CV). DCE presents respondents with several choice sets that contain varying attributes, such as varying quality levels of a good associated with varying cost levels. The respondents choose which set of attributes appeals the most to them. This allows researchers to indirectly estimate respondents' WTP values by analyzing their trade-offs between cost and quality. In contrast to DCE, CV directly asks the individual to indicate their WTP based on the change in a good (Barton, 2017).

Yue et al. (2017) used the DCE method to estimate U.S. growers' WTP for improved fruit quality traits in rosaceous fruit crops such as apples, peaches, strawberries, sweet cherries, and tart cherries. Part of their study analyzed which factors were most important to producers amongst all crops when deciding whether to adopt a new fruit cultivar. The most important determinants proved to be return on investment, consumer preference, suitability for climate, changes in fruit quality, and potential market performance. Their study also showed that fruit flavor was the dominant desirable trait amongst all five crops, with a WTP premium of $0.21/lb for peach growers to have improved flavor from mild to intense (Yue et al., 2017).

Zhao et al. (2017) also estimated WTP using a DCE, but their survey focused on studying only U.S. peach producers instead of all rosaceous fruit crops. They estimated growers' WTP for theoretical enhancements of certain peach fruit attributes (i.e., external appearance, external color, firmness, flavor, sweetness, and production costs). They found that the preferences depended on whether the producer's selling target was for fresh or processed fruit. Similar to Yue et al. (2017), they found that fresh peach producers were willing to pay more for improved flavor, along with improvements of color and size. The processed peach producers, on the other hand, place more importance on external appearance than on sweetness and size (Zhao et al., 2017). Since this study focuses mainly on the attributes of the tree and not the attributes of the fruit, the producer's selling target was not included in the analysis.

In 2020, Li et al. also used a choice experiment to analyze peach growers' preferences and looked at three key traits: fruit size, external color, and brown rot disease resistance. Instead of collecting data nationwide like the previous two surveys, they focused on southeastern U.S. producers. Including brown rot disease resistance as a characteristic proved to challenge the other surveys as they found that producers would actually prefer an improvement in brown rot resistance over fruit size and color (Li et al., 2020).

Although DCE's have been vastly used in other agricultural producer studies to extract WTP (e.g., Yue et al., 2017; Zhao et al., 2017; Li et al., 2020), they are often difficult to deliver through phone surveys as it is challenging for the participants to fully understand the choice options (Adams et al., 2015). Other formats that are often used to measure producers' WTP include open-ended, dichotomous-choice, and payment card questions (Kilduff & Tregeagle, 2022).

While there is research that analyzes peach producers' WTP (e.g., Yue et al., 2017; Zhao et al., 2017; Li et al., 2020), no research has been conducted in determining the WTP for an improvement in ARR resistance. This chapter aims to close the research gap by evaluating the maximum WTP of peach producers for an ARR-resistant rootstock.

Potential Adoption Rate

Potential adoption of new peach varieties was analyzed by Park and Florkowski in 2003. Their study analyzed the impact that external and internal peach quality attributes and operation characteristics (orchard conditions, geographic effects, economic factors) had on the adoption rate of new peach varieties in Georgia. Their results reinforced the significance of considering grower preferences when developing new peach varieties as it had a statistically significant impact on adoption decisions. Another notable finding from their data was that growers who have higher values for quality tend to adopt more varieties.

While Park and Florkowski's (2003) analysis focused on the adoption rate of varieties based on grower preferences, they did not assess overall risk level. Risk questions were included in the recently conducted survey to estimate the average risk level of growers in the peach industry for general, financial, and production decisions. This can estimate potential responsiveness of producers to new technological developments aside from just new varietal developments.

Data Collection

The data for this chapter was obtained through a telephone survey of peach growers across the United States. Telephone surveys in the past only targeted households with landlines but have been updated to include cellular phones as well. Phone surveys can typically be conducted quicker and less expensively than other survey methods such as mail-in surveys and face-to-face surveys. However, they also require careful construction since they do not offer visual aids for respondents that can be included in other methods. Questions must be structured for verbal administration and interviewers must be trained so that they fully understand the purpose of the study and expectations in answering questions (Israel & O'Leary, 2021). Phone surveys are typically structured for respondents to be able to finish the questionnaire in 15 minutes or less to maintain engagement (Research LifeLine, 2012).

Phone surveys in the past typically consisted of telephone-to-paper interviews, meaning that the interviewers would write out all responses for each participant on paper (e.g., Lewis et al., 2008; Gong & Aadland, 2010). Computer-assisted telephone interviewing (CATI) has been developed to assist interviewers in the phone survey process. CATI displays an online version of the questionnaire that allows interviewers to enter the data in real-time while speaking with participants. Using CATI has become more common as it reduces laborious data entry and potential subsequent error that could occur with telephone-to-paper interviews (Boland et al., 2006; Research LifeLine, 2012; Israel & O'Leary, 2021). CATI has been used in phone surveys to research topics from assessing women's access to agriculture extension during the COVID-19 pandemic in India and Nepal (Alvi et al., 2021) to estimating the value of protecting minimum instream flows in New Mexico (Berrens et al., 1996).

The target population for this study was all commercial (100+ acres) peach producers in the United States. Commercial operations were focused on because it was believed that smaller producers would not place much value on new rootstocks as they may not have the capital to afford higher per-tree prices. According to the USDA National Agricultural Statistics Service (NASS), there were over 9,200 peach operations with bearing acreage in the United States in 2017. Only 189 farms had over 100 acres of peach production, but they controlled over 60% of the total national peach acreage (NASS, 2017). A combined convenience-cluster sampling method was implemented through Qualtrics survey software to select the sample of peach producers (Qualtrics, Provo, UT). Convenience sampling was used to contact peach producers that Qualtrics already had contact information for. The cluster sampling method was used to target an equal number of responses from the east and west coasts.

All surveys consisted of eight sections and were conducted through phone interviews administered by Qualtrics between July 11 and July 25, 2022 (Qualtrics, Provo, UT). Two surveys were incomplete and replaced with new respondents on August 9, 2022. All survey interviewers used CATI to enter responses directly into Qualtrics to prevent errors. The survey took approximately 25 minutes for participants to complete.

While some previous research structured their surveys to start with demographic questions first and have the main content questions last (Gallardo & Wang, 2013; Krah, et al., 2018), this survey began with the content questions as did by Zhao et al. (2017) and Hu et al. (2009). We chose to do this after speaking with producers and an educated panel. Since the survey is longer than recommended for phone surveys, we also wanted to ask the main content questions first for more accurate estimates before respondent engagement began to decline.

Data

The first section of the survey included a screening question to eliminate respondents who were not the primary decision maker for the farm. This was set up so that information would only be gathered from those who decide farm practices. For example, information about how much an employee would value a new rootstock would not be useful since they do not have the authority to make the decision to switch to the new rootstock.

The second section of the survey consisted of general production questions such as how many varieties they grow, which two peach rootstocks they use the most, what their preferences are when selecting a rootstock, and if they experienced crop loss due to any major diseases (PTSL, brown rot, peach scab, etc.). In the third section, survey participants were asked questions specifically about ARR. These questions included estimations on percentage of tree loss due to ARR, costs spent on managing ARR, current control methods used for ARR management, and if they replant on land that has previous disease presence.

The fourth section of the survey contained questions related to respondents' WTP for certain rootstock attributes. This study will estimate producer preferences and WTP using a modified payment card (PC) contingent valuation method to attempt to prevent confusion for respondents over the phone. The PC format is, to some extent, a combination of an open-ended (OE) format and a dichotomous choice (DC) format. OE questions directly ask respondents to state their WTP given an improvement in some good, but respondents are not used to determining a monetary value for goods, so it is generally considered an unreliable method. The DC question format states a particular monetary value and asks the respondents to indicate if they would be willing to pay that amount for the good by choosing “yes” or “no”. The DC method has also proved to have question format issues as it can cause starting point bias and “yeah-saying” (Holmes & Kramer, 1995; Reaves et al., 1999; Kilduff & Tregeagle, 2022).

Payment cards have made extensive progress over the past few decades in valuation literature (Drichoutis et al., 2016). The payment card format has been found to have suitable response attributes and more conservative estimates than DCs by offering respondents a range of WTP values to choose from to indicate their maximum WTP (Reaves et al., 1999; Drichoutis et al., 2016). It is also typically easier for respondents to understand and answer PCs, which is advantageous to producers who may have lower education levels (Xiu et al., 2012).

Until 2006, the PC method was mainly used to estimate WTP for public goods (e.g., Klocek, 2004; Zhongmin, 2006). The modified payment card method was first proposed by Hu in 2006 to measure consumers’ WTP for non-genetically modified oil. The modified method uses spike models to adjust the conventional approach into the context of food by recognizing the possibility of zero WTP (Hu et al., 2011). Payment cards are typically used in research analyses for theoretical scenarios where a market is not developed (Drichoutis et al., 2016). Since all the WTP questions presented in this survey were theoretical rootstock attributes, the payment card method was chosen.

One example of using the PC method in agriculture is presented in Hu et al. (2011). They incorporated a payment card into their survey to determine which factors affect consumers' WTP for value-added blueberry products in Kentucky. They looked at three specific value-added blueberry products: blueberry herbal tea, blueberry basil vinegar, and blueberry syrup. The survey data allowed them to create consumer profile groups based on people who were willing to pay higher prices.

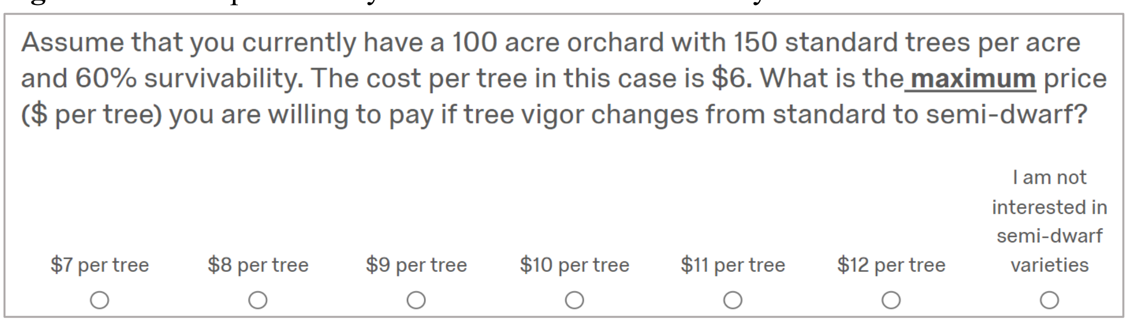
Problems associated with using PCs include range bias and implied value cues. However, research has shown that the range bias can be eliminated when the range of the WTPs is large enough to not restrict the respondent (Reaves et al., 1999). The range of values included on the payment cards in this study were based on industry research, expert knowledge, and a pre-test survey to diminish the range and centering biases.

To ensure that the respondents understood how to answer the payment card question correctly, they were given some disclosures. This included a statement that the questions may not reflect the current situation on their farm and an assumption that all fruit quality characteristics are at normal levels in all scenarios. Fruit quality defines the physical, mechanical, sensory, visual, nutrition, and food safety properties of fruits (Minas et al., 2018). We chose to assume standard fruit quality (e.g., firmness, texture, taste, flavor, appearance, etc.) as the payment cards focused on rootstock attributes and not fruit attributes.

The PCs implemented in the survey were modified payment cards since they offered respondents an option to indicate they were not interested in the rootstock, effectively representing a WTP value of $0. This is also known as a two-stage procedure, as it asks participants to answer two separate questions: i) whether or not they would buy the rootstock and ii) if they would buy the rootstock, what is the maximum amount they would be willing to pay for it. Each respondent was given eight payment cards to answer.

All payment cards assumed a 100-acre peach orchard with 150 standard trees per acre, 60% survivability, and a standard tree cost of $6.00. The eight payment cards asked their maximum WTP per tree for changes in the following rootstock attributes: tree vigor, tree survivability, tree density per acre, brown rot resistance score, ARR resistance score, and peach diameter. They all included maximum WTP price levels that ranged from $7 per tree to $12 per tree, as well as an option to indicate they were not interested in the specified rootstock attribute. An example of a payment card that was presented to the participants can be found in Figure 2.1.

Figure 2.1. Example of a Payment Card Used in the Survey


Assume that you currently have a 100 acre orchard with 150 standard trees per acre and 60% survivability. The cost per tree in this case is $6. What is the **maximum** price ($ per tree) you are willing to pay if tree vigor changes from standard to semi-dwarf?

$7 per tree	$8 per tree	$9 per tree	$10 per tree	$11 per tree	$12 per tree	I am not interested in semi-dwarf varieties
○	○	○	○	○	○	○

The fifth survey section asked the farmer about their current marketing practices and their future marketing expectations. Section six consisted of two questions that asked the respondents of their average risk level. Section seven contained questions about the experience of the respondent as well as questions about their farm. Section eight concluded the survey with demographic questions about the respondent.

Methodology

To assess the factors that influenced producers maximum WTP, an ordered logistic (OL) regression model, also known as a proportional odds model, was used. This model is suitable for situations when the dependent variables consist of ordinal responses (Richards et al., 2022). A variable is considered ordinal when it is a categorical variable that contains obvious ordering of category levels (Parry, 2020). Since the dependent variables that were analyzed (three payment cards and one ranked-response question) contained clear category distinctions, the OL model was deemed most suitable to use in this analysis.

An example of a basic ordered logistic model can be found in Equation (2.1):

(2.1) $$\Pr(Y_i = j) = \Pr(\mu_{j-1} < Y_i \leq \mu_j) = \Pr(\mu_{j-1} < [\beta_0 + \beta_i X_i + \varepsilon_i] \leq \mu_j)$$

where Y_i is the predicted ranking, μ_j is the categorical threshold μ with the cut point of j, X_i is the independent variables, β_i is the model coefficients representing the model parameters, and ε_i is the random error term (equation adapted from Richards et al., 2022). In this equation, if variable Y contains an order of responses, larger values of Y indicate a higher likelihood that the predicted variable falls into a threshold level between μ_{j-1} and μ_j. In other words, the equation models the log odds of Y falling into one of the category levels (Snedker et al., 2002).

With this model, the magnitude of the coefficients cannot be interpreted, but the sign of the coefficient can indicate direction. A positive coefficient indicates that an independent variable increases the likelihood of higher Y values. Negative coefficients suggest that the independent variable decreases the likelihood of higher Y values (Parry, 2020). The marginal effects (MEs) from OL models can be analyzed and interpreted as the change in the predicted odds when the independent/explanatory variable increases by one unit (Torres-Reyna, 2011).

Richards et al. (2022) used an OL model to assess how the maximum WTP for oysters in South Carolina was affected by consumer purchasing decisions. Their survey contained 5 cutoff points for 6 ordered WTP values, the lowest being \$0.50 to \$0.99 and the highest being \$3.00 and over. They were able to determine that age, gender, household income, and ethnicity were significant factors that influence higher WTP prices for oyster consumption at home. Age, gender, and household income also had significant effects for higher WTP prices for restaurant consumption.

An example of an ordinal dependent variable used in this thesis was the maximum willingness to pay per peach tree from the payment cards. The general dependent variable form for this can be found in Equation (2.2):

(2.2) $WTP_i^* = j \ if \ \mu_{j-1} < WTP_i^* \leq \mu_j$

where WTP_i^* represents the series of 6 per-tree WTP levels, and the coefficients μ_j represent the threshold values that move from one WTP category level to another higher level with $j - 1$ cutoff points. The model contains 6 ordered choices with 5 cutoff points that can be seen in Equations (2.3) through (2.8).

(2.3) $WTP_i = \$7.00 \ if \ WTP_i^* \leq \mu_1$
(2.4) $WTP_i = \$8.00 \ if \ \mu_1 < WTP_i^* \leq \mu_2$
(2.5) $WTP_i = \$9.00 \ if \ \mu_2 < WTP_i^* \leq \mu_3$
(2.6) $WTP_i = \$10.00 \ if \ \mu_3 < WTP_i^* \leq \mu_4$
(2.7) $WTP_i = \$11.00 \ if \ \mu_4 < WTP_i^* \leq \mu_5$
(2.8) $WTP_i = \$12.00 \ if \ \mu_5 < WTP_i^* \leq \mu_6$

All OLs were regressed using Stata 17.0 statistical software (StataCorp, 2021). The payment cards analyzed and used as dependent ordinal variables in this study were for changes in tree vigor, peach diameter and ARR resistance score. The WTP model in Equations (2) – (8) were also mimicked and applied to a ranked response question that contained 8 ordered choices with 7 threshold points, represented by RI_i^*. The ranked importance of ARR resistance when selecting a rootstock was used as the dependent ordinal variable for this analysis. Therefore, there were four OL regressions analyzed in this study.

Table 2.17 summarizes the dependent and explanatory variables used in the ordered logistic regressions. All regression models contained seven base independent variables: *bregion*, *ptotalacres*, *flown*, *education*, *yoe*, *rtigl*, and *peachincome*. Each of the WTP models contained additional independent variables that were considered relevant to the payment card analyzed. The marginal effects of $7, $8, and $9 WTP per tree were analyzed as these were the most frequent values selected for each payment card. For the ranked importance model, the MEs for ranking values of 7 and 8 were analyzed as these were the most common values indicated in the survey.

Table 2.1. Description of Variables Used in the Ordinal Regression Models

Variable	Description	Response Categories
Independent Variables		
bregion	Region	(0) East and (1) West
ptotalacres	Total peach acres in operation	Range of values from 70─340
flown	Percentage of farmland owned	(0) 21%─30% (only one response) and 61%─70%, and (1) more than 70%
education	Educational attainment	(0) High school graduate or equivalent, (1) some college/technical school or associate degree, (2) college graduate, and (3) graduate, professional, or other advanced degree
yoe	Years of management experience in farming	(0) 6─10 years and (1) 11─20 years
rtigl	Risk tolerance in general	(0) Risk-averse (values of 0─3), (1) risk-neutral (values of 4─6), and (2) risk-seeking (values of 7─10)
peachincome	Gross income from peaches (in thousands of dollars)	Range of values from $15.625─$350
treesize	Ranked importance of tree size when selecting a rootstock	Range of values from 2─8
diameter	Importance of peach diameter when selecting a variety	(0) Low importance, (1) moderate importance, and (2) important
arrrisk	Agreement of ARR being a major future risk to the industry	(0) Agree and (1) strongly agree
plarr	Percentage of tree loss due to ARR	(0) Less than 10% tree loss and (1) 11%─20% tree loss
arrca	Amount spent on ARR management options per acre	(0) $51─$100 per acre, (1) $101─$200 per acre, and (2) $201─$300 per acre
Dependent Variables		
stsd	Indicated maximum WTP for a change in tree vigor from standard to semi-dwarf	Range of values from $7─$11 per tree
idiam	Indicated maximum WTP for increase in peach diameter from 2.5 to 2.75 inches	Range of values from $7─$10 per tree
arrbi	Indicated maximum WTP for increase in ARR resistance score from 0─2 to 7 or higher	Range of values from $7─$12 per tree
rarr	Ranked importance of ARR resistance when selecting a rootstock	Range of values from 1─8

The regression analyzing WTPs for a change in tree vigor from standard to semi-dwarf included *treesize* as an additional independent variable, which is the indicated ranked importance of tree size when selecting a rootstock (see Equation 2.9). The analysis of WTPs for an increase in peach diameter from 2.5in. to 2.75in. included *diameter* as an added independent variable, which is the importance level assigned to peach diameter when selecting a peach variety (see Equation 2.10). The regression for WTPs for an increase in ARR resistance score from 0–2 to 7+ included three additional independent variables: *arrrisk*, the indicated agreement level of ARR being a major future risk to the peach industry; *plarr*, the specified percentage of tree loss due to ARR from years 5 to 10 of orchard life on replanted sites; and *arrca*, the stated amount spent per acre on ARR management options over the past 2 years (see Equation 2.11). The ranked importance of ARR-resistant as a rootstock attribute was regressed with only the base variables as adding other variables did not improve the model (see Equation 2.12).

(2.9) $$WTP^*_{stsd} = \beta_0 + \beta_1 bregion + \beta_2 ptotalacres + \beta_3 flown + \beta_4 education + \beta_5 yoe + \beta_6 rtigl + \beta_7 peachincome + \beta_8 treesize + \varepsilon_i$$

(2.10) $$WTP^*_{idiam} = \beta_0 + \beta_1 bregion + \beta_2 ptotalacres + \beta_3 flown + \beta_4 education + \beta_5 yoe + \beta_6 rtigl + \beta_7 peachincome + \beta_8 diameter + \varepsilon_i$$

(2.11) $$WTP^*_{arrbi} = \beta_0 + \beta_1 bregion + \beta_2 ptotalacres + \beta_3 flown + \beta_4 education + \beta_5 yoe + \beta_6 rtigl + \beta_7 peachincome + \beta_8 arrrisk + \beta_9 plarr + \beta_{10} arrca + \varepsilon_i$$

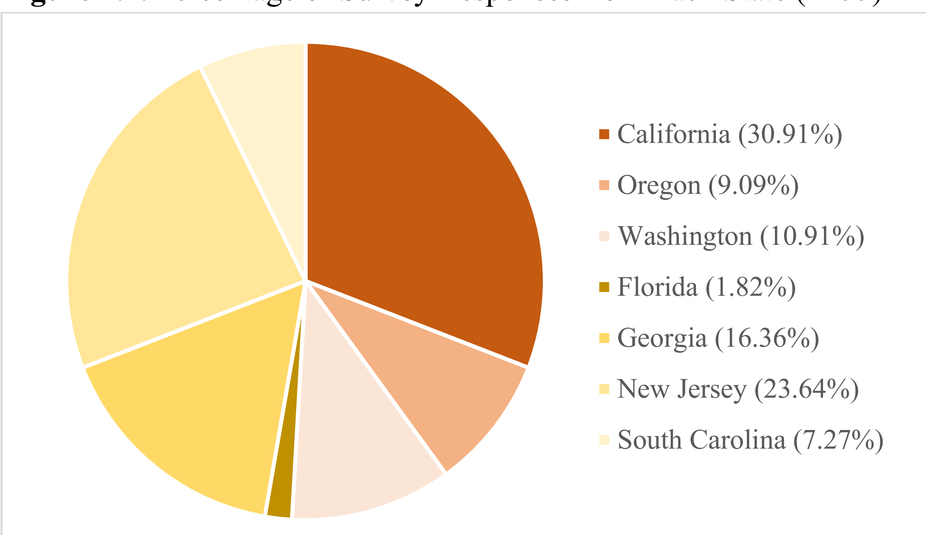
(2.12) $$RI^*_{rarr} = \beta_0 + \beta_1 bregion + \beta_2 ptotalacres + \beta_3 flown + \beta_4 education + \beta_5 yoe + \beta_6 rtigl + \beta_7 peachincome + \varepsilon_i$$

Results

Survey Summary Results

The final sample included 55 survey participants, with 27 responses from the East (Florida, Georgia, New Jersey, and South Carolina) and 28 from the West (California, Oregon, and Washington). The geographic distribution of respondents is depicted in Figure 2.2. The distribution of the total peach acreage from survey participants is compared by state and region to the 2017 United States Agricultural Census total peach acreage data in Table 2.2. The regional distribution of peach acreage by survey participants closely resembles the 2017 Census data. It should be noted that the results reveal that Oregon, Washington, Georgia, and New Jersey were overrepresented while California and South Carolina producers were underrepresented in the sample based on acreage.

Figure 2.2. Percentage of Survey Responses from Each State (n=55)



Note. Orange color variations represent responses from the West; yellow variations represent responses from the East.

Table 2.2. Distribution of Total Peach Acreage by Region and State from Survey Sample Compared to United States

Region/State	Survey Sample	2017 Census Peach Acreage*
West	50.78%	51.20%
California	29.49%	39.86%
Oregon	10.31%	0.58%
Washington	10.98%	1.37%
East	49.22%	48.80%
Florida	2.34%	0.91%
Georgia	16.52%	10.52%
New Jersey	21.95%	2.98%
South Carolina	8.40%	15.56%

*Source: *2017 Census of Agriculture*, National Agricultural Statistics Service, United States Department of Agriculture.

The demographic characteristics of the producers are reported in Table 2.3. The majority of respondents were 35–54-year-old Caucasian males who graduated from college. There were no female respondents and only one respondent reported having off-farm employment.

Table 2.3. Demographic Data Results

Variable	Frequency	Percentage
Age		
35-54	31	56.36%
55-64	24	43.64%
Gender		
Male	55	100.00%
Ethnicity		
African American	2	3.64%
Caucasian	37	67.27%
Hispanic	6	10.91%
Native American	9	16.36%
Prefer not to answer	1	1.82%
Highest Education Level		
High school graduate or equivalent	12	21.82%
Some college/technical school or associate degree	9	16.36%
College graduate	24	43.64%
Graduate, professional, or other advanced degree	10	18.18%
Off-Farm Employment		
Employed full-time (30+ hours/week)	1	1.82%
No off-farm employment	54	98.18%

Most respondents also reported having 11–15 years of farming experience with 6–10 years of experience as the decision maker. The dominant gross income indicated was $50,000 to $74,999 with 51%–60% of the gross income coming from peach production. The general farm and farm manager results can be found in Table 2.4. The average farm size was approximately 420 acres, with an average of 237 acres of peach orchards planted at a density of 125 trees per acre. Further statistics on farm size and density can be found in Appendix A.

Table 2.4. General Farm and Farm Manager Results

Variable	Frequency	Percentage
Years of Farming Experience		
11 - 15 years	30	54.55%
16 - 20 years	25	45.45%
Years of Experience as Orchard Farm Owner, Manager, or Decision Maker		
6 - 10 years	21	38.18%
11 - 15 years	32	58.18%
16 - 20 years	2	3.64%
Percent of Farmland Owned		
21% - 30%	1	1.82%
61% - 70%	31	56.36%
More than 70%	23	41.82%
Production of other agricultural products (besides tree fruits)		
Yes	14	25.45%
No	41	74.55%
Gross income from all farming activities		
$50,000 - $74,999	29	52.73%
$75,000 - $99,999	18	32.73%
$100,000 - $250,000	2	3.64%
$250,000 - $499,999	2	3.64%
More than $500,000	4	7.27%
Percentage of farm income from peach production		
21% - 30%	1	1.82%
31% - 40%	9	16.36%
41% - 50%	14	25.45%
51% - 60%	17	30.91%
61% - 80%	14	25.45%
Number of peach varieties grown		
10 or less	52	94.55%
11 - 20	2	3.64%
20 or more	1	1.82%
Minimum tree survival percentage to maintain profitability		
Less than 40%	1	1.82%
40% - 49%	1	1.82%
50% - 59%	25	45.45%
60% - 69%	28	50.91%
5-year production plan		
Maintain orchard size	5	9.09%
Increase orchard size	50	90.91%

Growers in the peach industry have several marketing channels that they can sell their fruit. Some of these options include wholesale markets, farmer's markets, and contract markets. The participants in this survey indicated using many different channels and the results are reported in Table 2.5. All the respondents reported using wholesale markets and almost all use farmer's markets. Brokers and cooperatives are almost never used by participants.

Table 2.5. Current Marketing Channels Used by Peach Producers

Market	Never Use This Outlet	Sometimes Use This Outlet	Often Use This Outlet
Community supported agriculture (CSA)		12.73%	87.27%
Farmer's market		1.82%	98.18%
Wholesale			100.00%
Online/social media		65.45%	34.55%
Contracts - private sector (e.g., grocery stores)		9.09%	90.91%
Contracts - public sector (e.g., schools, hospitals)	1.82%	80.00%	18.18%
Local restaurants		60.00%	40.00%
Cooperatives	96.36%	3.64%	
On-farm sales	1.82%	5.45%	92.73%
Broker	93.36%	3.64%	

The respondents also indicated how they expected sales to change in specified marketing channels over the next 2 years in their area. The expected market changes are reported in Table 2.6. Most producers expect sales to increase in farmers markets, on-farm sales, certified local sales, and organic produce sales. All producers reported expected increases in wholesale grocery store/online markets.

Table 2.6. Reported Expected Sales Changes in the Next 2 Years for Peach Markets

Market	Sales Will Decrease	Sales Will Stay the Same	Sales Will Increase
Farmers market		1.82%	98.18%
On-farm retail / community supported agriculture		10.91%	89.09%
Wholesale to grocery stores / online sales			100.00%
Wholesale to institutions (e.g., schools)		90.91%	9.09%
Certified local	1.82%	7.27%	90.91%
Direct sales to restaurants		81.82%	18.18%
Organic produce		7.27%	92.73%

The importance of specific fruit characteristics when choosing what varieties to grow was analyzed, including shape, color, diameter, firmness, flavor, and sweetness. Participants ranked the characteristics based on a five-point Likert scale ranging from "Not Important" to "Highly Important". Fruit sweetness and flavor were the most important characteristics to the producers, with 89.1% and 90.9% of respondents ranking them as highly important, respectively (see Table 2.7).

Table 2.7. Importance of Fruit Attributes When Selecting Peach Varieties

Fruit Attribute	Low Importance	Moderate Importance	Important	Highly Important
Consistency of shape		65.45%	34.55%	
Presence of high color	1.82%	1.82%	94.55%	1.82%
Peach diameter (inches)	1.82%	85.45%	12.73%	
Firmness		56.36%	43.64%	
Flavor			9.09%	90.91%
Sweetness			10.91%	89.09%

Note. "No Importance" was included in the survey but not in results as no respondents selected it.

Producers were asked to specify which two peach rootstocks they currently use the most in their operation. Nemaguard is the most popular among the producers, with

74.5% using the rootstock. Halford and Lovell are both used by 38.2%, Nemared is used by 32.7%, and Bailey is used by 16.4% of survey participants.

Respondents then identified whether they experienced crop loss during the last 5 years from a list of diseases (see Table 2.8). None of the producers indicated that they had crop loss due to Phytophthora root/crown rot. Only 5.5% of the respondents indicated having experienced crop loss due to peach tree short life while 47.3% reported having brown rot issues. The only unanimous problem over the past 5 years indicated by producers was Armillaria root rot. From correspondence with industry experts and producers though, ARR is not currently a common issue on the west coast. This could question the survey results as participants may not have confirmed the disease that caused their tree loss and just assumed that it was ARR.

Table 2.8. Reported Crop Loss Experience from the Past 5 Years

Disease	Yes	No
Peach tree short life (PTSL)	5.45%	94.55%
Brown rot	47.27%	52.73%
Peach scab	25.45%	74.55%
Phytophthora root/crown rot	0.00%	100.00%
Armillaria root rot (oak root rot)	100.00%	0.00%
Nematodes	36.36%	63.64%

Future risk concerns were also considered by respondents in the survey. Included risks were ARR, brown rot, bacterial canker, bacterial spot, peach scab, climate change, and labor issues. Participants categorized the options based on a five-point Likert scale that ranged from “Strongly Disagree” to “Strongly Agree” to indicate whether they thought the identified possible production risk would be a future problem for their operation. The highest rated problem from the respondents was ARR, with 49.1% of respondents strongly agreeing and 50.9% agreeing that ARR was a major risk for future peach production. All results from this section can be found in Table 2.9.

Table 2.9. Reported Future Risk Concerns for Peach Production

Risk Category	Disagree	Neutral	Agree	Strongly Agree
Armillaria root rot			50.91%	49.09%
Brown rot		52.73%	38.18%	9.09%
Bacterial canker		61.82%	36.36%	1.82%
Bacterial spot	1.82%	30.91%	67.27%	
Peach scab	1.82%	69.09%	29.09%	
Climate change		27.27%	72.73%	
Labor issues	7.27%	40.00%	52.73%	

Note. "Strongly Disagree" was an option in the survey but was removed from the results as no respondents selected it.

To determine the most important characteristics to growers when selecting a rootstock, a ranked-response question was presented. The lowest value of 1 was to indicate the least important characteristic while the highest value of 8 was to indicate the most important characteristic. The frequency of the ranked responses for the included rootstock attributes are depicted in Figure 2.3. Statistical findings showed that resistance to ARR had the highest average ranking of 6.85 while resistance to root-knot nematodes had the lowest average ranking of 1.75 (see Table 2.10).

Figure 2.3. Importance Ranking of Rootstock Attributes by Frequency of Responses

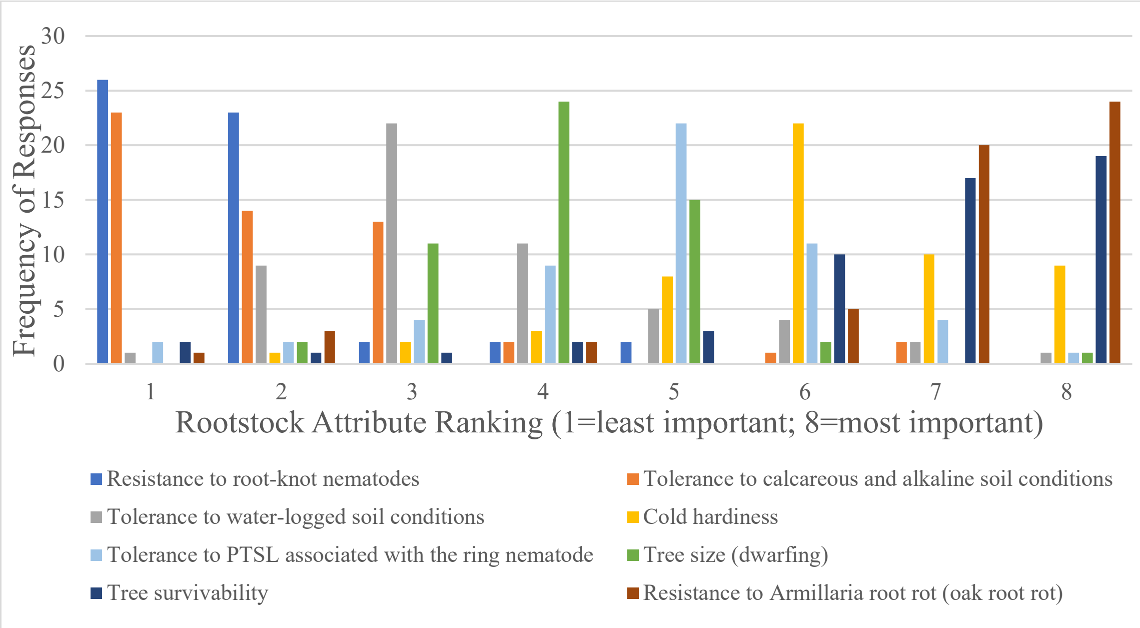


Table 2.10. Descriptive Statistics of Importance Ranking of Rootstock Attributes

Rootstock Attribute	Mean	Std. Dev.	Min.	Max.
Resistance to root-knot nematodes	1.75	0.97	1	5
Tolerance to calcareous and alkaline soil conditions	2.15	1.42	1	7
Tolerance to water-logged soil conditions	3.64	1.46	1	8
Cold hardiness	6.07	1.36	2	8
Tolerance to peach tree short life (PTSL) associated with the ring nematode	4.84	1.42	1	8
Tree size (dwarfing)	4.15	1.03	2	8
Tree survivability	6.56	1.73	1	8
Resistance to Armillaria root rot (oak root rot)	6.85	1.70	1	8

There are a variety of resources available to growers to inform them on treatments for various diseases and issues. A survey question was included to determine if peach producers use data from university specialists, other producers, research publications, internet resources, consultants, or books (see Table 2.11). Most producers indicated that they use advice from other farmers the most, with internet resources being the second most used. University extension agents also proved to be a vital resource for growers. There were 87.27% of respondents that indicated using research publications, though the participants may have considered any online document, such as fact sheets, as research publications.

Table 2.11. Resources Used by Peach Producers

Resource	Yes	No
Advice from University Extension Agents/Extension Specialists	89.09%	10.91%
Other farmers	98.18%	1.82%
Research publications	87.27%	12.73%
Internet resources	92.73%	7.27%
Advice or information from consultants	34.55%	65.45%
Textbooks or other reference books	50.91%	49.09%

Survey participants' preference for research over the next 5 years were also investigated. Producers were asked to choose their top two priorities for future research from development of new rootstocks to manage diseases, food safety and marketing, improving harvest/storage processes, orchard management practices, and utilizing new technologies. The top research priority from respondents was food safety and marketing, which could be explained due to the impact of COVID-19 on sales channels and the resulting challenges that followed. Orchard management practices were the second highest in priority (see Table 2.12).

Table 2.12. Top Two Future Production Research Priorities

Research Priority	Frequency	Percentage
Development of new rootstocks to manage diseases	12	10.91%
Food safety and marketing	32	29.09%
Improving harvest and storage process	18	16.36%
Orchard management practices	28	25.45%
Utilizing new technology (i.e., data analytics, drones, sensors)	20	18.18%

Questions specifically pertaining to Armillaria root rot included percentage of tree loss on replanted sites from years 5 to 10 of orchard life, current management options used to control ARR, amount spent on management options over the past two years, and whether they replanted on disease-infested land, among others. The current management options that are available to control ARR are preplant root raking and destruction, fumigation, root collar excavation (RCE), tolerant rootstocks, or abandoning the site to grow something else for more than 10 years. Most producers indicated replanting on ARR-infected land and spending \$101–\$200 per acre annually on ARR management options. Preplant root raking and destruction and tolerant rootstocks were the most used ARR management options amongst respondents. Though peach trees are typically considered to have a 15-year lifespan, a large majority of growers reported removing orchards at an average age of 9–12 years due to tree death (see Table 2.13).

Table 2.13. Armillaria Root Rot Summary Results

Variable	Frequency	Percentage
Percentage of tree loss due to ARR from years 5 to 10 of orchard life on replant sites		
Less than 10%	30	54.55%
11%–20%	25	45.45%
Amount spent for ARR management over the last 2 years		
$51–$100 per acre	2	3.64%
$101–$200 per acre	28	50.91%
$201–$300 per acre	25	45.45%
Management options used to control ARR (respondents were able to select more than one)		
Fumigation	2	1.83%
Preplant root raking and destruction	53	48.62%
Root collar excavation (RCE)	2	1.83%
Tolerant rootstocks (MP-29)	52	47.71%
Replant on ARR infected land		
Yes	54	98.18%
No	1	1.82%
Option utilized instead of replanting on infected land		
Grow something different	1	1.82%
Average age of orchards removed due to tree death on replant sites		
Less than 9 years	5	9.09%
9–12 years	50	90.91%

Since there are known issues for the current ARR management options from past research, producers were asked to identify their thoughts. The most common indicated issue with fumigation and root collar excavation was that they are not effective enough while tolerant rootstocks and preplant root raking and destruction were identified to have potential lower yields (see Table 2.14). However, preplant root raking and destruction is not known in the literature or by university specialists to have lower yields. Therefore, the participants may not have fully understood the survey question or may be unfamiliar with the method.

Table 2.14. Indicated Problems with Current ARR Management Options

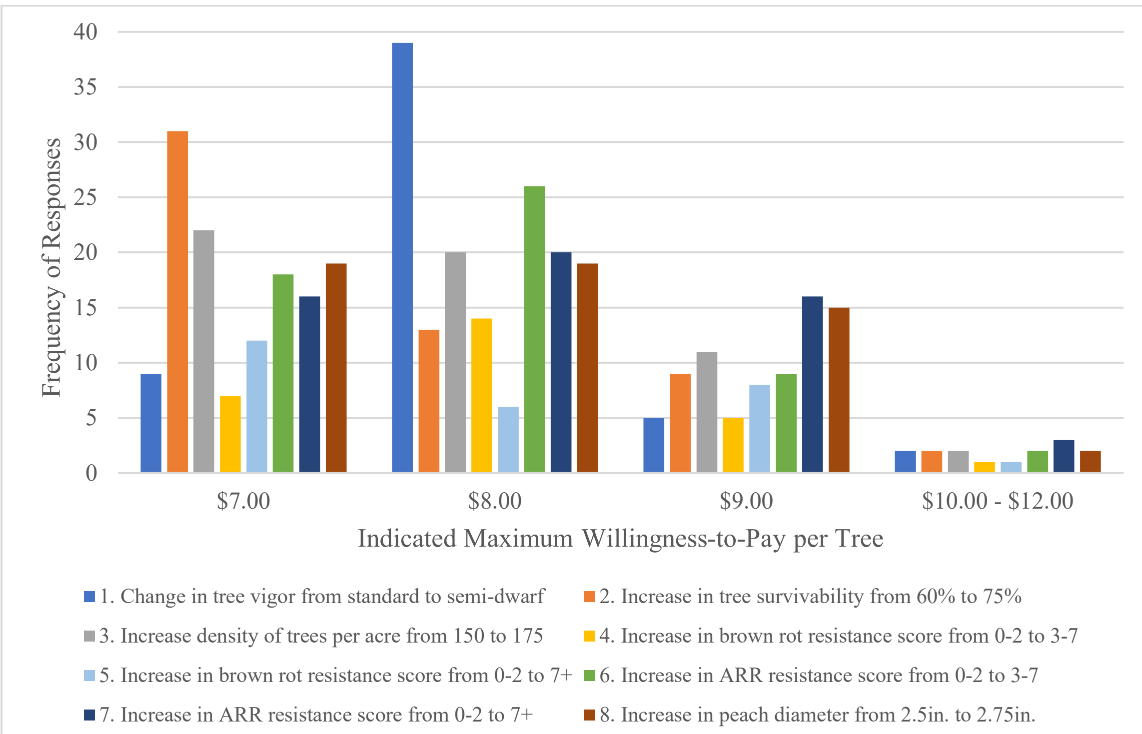
Management Option	Issue			
	Too Expensive	Not Effective Enough	Unavailability of Labor	Potential Lower Yield
Preplant root raking and destruction	1.82%	3.64%		94.55%
Fumigation	1.82%	94.55%		3.64%
Root collar excavation (RCE)		94.55%	5.45%	
Tolerant rootstocks			3.64%	96.36%

Eight payment card questions were included in the survey that required participants to indicate their maximum WTP for distinct rootstock attributes. The maximum WTP values that producers could choose from ranged from $7 per tree to $12 per tree. They were also given a choice to indicate that they were not interested in the stated rootstock improvement, though no participants selected it for any of the PCs. The attributes included in the survey are listed below:

1. Change in tree vigor from standard to semi-dwarf,
2. Increase in overall tree survivability from 60% to 75%,
3. Increase in density of trees per acre from 150 to 175,
4. Increase in brown rot resistance score from 0–2 to 3–7,
5. Increase in brown rot resistance score from 0–2 to 7 or higher,
6. Increase in ARR resistance score from 0–2 to 3–7,
7. Increase in ARR resistance score from 0–2 to 7 or higher,
8. Increase in fruit diameter from 2.5 inches to 2.75 inches.

Disease resistance score ranges from 0–10 with 0 being highly susceptible and 10 being fully resistant to the disease. Though most rootstocks being developed contain disease resistance to more than one disease, only one factor was included in each payment card to assess the direct premium producers were WTP for the specific attributes. The frequency of responses for maximum WTP per tree for each attribute can be found in Figure 2.4.

Figure 2.4. Maximum Willingness to Pay for Rootstock Attributes by Frequency of Responses



Overall, the average maximum WTP for an increase in ARR resistance score from 0–2 to 7 or higher was the highest at $8.16. Since all costs per tree before rootstock improvement was assumed to be $6.00, this suggests that producers are willing to pay a premium of $2.16 per tree for the increased resistance score. The second highest average maximum WTP value was for the tree vigor changing from standard to semi-dwarf at

$8.02, or a premium of $2.02 per tree for the change. The lowest average minimum WTP was for an increase in overall tree survivability, with a premium of $1.69 per tree. Further statistics can be found in Table 2.15.

Table 2.15. Payment Cards Descriptive Statistics

Rootstock Attribute	Maximum WTP per Tree				Average Premium per Tree
	Mean	Std. Dev.	Min.	Max.	
1. Change in tree vigor from standard to semi-dwarf	$8.02	$0.71	$7.00	$11.00	$2.02
2. Increase in tree survivability from 60% to 75%	$7.69	$0.94	$7.00	$11.00	$1.69
3. Increase density of trees per acre from 150 to 175	$7.91	$0.97	$7.00	$11.00	$1.91
4. Increase in brown rot resistance score from 0–2 to 3–7	$8.00	$0.78	$7.00	$10.00	$2.00
5. Increase in brown rot resistance score from 0–2 to 7+	$8.00	$1.18	$7.00	$12.00	$2.00
6. Increase in ARR resistance score from 0–2 to 3–7	$7.93	$0.86	$7.00	$11.00	$1.93
7. Increase in ARR resistance score from 0–2 to 7+	$8.16	$1.05	$7.00	$12.00	$2.16
8. Increase in peach diameter from 2.5in. to 2.75in.	$8.00	$0.88	$7.00	$10.00	$2.00

The last producer assessment in the survey contained risk questions to estimate average peach producers' risk-level. Producers were asked to assess their risk tolerance in general, in terms of financial and investment decisions, and in terms of farm production decisions. The minimum value of 0 was to indicate a producer that does not tolerate any risk (risk-averse) while the maximum of 10 indicated that the producer is fully prepared to accept risks (risk-seeking). The average risk levels indicated by the participants are presented in Table 2.16. Density distributions of the frequency of responses from the risk tolerance questions are depicted in Appendix B. Producers were also asked to specify their level of agreement for two risk statements. Results from these questions can be found in Table 2.17.

Table 2.16. Reported Risk Tolerances for Peach Producers (0 = no risk; 10 = fully prepared to take risks)

Risk category	Risk Tolerance			
	Mean	Std. Dev.	Min.	Max.
In general	4.93	1	2	8
In terms of financial/investment decisions	5.51	0.92	2	7
In terms of farm production decisions	6.05	0.95	3	8

Table 2.17. Reported Agreement Levels of Risk Statements

Risk Statement	Disagree	Neutral	Agree	Strongly Agree
"I am more concerned about facing a loss than foregoing profit."	14.55%	67.27%	18.18%	
"Avoiding risky options in farm decision making is important."		43.64%	52.73%	3.64%

Note. “Strongly Disagree” was an option in the survey but was removed from the results as no respondents selected it.

Methodology from Browne et al. (2019) was used to analyze the indicated risk levels. Risk-averse producers were those who indicated risk values from 0–3, risk-neutral was represented by indicated values from 4–6, and risk-seeking producers indicated values from 7–10. According to Roe (2015), the average risk level for United States agricultural producers who do not have non-agricultural employment is 5.89. Overall, producers in the peach industry appear to be risk-neutral, though some respondents appear to be relatively risk-averse while others are relatively risk-seeking. Respondents indicated higher risk levels for farm production decisions than for financial and investment decisions. Their tolerance in general and in terms of financial/investment decisions is lower than the national average by 16.3% and 6.45%, respectively. Their tolerance in terms of production decisions appears to be 2.72% higher than the national grower risk average.

Ordered Logistic Regression Results

The first regression examined factors that influence producers' willingness to pay higher prices for a change in tree vigor from standard to semi-dwarf. Table 2.18 shows the ordinal regression coefficients and marginal effects for the change in tree vigor. The region, overall risk tolerance, and gross income from peaches were all significant variables. The ranked importance of tree size was included as an additional independent variable as it was predicted to be related to the model, but it did not show statistical significance.

Table 2.18. OL Regression Results for the Maximum WTP for a Change in Tree Vigor from Standard to Semi-Dwarf (*n*=55)

Coefficients	Value / SE	Marginal Effect of $7 / SE	Marginal Effect of $8 / SE	Marginal Effect of $9 / SE
bregion	-1.6345**	0.1476*	-0.0600	-0.0777
	(0.8047)	(0.0771)	(0.0655)	(0.0528)
ptotalacres	0.0122	-0.0010	0.0004	0.0005
	(0.0076)	(0.0007)	(0.0005)	(0.0004)
flown	1.1162	-0.0919	0.0301	0.0549
	(0.7651)	(0.0662)	(0.0449)	(0.0470)
education	0.4242	-0.0364	0.0153	0.0188
	(0.3400)	(0.0299)	(0.0198)	(0.0171)
yoe	-0.1866	0.0158	-0.0063	-0.0084
	(0.7337)	(0.0610)	(0.0237)	(0.0342)
rtigl	-3.6615**	0.3144**	-0.1323	-0.1623*
	(1.5143)	(0.1513)	(0.1466)	(0.0981)
peachincome	0.0094*	-0.0008*	0.0003	0.0004
	(0.0054)	(0.0005)	(0.0004)	(0.0003)
treesize	0.4105	-0.0352	0.0148	0.0182
	(0.3652)	(0.0325)	(0.0206)	(0.0174)
AIC	92.2566			
Log Likelihood	-35.1283			

Note. *p < 0.10; **p < 0.05; ***p < 0.01.

Though the magnitude of the coefficients cannot be interpreted, it can be used to determine direction. The risk level coefficient being negative is an unexpected result as it indicates those with higher risk levels are less likely to indicate higher WTP levels. The peach income coefficient was expected to and did present a positive sign, indicating that those with higher gross income from peaches would be more likely to indicate higher WTP levels. The regional coefficient also showed an anticipated negative sign, meaning that producers in the West were more likely to indicate lower WTPs. This could be explained by producers in the West having higher labor costs (personal communication), which could decrease their indicated WTPs as they do not want to raise their costs more than necessary.

From the marginal effects, it can be determined that a one unit increase in peach income is associated with being 0.08 percentage points (p.p.) less likely to indicate a WTP of $7 per tree. The general risk marginal effect suggests that a one unit increase in the general risk level indicates the producer is 31.44 p.p. more likely to indicate a WTP of $7 and 16 p.p. less likely to indicate a WTP of $9. The regional marginal effect suggests that a respondent from the West is 14.76 p.p. more likely to indicate a WTP of $7 for a change in tree vigor.

The second regression analyzed determinants that influence growers' WTP higher prices for an increase in peach diameter from 2.5 inches to 2.75 inches. Table 2.19 depicts the coefficients and marginal effects for the increased fruit size. The risk level had a significant coefficient and marginal effect, and the region showed a significant marginal effect. The importance of peach diameter when selecting a variety was included as an additional independent variable as it was anticipated to be related to the model, but it did not show statistical significance.

Table 2.19. OL Regression Results for the Maximum WTP for an Increase in Peach Fruit Diameter from 2.5 inches to 2.75 inches (*n*=55)

Coefficients	Value / SE	Marginal Effect of $7 / SE	Marginal Effect of $8 / SE	Marginal Effect of $9 / SE
bregion	-0.9430	0.2051*	-0.0185	-0.1757*
	(0.5775)	(0.1243)	(0.0418)	(0.1050)
ptotalacres	0.0014	-0.0003	0.0000	0.0003
	(0.0056)	(0.0012)	(0.0001)	(0.0011)
flown	0.4913	-0.1064	0.0071	0.0936
	(0.5600)	(0.1189)	(0.0219)	(0.1081)
education	0.3748	-0.0825	0.0078	0.0705
	(0.2715)	(0.0598)	(0.0176)	(0.0518)
yoe	-0.0395	0.0087	-0.0008	-0.0074
	(0.5670)	(0.1243)	(0.0110)	(0.1071)
rtigl	-3.3586*	0.7391*	-0.0697	-0.6320*
	(1.7575)	(0.3837)	(0.1494)	(0.3588)
peachincome	0.0058	-0.0013	0.0001	0.0011
	(0.0042)	(0.0009)	(0.0003)	(0.0008)
diameter	-0.6241	0.1373	-0.0130	-0.1174
	(0.6825)	(0.1502)	(0.0310)	(0.1291)
AIC	136.7960			
Log Likelihood	-57.3980			

Note. *p < 0.10; **p < 0.05; ***p < 0.01.

The risk coefficient is again unexpected and suggests that a lower general risk tolerance indicates higher WTP prices. The marginal effects estimate that a one unit increase in general risk tolerance increases the likelihood of choosing $7 WTP per tree by 73.91 p.p. and decreases the likelihood of choosing $9 by approximately 63 p.p. Though the coefficient is not significant, the marginal regional effect suggests that producers in the West were 20.51 p.p. more likely to choose $7 and 17.57 p.p. less likely to choose $9 WTP per tree for a change in peach diameter. This aligns with the first regression analyzed as producers in the West are likely to choose lower WTPs.

The next analysis looked at the factors that influenced higher maximum WTPs for an increase in ARR resistance score from 0–2 to 7 or higher, the results of which are shown in Table 2.20. Three additional independent variables were added to the base model as they were projected to be related: agreement level of ARR being a major future risk to the industry, percentage of tree loss due to ARR, and amount spent on ARR management options per acre. Before incorporating the variables *arrrisk*, *plarr*, and *arrca*, correlation coefficients were estimated and all determined to be weak, with the highest absolute value being 0.21, so they were considered suitable to include.

Table 2.20. OL Regression Results for the Maximum WTP for an Increase in ARR Resistance Score from 0–2 to 7 or Higher (*n*=55)

Coefficients	Value / SE	Marginal Effect of $7 / SE	Marginal Effect of $8 / SE	Marginal Effect of $9 / SE
bregion	-0.2463	0.0456	0.0071	-0.0486
	(0.5923)	(0.1089)	(0.0216)	(0.1171)
ptotalacres	0.0024	-0.0005	-0.0001	0.0005
	(0.0065)	(0.0012)	(0.0002)	(0.0013)
flown	0.2957	-0.0541	-0.0097	0.0588
	(0.5854)	(0.1057)	(0.0258)	(0.1174)
education	0.0992	-0.0184	-0.0029	0.0196
	(0.2881)	(0.0533)	(0.0097)	(0.0570)
yoe	-1.2523**	0.2145**	0.0607	-0.2502**
	(0.5928)	(0.0969)	(0.0651)	(0.1202)
rtigl	-1.3667	0.2529	0.0398	-0.2702
	(1.2808)	(0.2375)	(0.0773)	(0.2607)
peachincome	0.0092**	-0.0017**	-0.0003	0.0018*
	(0.0046)	(0.0009)	(0.0005)	(0.0010)
arrrisk	-1.4642**	0.2710**	0.0426	-0.2894**
	(0.7047)	(0.1335)	(0.0734)	(0.1458)
plarr	1.8343***	-0.3234***	-0.0618	0.3489***
	(0.6407)	(0.1108)	(0.0743)	(0.1182)
arrca	-0.9225*	0.1707	0.0268	-0.1824
	(0.5586)	(0.1056)	(0.0474)	(0.1158)
AIC	143.0251			
Log Likelihood	-57.5125			

Note. *p < 0.10; **p < 0.05; ***p < 0.01.

Years of management experience, gross peach income, agreement of ARR being a future production risk, and percent loss per acre due to ARR all presented statistically significant coefficients and marginal effects. The amount spent on ARR management per acre also presented a significant coefficient but had an insignificant marginal effect. The region, total acres in peach production, percentage of farmland owned, education, and general risk level all presented no statistical significance.

From the coefficients, it can be concluded that a decrease in years of management experience, lower level of agreement for ARR being a future production risk, lower amounts spent on ARR management per acre, increase in peach income, and higher percent tree loss due to ARR indicated higher WTP levels. The years of experience in management presented an unanticipated sign as it indicates that those with 11–20 years of experience are more likely to indicate lower WTPs than those with 6-10 years of experience. This could indicate that those with more years in management do not see higher increases in per-tree prices as feasible. The *arrrisk* coefficient also showed a surprising sign as it indicates that those who "Strongly Agree" that ARR will be a major future risk to the industry were likely to choose lower WTPs than those who "Agree".

The coefficient for gross peach income once again had an expected positive sign. The *plarr* also presented an anticipated positive coefficient sign, as it indicates that those who experienced 11%–20% of crop loss due to ARR were more likely to indicate higher WTP levels than those who experienced less than 10% of tree loss due to the disease. The coefficient for *arrca* indicates that producers who currently spend more on ARR management options per acre are likely to indicate lower WTP values. This could indicate that the producers who spend more per acre may not want to increase their already high disease management costs.

The marginal effect of *yoe* indicates those who fell into the higher category of management experience were 21.45 p.p. more likely to choose $7 WTPs and approximately 25 p.p. less likely to choose $9 WTPs for the increase in ARR resistance. The marginal effects for a one unit increase in income (in thousands of dollars) suggest a

0.17 p.p. less likelihood of choosing $7 and a 0.18 p.p. more likelihood of choosing $9 WTP. MEs for percent tree loss due to ARR implies that a one-unit increase will decrease the likelihood of choosing the $7 WTP level by approximately 32 p.p. and increase the likelihood of choosing $9 by 34.89 p.p. A one unit increase in the agreement level of ARR being a future production risk indicated 27.10 p.p. higher likelihood of choosing $7 WTP and 28.94 p.p. lower likelihood of choosing $9 WTP for increase in ARR resistance score.

The last regression model was implemented to determine potential factors that affected the importance ranking of ARR resistance when selecting a rootstock. The ordered logistic regression results for this model are shown in Table 2.21. The only value of the results with statistical significance was for gross peach income. Therefore, the only determinant that can be made from this model is that a decrease in gross income collected from peaches suggests a higher ranked value, and a one unit increase in peach income would decrease the likelihood of choosing a ranked value of 8 by 0.2 p.p.

Table 2.21. OL Regression Results for the Ranked Importance of ARR Resistance when Selecting a Rootstock (*n*=55)

Coefficients	Value / SE	Marginal Effect of 7 / SE	Marginal Effect of 8 / SE
bregion	0.7821	-0.0769	0.1894
	(0.5819)	(0.0642)	(0.1380)
ptotalacres	0.0021	-0.0002	0.0005
	(0.0061)	(0.0006)	(0.0015)
flown	0.4542	-0.0476	0.1113
	(0.5756)	(0.0652)	(0.1406)
education	-0.3308	0.0336	-0.0810
	(0.2682)	(0.0304)	(0.0656)
yoe	0.0067	-0.0007	0.0016
	(0.5813)	(0.0590)	(0.1424)
rtigl	1.5597	-0.1586	0.3821
	(1.2905)	(0.1463)	(0.3159)
peachincome	-0.0082*	0.0008	-0.0020*
	(0.0048)	(0.0006)	(0.0012)
AIC	154.6632		
Log Likelihood	-65.3316		

Note. *p < 0.10; **p < 0.05; ***p < 0.01.

Conclusion, Limitations, and Future Research

Conclusion

The survey sample consisted of 55 producer respondents, half from the eastern and half from the western region of the United States. The majority of growers receive 51%–60% of their gross farm income from peach production, grow 10 or less peach varieties, require 60%–69% tree survivability to maintain profitability, and plan to increase their orchard size in the next 5 years. Flavor and sweetness were the most important fruit attributes considered when choosing which variety to grow. Wholesale, farmer's markets, on-farm sales, and contracts in the private sector are the most common marketing channels used, respectively. The most common information resources used by peach producers were other farmers, internet resources, and extension agents/specialists, respectively.

All risk-tolerance questions from the survey suggested that peach producers on average are risk-neutral, though they did show higher average risk levels for farm production decisions. The risk tolerance in general and in terms of financial/investment decisions were lower than the national average for agricultural producers, while the tolerance for production decisions was higher.

ARR had the highest average importance ranking amongst rootstock attributes. Every respondent in the sample indicated experiencing crop loss over the past 5 years due to Armillaria root rot, making it the most important problem indicated in the survey. ARR was also the only issue that all growers agreed on for being a future risk concern in the industry. Most producers reported an average tree loss of less than 10% from years 5 to 10 of orchard life on replant sites due to ARR with an average ARR-management cost per acre of $101–$200. Almost all respondents replanted on ARR infected land, and the majority reported removing orchards at 9–12 years of tree age due to tree death.

The most commonly used ARR management options reported were preplant root raking and destruction and tolerant rootstocks, both of which were indicated to present potential lower yields. Fumigation and root collar excavation were the least used options and were indicated by participants to not be effective enough to implement. Of the eight payment cards included in the survey, the maximum average willingness-to-pay was highest for the large increase in ARR resistance score from 0–2 to 7 or more with an average premium per tree of $2.16.

Of the four ordinal regression models analyzed in this study, there were seven independent variables that were used as a base for all models. Total acres in peach production, percentage of farmland owned, and education level were not statistically significant determinants in any model. The years of management experience was only a statistically significant factor for the increase in ARR resistance score and was positive. The region where the producer is located and the general risk tolerance, both of which reported negative coefficients, were only statistically significant factors when analyzing producer WTP values for change in tree vigor and fruit diameter. From personal communication with producers and industry experts, ARR currently seems to be more common in the eastern than the western United States. Based on this information, region was expected to be a statistically significant factor for the model analyzing WTP for an increase in ARR resistance score and for ranked importance of ARR resistance; however, the data suggested otherwise.

Gross peach income was the most common significant factor as it showed statistical importance for three of the models: maximum WTP values for a change in tree vigor (positive coefficient), maximum WTP values for an increase in ARR resistance score (positive coefficient), and ranked importance of ARR resistance in rootstock selection (negative coefficient). Incorporating additional independent variables that were predicted to impact the dependent variable only proved to add significant factors when analyzing the maximum WTP values for increased ARR resistance.

The ordered logistic regression model that evaluated the WTP for a change in tree vigor was presented as the best fit to the data based on the log likelihood values and the

AIC. Though the model for an increase in ARR resistance contained more predictor variables, the log likelihood value was still lower. The model with the worst fit to the data compared to the others was the ranked importance of ARR resistance for rootstock selection based on both the log likelihood and the AIC. This was to be expected since it contained the least amount of statistically significant variables.

Limitations

There are a few types of bias that can occur with the sampling strategy implemented that should be noted. One bias that could be a factor is sampling bias, which arises when "sampling procedures employed in a study favor certain individuals or groups over others," (Privitera, 2019, p. 129). Sampling bias can occur in this study by excluding the producers who are technologically inept (producers who do not own phones). Nonresponse bias can also be an issue, which "occurs when participants choose not to respond to a survey or request to participate in a study," (Privitera, 2019, p. 129). It can be an issue in this study because the producers who choose not to answer may be a specialized group that would be excluded from the data. For example, the producers who do not have significant ARR problems may have chosen not to respond to the survey as the disease may not be a concern to them.

Another limitation of the survey is the difference in the sample from the U.S. population of peach producers. Georgia, New Jersey, Oregon, and Washington all were overrepresented in the sample while the larger peach producing states of California and South Carolina were underrepresented. This could skew the collected data as it may not accurately estimate the opinions of those who grow the majority of the peaches in the nation. There were also some inconsistencies in the responses which indicated that the survey participants may not have known how to correctly identify ARR in orchards or they may not have fully understood some of the survey questions.

Future Research

Though most participants indicated that they lose less than 10% of trees during years 5–10 of orchard life due to ARR, the rest of the survey results indicate that it is a major problem. Current management options are limited but are currently and should continue to be a main research priority. Horticultural tree producers can use the estimated $2.16 per tree premium for a large increase in ARR resistance score as motivation to develop a new rootstock.

The top two production research priorities indicated by participants were food safety and marketing and orchard management practices. This information can help guide research institutions in their future research as well.

CHAPTER 3

AN ECONOMIC IMPACT AND INVESTMENT ANALYSIS OF ARR AND USING THE ROOT COLLAR EXCAVATION METHOD IN THE PEACH INDUSTRY

Objective

The purpose of this chapter is to estimate the economic impact of ARR and the net benefits of using the root collar excavation method in the United States peach industry. Enterprise budgets from California (CA), Florida (FL), and South Carolina (SC) were used to estimate the impact the RCE method had on net returns. The net present value (NPV) method was implemented to estimate the present value of all cash flows. This analysis can provide critical information to producers nationally who are trying to make investment decisions for their operations.

Sections in this chapter are organized as follows; a) relevant literature review on the root collar excavation method, enterprise budgets, stochastic variables, net present value and sensitivity analyses, and Monte Carlo simulations; b) a description of the methodology used; c) summary of the data; d) results from the California, Florida, and South Carolina investment analyses; and e) conclusion and potential future research.

Literature Review

Root Collar Excavation Method

ARR is the leading cause of early tree mortality in peach production. Contrasting to other common peach diseases (e.g., brown rot and peach scab), ARR affects trees that are stressed and trees that are well-managed equally (Miller et al., 2020; Doubrava et al., 2021). Therefore, reducing the stress on a tree has proven ineffective in preventing ARR or slowing down the progression. There are many pre- and post-plant management options that have also been evaluated and deemed ineffective. One option is preplant soil fumigation, which uses methyl bromide, sodium thiotetracarbonate, or metam sodium. It has proved to decrease, but not eradicate the microorganisms in the soil that cause the disease (Cox, 2004; Miller et al., 2020; Schnabel et al., 2012). Methyl bromide has proven to be the most effective out of the three but has been phased out according to the Clean Air Act due to ozone depletion effects (Farnsworth, 2017; Schnabel et al., 2012).

Two postplant options are infusing the trunks of the trees with systemic fungicides or removing the trees around the diseased tree. Both options have also proved to somewhat decrease disease progression, but they are also considered economically infeasible. The best environmentally and economically friendly “solution” to ARR is to use resistant rootstocks. However, this is not feasible either since the only successful development of an ARR resistant rootstock is ‘MP-29’, which is scarce (Miller et al., 2020; Schnabel et al., 2012).

The root collar excavation method (RCE) was first proposed by Rhoads in 1950 and involves physically cutting out the infected wood of diseased trees and removing soil to expose the root crown. This was developed as a method to prevent the fungus from girdling the trunk of the symptomatic tree when already present in the root collar (Miller et al., 2020). Girdling occurs when the disease from the infected root travels upwards to underneath the bark of the root collar and eventually decomposes the bark. Once the trunk is completely girdled (bark is fully decomposed), water and nutrient transport to the trunk is completely blocked and the tree will die (Baumgartner, 2004; Layne, 2005).

Current implementation of the RCE method often uses an AirSpade to remove the soil from the lower trunk and root collar. The full execution process of RCE can be seen in Figure 3.1 (Miller et al., 2020).

Figure 3.1. Implementation of the Root Collar Excavation Method in a Peach Orchard in South Carolina

Note. Panel A shows a standard peach orchard with trees planted on shallow berms, panel B shows excavation of the lower trunk and root collar using an AirSpade, and panel C shows a peach tree with an excavated root collar.
Source: "Preventative Root-Collar Excavation Reduces Peach Tree Mortality Caused by Armillaria Root Rot on Replant Sites," by S. B. Miller, K. Gasic, G. L. Reighard, W. G. Henderson, P. A. Rollins, M. Vassalos, and G. Schnabel, 2022, *Plant Disease*, *104*(5), 1274-1279 (https://doi.org/10.1094/PDIS-09-19-1831-RE). Copyright 2020 by the The American Phytopathological Society.

The RCE method proved to be an effective postinfection management option for ARR in grapevines and citrus trees by increasing lifespan and yield when compared to nonexcavated trees. Removing the soil from the root crown to expose primary roots caused the fungus to retreat back into the soil and away from the new exposure due to dryness and heat. RCE was then investigated as a preventative measure to decrease early tree mortality on replant sites in a study conducted by Higher Caliper Growing using open-bottom Smart Pots. The trees were planted approximately 40 cm higher than the industry standard. After excavation, the primary roots remained above ground, deeming the system effective because the fungus does not typically grow above the soil level in peach trees. Although the disease remains in the roots that are below ground, further infection of the root collar is avoided (Miller et al., 2020; Schnabel et al., 2012).

In 2010, Clemson University conducted a study to evaluate the feasibility and efficacy of the preventative RCE method on a commercial scale. Their results showed a 2-year delay in disease progression and an annual reduction of tree mortality by up to 55.8%. Their investigation proved that implementing RCE as a preventative management option could extend the productive life of peach orchards on highly infected replant sites without affecting fruit quality or yields. It also showed to allow surface water to distribute more evenly between rows and decrease runoff (Miller et al., 2020; Schnabel et al., 2012).

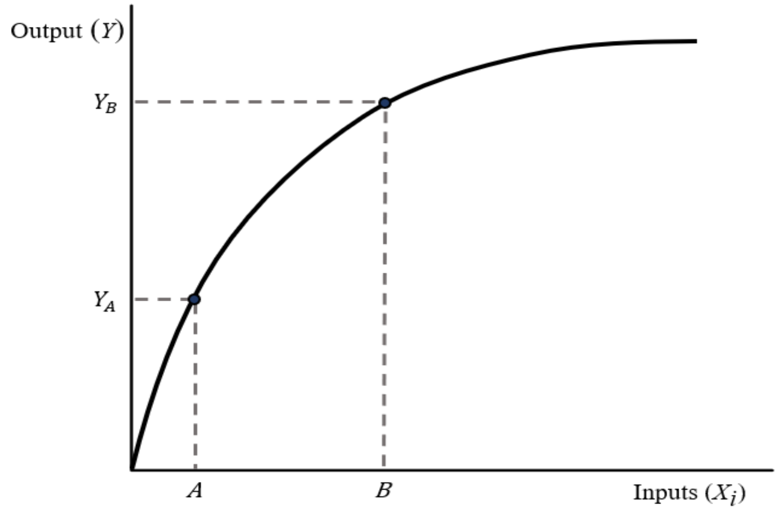
Enterprise Budgets and Stochastic Variables

Enterprise budgets (EBs) are a tool that producers can utilize to project the costs and returns for a specific enterprise, such as growing peaches or raising livestock. They include potential revenues, costs of inputs, and production practices for the specified enterprise. EBs are developed on a per unit basis (e.g., per acre or per head) so that comparisons can be made amongst various enterprises. Enterprise budgets are often used by producers, consumers, and research institutions to determine the efficiency of a specific industry (Greaser & Harper, 1994; Curtis et al., 2005; Sahs & Bir, 2022).

Enterprise budgets have frequently been utilized to assess the benefits and costs for significant changes in production methods, such as implementing a new technology. For example, Pierce et al. (2005) used EBs to estimate the economic impact of using precision deep tillage practices in corn production. Mussell and Schmidt (2009) used peach EBs to analyze the effect of increasing minimum wages in the horticulture industry. The impact of using soybean oil to decrease freeze damage in peaches was also assessed using enterprise budgets (Pendergrass et al., 2000).

One limitation of enterprise budgets is that they are often location specific (Curtis et al., 2005). For example, growing a crop in California will not have the same EB as growing the same crop in South Carolina. This is due to variations in market input and output prices, as well as climate differences (e.g., soil types, average temperatures, average rainfall). EBs are also specific to a given set of inputs and outputs. This can be explained by analyzing the production function in Figure 3.2. Point *A* on the graph represents a given set of inputs that produce Y_A outputs, while point *B* represents the set of inputs that produce Y_B. Since enterprise budgets specify a given set of inputs to estimate the production for a given set of outputs, each point on the graph would require a distinct EB. Therefore, without creating multiple enterprise budgets, scale of production is not accounted for (Tweeten, 2019).

Figure 3.2. Example of a Typical Production Function



Another limitation of enterprise budgets is that they are deterministic, meaning that they are stagnant estimates that do not account for any variability. This can be overcome by incorporating stochastic variables into the budget to account for risk and unpredictability. Stochastic variables are variables that are random, often follow probability distributions, and can be set over a specified range (Ludena et al., 2003). Since the agricultural industry is unpredictable, incorporating stochastic variables can create more accurate estimations of net returns. Stochastic variables have been incorporated into research to estimate the efficiency of alternative cover crops in Louisiana (Wang et al., 2020), to assess and compare the production costs for flowers for plant growers (Ludena et al., 2003), and other studies (Khakbazan et al., 2014; Awondo et al., 2017; Bingham, 2017).

Most enterprise budgets are based on the costs and returns that could occur over a 1-year period for annual crops. However, peaches have an estimated lifespan of 12–15 years with varying costs and production levels associated with distinct stages of tree maturity. Peach trees also do not produce harvestable fruit until they are 3 years old, while full production levels are not typically reached until year 4 or 5. Because of this, EBs for peaches must include budgets for each year of tree age until the full maturity is reached (White, 2019).

Using Net Present Value and Sensitivity Analyses for Capital Budgeting

There are several methods used to analyze capital investment projects, including payback period, simple rate of return, and internal rate of return (White, 2019). The most popular investment analysis method is the net present value (NPV) method. According to a study conducted by Payne et al. (1999), 75% of the companies included in the sample use the NPV method to aid in making investment decisions. NPV is calculated by summing all potential future revenues and costs of an investment and discounting the net benefits to the present value (Jory et al., 2016). This method allows the opportunity cost of having funds tied up in capital-heavy projects to be factored into the investment analysis (Boehlje & Eidman, 1984).

An investment is considered profitable when the NPV is positive, as this signifies that the present value of all future cash inflows is greater than the present value of initial investment costs (if applicable) and all future cash outflows (Jory et al., 2016). The NPV method also allows for comparison of possible industry changes by comparing the NPVs before and after the change and seeing which is greater (the higher the NPV, the higher the present value of the net returns).

NPV has been used numerous times in agricultural investment analyses to determine potential profitability of an enterprise. Bailey et al. (1997) used the NPV method in an investment analysis of aquaponic systems with tilapia and lettuce in the U.S. Virgin Islands. They were able to determine that aquaponic farms can be profitable in the area, while larger scale operations provided the highest returns. Spreen et al. (2006) also used the NPV method to analyze the future for the Florida citrus industry. They concluded that there are significant barriers to entry in the industry due to high up-front costs that are tough to recover. Due to this, it was predicted that preexisting firms could be profitable and may even expand, but there would most likely be no new entrants into the industry.

Though the NPV method is a useful tool, future markets and expectations cannot be exactly predicted as they are only estimates based on past data. Incorporating a sensitivity analysis can help producers estimate this uncertainty. A sensitivity analysis determines how changes in values of certain variables affect the profitability of a project. This can be conducted alongside the NPV method to analyze changes in NPV due to an input or output change in production (e.g., change in input costs, market prices, discount rates, etc.; Jovanović, 1999).

Sensitivity analyses have also frequently been implemented in agricultural evaluations to estimate some of the potential volatility in an industry. For example, Royan et al. (2012) used a sensitivity analysis to estimate how a change in the use of energy inputs affected peach yields in Iran. The energy inputs analyzed in their study were human labor, machinery, diesel fuel, chemicals, fertilizers, water, and electricity. Their analysis found that a change in human labor, diesel fuel, and farmyard manure inputs had the highest, second highest, and third highest impacts on peach yields, respectively.

Wannemuehler et al. (2020) also used a sensitivity analysis in peaches but focused on the United States industry. Their study analyzed how potential decreases in costs of inputs would affect the profitability of implementing DNA-informed breeding into peach breeding programs. The input costs that were analyzed in this study were decreased costs for DNA market tests and labor rates for disease resistance evaluations. Their results confirmed that reducing the costs of both inputs would increase the cost-effectiveness of implementation. White (2019) implemented a sensitivity analysis to examine how the discount rate affected the NPV in his investment analysis of the South Carolina peach industry. As predicted, he found the lowest discount rate to have the highest net present value. He used a range of discount rates from 3%–12% and found that the NPV became negative between 5% and 6% for a 12-year orchard life and between 8% and 9% for a 15-year orchard life.

Monte Carlo Simulations

As with the sensitivity analysis, the Monte Carlo simulation (MCS) method can also be implemented to further estimate unknown variability. MCSs are developed using computer generations to create a statistical distribution of pseudo-random numbers (numbers that are randomly derived from a known base level; Srivastava et al., 2020). Repetitive random sampling and statistical analyses are then applied to calculate results. The outcomes can assist researchers in evaluating risk and profitability ranges related to risky variables by incorporating stochastic behaviors. A static model is often determined as well to serve as the basis for comparison of simulated values (Raychaudhuri, 2008).

There is a plethora of past agricultural research studies that implement a Monte Carlo simulation into their model. One example is an evaluation by Koroteev el al. (2022) that analyzed optimization of the food industry by developing a case study that focused on a meat processing plant in Russia. Their methodology discussed that simulation modeling, such as MCSs, are effective under three conditions:

1. There are multiple parameters that are not linearly related;
2. The model contains probabilistic behavior and feedback;
3. The model contains multiple states and a changing time trajectory.

They researched an optimal production system that required a higher efficiency production plan and reduced manual labor costs. The results showed that implementing the new production system into a company in the meat processing industry could increase profits from 0.5 to 1.5 percentage points.

Though Monte Carlo simulations are commonly used in enterprise budget analyses, implementing one to estimate ARR impacts would be inaccurate. There is no known behavior pattern for the disease, which means there is not a probability distribution that could be implemented into an MCS. The disease is still being studied, but it currently presents as a random effect and not a probabilistic effect. Therefore, a simulation model that is constructed using random variations was deemed more suitable for estimating ARR impact.

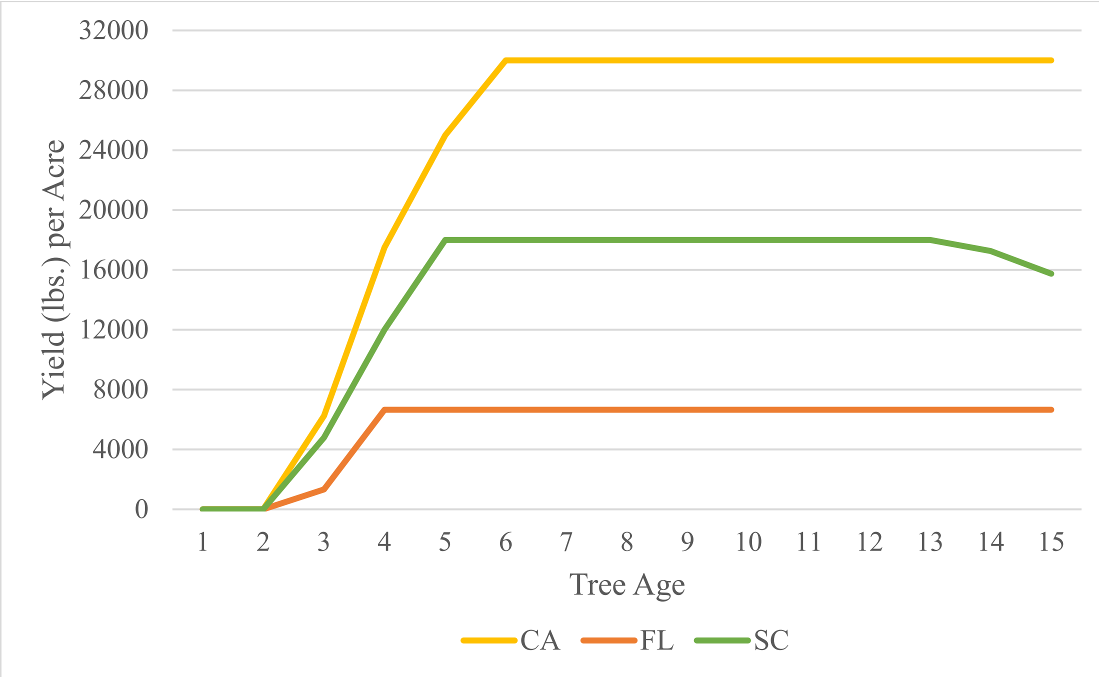
Data

This chapter will perform an investment analysis on ARR impacts and implementation of the RCE method in peach production using enterprise budgets. The data was collected for California (CA), Florida (FL), and South Carolina (SC) peach enterprise budgets. The peach EBs for Florida were obtained from University of Florida's IFAS Extension (2017) using Scenario 1, and California budgets were obtained from University of California's Cooperative Extension fresh market peach budget (2009). It should be noted that the most current fresh market peach budget that has been published by the University of California was released in 2009, so the price data could be outdated.

There is currently not an updated comprehensive enterprise budget for South Carolina peach production from the state's cooperative extension service. White (2019) developed a partial peach enterprise budget that did not include irrigation methods. This budget was used as the basis for SC data and was modified to include irrigation costs using data from peach producers in the state. The California and Florida peach budgets were also used as comparisons.

To accurately estimate enterprise budgets for peaches, a peach yield curve is needed since production during each year of tree age varies. The enterprise budgets for FL and CA provided a yield curve, but one had to be developed for SC. The yield curves for each state used in the analysis can be found in Figure 3.3. The FL yield curve reaches maximum production in year 4, SC reaches maximum production in year 5, and CA reaches maximum production in year 6.

Figure 3.3. Peach Yield Curve per Acre by Tree Age for California, Florida, and South Carolina



The Florida enterprise budget originally included yields during year 2 of tree age, but these were removed due to infeasibility after speaking with industry expert Chalmers Carr. It should also be noted that the SC yield curve shows a decrease in production after year 13. After speaking with producers, they indicated that yields do begin to decline after a certain age, but the CA and FL enterprise budgets ignore this. However, this factor was not an issue in the calculations since the time horizon was limited to 12 years.

All enterprise budgets were estimated for peach operations that were already established. The budgets were adjusted by removing irrigation and machinery initial investment costs to assume that the equipment is already owned. This was implemented to depict the impacts of ARR and RCE implementation for current U.S. producers and not potential producers. To fully estimate the impacts that ARR causes on the revenues and costs of a peach operation, some modifications were made to each of the state budgets by adjusting per acre variables to per tree variables. This was used to simulate how the costs and revenues per acre would change if a certain number of trees died. To account for decreased production in ARR-infested replant sites, the yields per acre from each budget were adjusted to yields per tree. The costs adjusted were determined to be directly impacted by the number of trees present per acre and include thinning, pruning, harvesting, hauling, packaging, and selling costs.

The pruning costs for tree age of 2 was further adjusted for each state to reflect less branches since the tree is not fully developed at that time. Most producers do not have the technology to limit chemical or water applications to only specific trees as the equipment is expensive. Therefore, all other variable costs, such as establishment, irrigation, chemicals, and fuel were not determined to be impacted by the number of trees present and were left as per acre calculations. Fixed costs were also kept as per acre calculations. The cost of implementation for the RCE method was obtained from Miller et al. (2020) and estimated to be $2,162.57 per acre. This cost was included in year 2 of orchard life as that is when the method is implemented so that the roots have had time to establish in the soil.

Methodology

This chapter implements the net present value method of investment analysis to determine the monetary benefits of using the RCE method. Since peach trees are a perennial crop that can live for 12 to 15 years and have a delay from planting to harvestable yields, the NPV technique was chosen because it allows the benefits and costs from several years of a project to be calculated into present value. Using a specified discount rate, the NPV method will be used to analyze the profitability of peach producers using the enterprise budgets. The model NPV formula can be found in Equation (3.1):

$$(3.1) \quad NPV = \sum_{t=1}^{n} \frac{NR_t}{(1+r)^t} - I$$

where NPV is the net present value of the investment, n is the lifetime of the peach orchard, NR_t is the annual net returns for year t, r is the annual discount rate, and I is the initial investment required to establish the orchard.

While some agricultural enterprises replant once a plant has died (e.g., the apple industry), this is not implemented in the peach industry and therefore was not used in the model. The variability in tree age in individual peach orchards would cause more complications and increase the costs more than the benefit it would provide from extra yields. For example, if three trees per acre died in year 7 of orchard life and were replanted, growers would have to ensure that the young trees had the proper establishment care. They would also have to be sure that those trees had the correct chemicals applied for establishment and were not exposed to the chemicals used on the other mature trees in the orchard. Caution would also be needed once the mature trees in the orchard had reached their maximum life and were removed so that the few younger trees were not disturbed. Then, once the entire orchard was replanted, they would have a few trees on each acre that were mature and require different care than the newly established trees. Eventually, each orchard would have a wide variety of peach tree ages, all needing different care, which is economically infeasible due to costs.

To estimate the ARR impact on replant sites, the NPV method was applied to static models and simulations. A base model was developed with fixed variables that did not include ARR impact to assess the profitability without disease presence. The simulations were implemented to estimate the effects of the disease spread and account for unknown variability. From all the research conducted for this thesis, the rate and method at which the disease spreads seem to still be undetermined. Therefore, each model was assessed with an average and exponential disease impact rate to account for this unknown factor.

Based on the producer survey results presented in Chapter 2, the NPV was estimated over a 12-year orchard life as the respondents indicated that the average age of orchard removal due to tree death was 9–12 years. Based on the research conducted by Schnabel et al. (2012), the static models assumed that the disease presence began to affect orchards at an average tree age of 5. The RCE method was estimated to delay the impact by at least 2 years, so the RCE model assumed an average impact tree age of 7. The average impact rate and exponential impact rate was assumed to be 3% tree loss annually, with the exponential model being compounded annually. A sensitivity analysis was also implemented for each scenario to show how the discount rate affects the NPV estimations. The RCE method also presented to decrease the average annual tree loss due to ARR by 1%–2%. To account for this, RCE models assumed a decreased impact rate of 1.5% for average and exponential analyses.

In the simulation, disease impact year and rate were both used as stochastic random variables, while all other variables (yields, revenues, costs, etc.) were held constant. The random effects were calculated using Microsoft Excel's RANDBETWEEN function (2022). To estimate the loss on ARR-infected fields, the impact year was randomly determined from years 4 to 6 of tree life (see Equation 3.2). To estimate the potential gains from implementing the RCE method, the impact year was then randomly determined from years 6 to 8 of tree life (see Equation 3.3). The average and exponential impact rate simulations assumed a random annual impact between 2% and 4% per year (see Equation 3.4). To account for the decrease in tree loss from ARR with the RCE method, the average and exponential rates were then analyzed with a random annual impact between 1% and 2%. (see Equation 3.5).

(3.2) $= RANDBETWEEN(4, 6)$
(3.3) $= RANDBETWEEN(6, 8)$
(3.4) $= RAND(\,) * 0.02 + 0.02$
(3.5) $= RAND(\,) * 0.01 + 0.01$

Each simulation model estimated the average NPV from random effects executed through 10,000 trials. The assumptions and purpose for each model developed can be found in Table 3.1.

Table 3.1. Summary of Models, Assumptions, and Purpose of Each Model Used

Model	Assumptions	Purpose
Static Models		
CA-base, FL-base, SC-base	No disease impact	To determine the profitability without disease presence
CA1, FL1, SC1	Average disease impact rate of 10% beginning in year 5 of orchard life	To determine the profitability of disease-infected replant sites based on average impact rate and year
CA2, FL2, SC2	Average disease impact rate of 10% beginning in year 7 of orchard life	To determine the profitability of disease-infected replant sites based on average impact rate and year using the RCE method
CA3, FL3, SC3	Exponential disease impact rate of 2% per year beginning in year 5 of orchard life	To determine the profitability of disease-infected replant sites based on exponential impact rate and average impact year
CA4, FL4, SC4	Exponential disease impact rate of 2% per year beginning in year 7 of orchard life	To determine the profitability of disease-infected replant sites based on exponential impact rate and average impact year using the RCE method
Simulations		
CA5, FL5, SC5	Average disease impact at a random rate between 5% and 15%, beginning in a random year between 5 and 7 of orchard life	To include unknown variability into the model to determine the profitability of disease-infected replant sites based on random average impact rates and years
CA6, FL6, SC6	Average disease impact at a random rate between 5% and 15%, beginning in a random year between 7 and 9 of orchard life	To include unknown variability into the model to determine the profitability of disease-infected replant sites based on random average impact rates and years using the RCE method
CA7, FL7, SC7	Exponential disease impact at a random annual rate between 1% and 3%, beginning in a random year between 5 and 7 of orchard life	To include unknown variability into the model to determine the profitability of disease-infected replant sites based on random exponential impact rates and years
CA8, FL8, SC8	Exponential disease impact at a random annual rate between 1% and 3%, beginning in a random year between 7 and 9 of orchard life	To include unknown variability into the model to determine the profitability of disease-infected replant sites based on random exponential impact rates and years using the RCE method

Results

Each state enterprise budget contained different assumptions for farm size, tree density per acre, packout rates, fruit price per pound, and costs. A summary of each states' assumptions can be found in Table 3.2. The grower fruit price per pound for SC and CA were estimated based on historical USDA prices from 2018–2021. Updated FL grower fruit price information could not be found, so the median price listed on the enterprise budget was used. It was stated in the budget details that Florida producers typically receive higher fruit prices as they have an advantage of being the first domestic peaches available each year, which could explain the price variation.

Table 3.2. Farm and Cost Assumptions by State

Assumption	State		
	California	Florida	South Carolina
Farm size	100 acres	100 acres	100 acres
Trees per acre	151	156	150
Packout rate	72%	84%	78%
Grower fruit price per pound	$0.70	$1.88	$0.83
Thinning cost per tree*	$7.53	$6.00	$5.95
Pruning cost per tree*	$5.64	$4.00	$3.55
Harvesting/hauling cost per tree*	$13.25	$10.75	$11.05
Packaging costs per tree*	$28.77	$20.21	$19.50
Establishment costs per acre	$4,882.00	$5,779.64	$5,274.32
Other variable costs per acre*	$1,954.00	$2,002.46	$1,556.00
Fixed costs per acre*	$1,469.00	$1,192.19	$1,215.00

Note. *costs once orchard maturity has been reached; color distinctions are used for each state throughout the chapter for clarification purposes.

California Results

The base NPV without disease impact for California can be found in Table 3.3. The varying costs per acre represent the costs that would be affected by a tree that has died. These costs include thinning, pruning, harvesting, hauling, packaging, and selling costs. The original 2009 California enterprise budget also included a cost per pound of sold fruit for the California Tree Fruit Agreement marketing order, but those costs were removed as the marketing order has expired (Plakias, 2020). The other costs per acre include all other variable costs along with the fixed costs from the enterprise budget. The baselevel NPV for California was determined to be $4,492.42, which was used as a comparison in the rest of the models.

Table 3.3. California Peach Profitability Analysis Without Disease Presence (CA-base)

Tree Age	Yield / Plant (lbs.)	Packout Yield / Plant (lbs.)	Total Revenue / Acre	Varying Tree Costs / Acre	Other Costs / Acre	Total Costs / Acre	Discounted Net Returns / Acre*
1	0	0	$0.00	$0.00	($5,470.00)	($5,470.00)	($5,259.62)
2	0	0	$0.00	($71.00)	($1,830.00)	($1,901.00)	($1,757.58)
3	40	28.8	$3,044.16	($2,078.00)	($2,194.00)	($4,272.00)	($1,091.55)
4	115	82.8	$8,751.96	($5,501.00)	($2,330.00)	($7,831.00)	$787.24
5	165	118.8	$12,557.16	($7,110.65)	($2,381.00)	($9,491.65)	$2,519.63
6	195	140.4	$14,840.28	($9,533.27)	($3,423.00)	($12,956.27)	$1,488.96
7	195	140.4	$14,840.28	($9,533.27)	($3,423.00)	($12,956.27)	$1,431.69
8	195	140.4	$14,840.28	($9,533.27)	($3,423.00)	($12,956.27)	$1,376.63
9	195	140.4	$14,840.28	($9,533.27)	($3,423.00)	($12,956.27)	$1,323.68
10	195	140.4	$14,840.28	($9,533.27)	($3,423.00)	($12,956.27)	$1,272.77
11	195	140.4	$14,840.28	($9,533.27)	($3,423.00)	($12,956.27)	$1,223.82
12	195	140.4	$14,840.28	($9,533.27)	($3,423.00)	($12,956.27)	$1,176.75
					Net Present Value:		**$4,492.42**

Note. *based on a 4% discount rate

The results from the static models and the sensitivity analysis of the discount rates are shown in Table 3.4. The discount rates included are 3%, 4%, and 5%, but all results will be analyzed using the average 4% rate. Based on the average disease impact rate of 3% annually, the NPV per acre of peach production was estimated to decrease by $3,938 due to ARR presence. The results also indicate that implementing the RCE method would increase potential profitability on infected land by $822 per acre. Based on the exponential disease impact rate of 3% compounded annually, the per acre NPV with disease presence decreased by $3,683 while using the RCE method increased profitability by $594.

Table 3.4. California Static Model Results with Sensitivity Analysis

Model	Discount Rate		
	3%	4%	5%
Average Impact Rates			
CA-base	$5,361.62	$4,492.42	$3,706.82
CA1	$1,043.55	$554.06	$110.27
CA2	$2,090.28	$1,376.40	$732.87
Change in NPV Due to ARR	($4,318.07)	($3,938.36)	($3,596.55)
% Change	-80.54%	-87.67%	-97.03%
Change in NPV with ARR Using RCE	$1,046.72	$822.34	$622.60
% Change	100.30%	148.42%	564.61%
Exponential Impact Rates			
CA-base	$5,361.62	$4,492.42	$3,706.82
CA3	$1,325.33	$808.91	$341.03
CA4	$2,120.04	$1,403.17	$756.98
Change in NPV Due to ARR	($4,036.29)	($3,683.51)	($3,365.79)
% Change	-75.28%	-81.99%	-90.80%
Change in NPV with ARR Using RCE	$794.71	$594.26	$415.95
% Change	59.96%	73.46%	121.97%

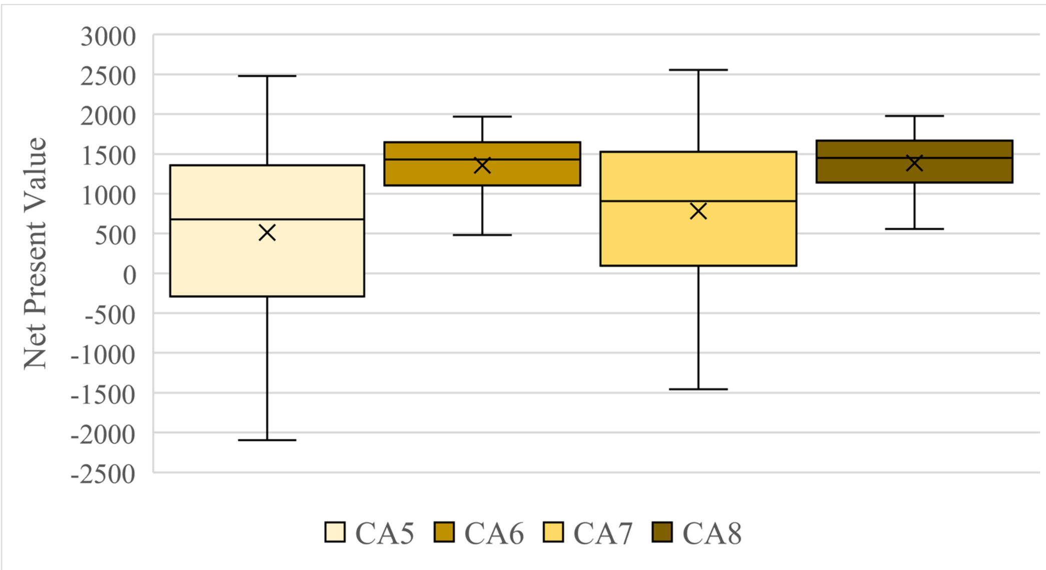
The simulations with the 10,000 trials showed similar results, but also demonstrated the minimum and maximum NPVs with the associated disease variability (see Table 3.5). With the average disease rate, the average NPV assuming ARR presence using the RCE method increased by over 150%. The minimum NPV increased by 77% while the potential maximum decreased by 20.63%. The RCE method showed an increase in the probability of the NPV being positive from 69.88% to 100%. Therefore, the simulation suggests implementation of RCE could eliminate the probability of negative profits due to ARR for producers in California. Using the exponential disease impact rate, the average NPV was increased by 76.86% using the RCE method, while the minimum and maximum showed an increase of 76.86% and a decrease of 22.72% in profitability, respectively. RCE showed an increase in the probability of positive NPVs from 77.52% to 100% in ARR-infected orchards.

Table 3.5. California Simulation Results

Simulation	Net Present Value				
	Average	Minimum	Maximum	Std. Dev.	Probability of Being Positive
Average Impact					
CA5	$540.85	($2,094.80)	$2,479.93	$1,100.50	69.88%
CA6	$1,352.73	$480.70	$1,968.38	$374.22	100.00%
Change using RCE	$811.88	$1,614.10	($511.56)	($726.29)	30.12%
% Change	150.11%	77.05%	-20.63%		
Exponential Impact					
CA7	$783.67	($1,457.36)	$2,555.97	$970.07	77.52%
CA8	$1,385.99	$557.34	$1,975.16	$353.48	100.00%
Change using RCE	$602.32	$900.01	($580.81)	($616.60)	22.48%
% Change	76.86%	61.76%	-22.72%		

A box and whisker plot of the 10,000 trials implemented in each simulation can be found in Figures 3.4. A clear distinction is present between the NPVs calculated for ARR-infected replant sites with (CA6, CA8) and without (CA5, CA7) the use of the RCE method. Implementing RCE in California shows to increase the mean and median potential NPVs. The minimum NPV using the method shows a large increase when compared to not using the method, though the maximum NPV shows a decrease. Risk-averse producers may find implementation attractive as it appears to eliminate the probability of negative profitability.

Figure 3.4. Box Plots of Simulation NPVs With and Without the Use of the RCE Method in California



Florida Results

The base NPV without ARR impact for Florida can be found in Table 3.6. The varying costs per acre include thinning, pruning, harvesting, hauling, and packaging costs. The original Florida enterprise budget also included a cost on revenues for brokerage fees, but these costs were removed since the majority of the producers from the survey in Chapter 2 reported not using brokers. The other costs per acre include all other variable costs along with the fixed costs from the University of Florida enterprise budget. The base-level NPV for Florida was determined to be -$653.17.

Table 3.6. Florida Peach Profitability Analysis Without Disease Presence (FL-base)

Tree Age	Yield / Plant (lbs.)	Packout Yield / Plant (lbs.)	Total Revenue / Acre	Varying Tree Costs / Acre	Other Costs / Acre	Total Costs / Acre	Discounted Net Returns / Acre*
1	0	0	$0.00	$0.00	($6,971.83)	($6,971.83)	($6,703.68)
2	0	0	$0.00	($468.00)	($3,175.52)	($3,643.52)	($3,368.64)
3	28	23.52	$6,897.95	($4,376.49)	($3,178.12)	($7,554.61)	($583.77)
4	43	36.12	$10,593.27	($5,885.32)	($3,194.65)	($9,079.97)	$1,293.58
5	43	36.12	$10,593.27	($5,885.32)	($3,194.65)	($9,079.97)	$1,243.83
6	43	36.12	$10,593.27	($5,885.32)	($3,194.65)	($9,079.97)	$1,195.99
7	43	36.12	$10,593.27	($5,885.32)	($3,194.65)	($9,079.97)	$1,149.99
8	43	36.12	$10,593.27	($5,885.32)	($3,194.65)	($9,079.97)	$1,105.76
9	43	36.12	$10,593.27	($5,885.32)	($3,194.65)	($9,079.97)	$1,063.23
10	43	36.12	$10,593.27	($5,885.32)	($3,194.65)	($9,079.97)	$1,022.33
11	43	36.12	$10,593.27	($5,885.32)	($3,194.65)	($9,079.97)	$983.01
12	43	36.12	$10,593.27	($5,885.32)	($3,194.65)	($9,079.97)	$945.21
					Net Present Value:		**($653.17)**

Note. *based on a 4% discount rate.

The results from the Florida static models and the sensitivity analysis of the discount rates are shown in Table 3.7. From the average annual disease impact rate, the NPV per acre will decrease by approximately $3,491 due to ARR presence. The outcomes also suggest that applying the RCE method would increase profitability on replanted orchards by $501, or 12% per acre. Using the annually compounded exponential disease impact rate, the NPV per acre of operation with disease incidence decreased by $3,264.66. When compared to non-implementation, using the RCE method could increase profitability levels by 7.62% per acre on replant sites.

Table 3.7. Florida Static Model Results with Sensitivity Analysis

Model	Discount Rate		
	3%	4%	5%
Average Impact Rates			
FL-base	($21.18)	($653.17)	($1,220.17)
FL1	($3,848.62)	($4,143.92)	($4,407.83)
FL2	($3,153.35)	($3,643.15)	($4,079.84)
Change in NPV Due to ARR	($3,827.44)	($3,490.75)	($3,187.66)
% Change	-18072.77%	-534.43%	-261.25%
Change in NPV with ARR Using RCE	$695.27	$500.77	$327.99
% Change	18.07%	12.08%	7.44%
Exponential Impact Rates			
FL-base	($21.18)	($653.17)	($1,220.17)
FL3	($3,598.65)	($3,917.83)	($4,203.12)
FL4	($3,126.95)	($3,619.40)	($4,058.44)
Change in NPV Due to ARR	($3,577.47)	($3,264.66)	($2,982.95)
% Change	-16892.42%	-499.82%	-244.47%
Change in NPV with ARR Using RCE	$471.70	$298.44	$144.67
% Change	13.11%	7.62%	3.44%

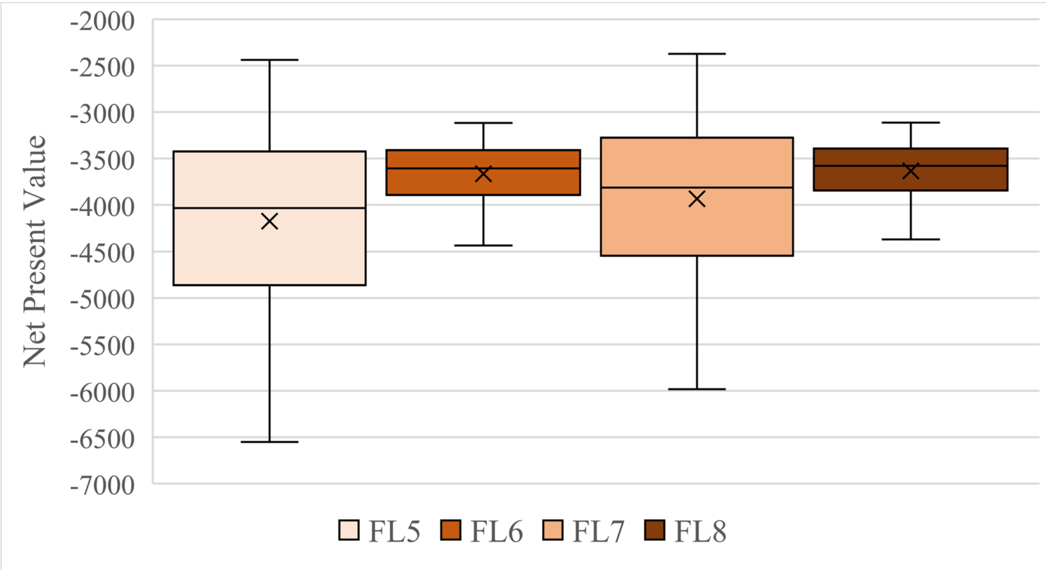
The 10,000 trials computed in the simulations allowed analysis of the minimum and maximum NPVs across disease variability as well as the likelihood of positive profitability (see Table 3.8). Using the average impact rate, the average NPV assuming ARR infection increased by 12.21% using the RCE method. The minimum NPV showed an increase of 32.25% while the maximum decreased by 27.84%. The average NPV on ARR-infected sites with the exponential impact rate revealed a potential increase of 7.58% with RCE implementation. The minimum showed an increase in NPV of 26.98% and the maximum showed a decrease of 31.25%. None of the trials in the simulation revealed positive NPVs with ARR impacts in Florida.

Table 3.8. Florida Simulation Results

Simulation	Net Present Value				
	Average	Minimum	Maximum	Std. Dev.	Probability of Being Positive
Average Impact					
FL5	($4,175.61)	($6,550.26)	($2,439.31)	$990.99	0.00%
FL6	($3,665.77)	($4,437.68)	($3,118.41)	$329.80	0.00%
Change using RCE	$509.84	$2,112.58	($679.10)	($661.18)	
% Change	12.21%	32.25%	-27.84%		
Exponential Impact					
FL7	($3,931.73)	($5,984.87)	($2,371.01)	$871.19	0.00%
FL8	($3,633.89)	($4,369.88)	($3,111.97)	$314.43	0.00%
Change using RCE	$297.84	$1,614.99	($740.96)	($556.76)	
% Change	7.58%	26.98%	-31.25%		

Figures 3.5 depicts box plots of all 10,000 trials computed in the four simulations. Similar to the California results, a large difference exists between the profitability calculated for ARR-infected replant sites with (FL6, FL8) and without (FL5, FL7) the implementation of RCE. The medians and means are, once again, higher with implementation while the minimums are higher and the maximums are lower. Risk-averse producers in Florida may choose to implement the method as it decreases the variability associated with profitability on replanted sites.

Figure 3.5. Box Plots of Simulation NPVs With and Without the Use of the RCE Method in Florida



South Carolina Results

South Carolina's base NPV for peach production without ARR impact is shown in Table 3.9. Again, varying costs per acre include thinning, pruning, harvesting, hauling, and packaging costs. Other costs per acre in the table include the fixed and variable costs that are not affected by the number of trees per acre. It should be noted once more that the South Carolina enterprise budget was estimated and not sourced from a state university like the previous two. The base net present value per acre for South Carolina was calculated to be $1,292.84.

Table 3.9. South Carolina Peach Profitability Analysis Without Disease Presence (SC-base)

Tree Age	Yield / Plant (lbs.)	Packout Yield / Plant (lbs.)	Total Revenue / Acre	Varying Tree Costs / Acre	Other Costs / Acre	Total Costs / Acre	Discounted Net Returns / Acre*
1	0	0	$0.00	$0.00	($6,489.32)	($6,489.32)	($6,239.73)
2	0	0	$0.00	($37.50)	($2,715.00)	($2,752.50)	($2,544.84)
3	32	24.96	$3,107.52	($6,082.50)	($2,771.00)	($8,853.50)	($5,108.16)
4	80	62.4	$7,768.80	($6,082.50)	($2,771.00)	($8,853.50)	($927.21)
5	120	93.6	$11,653.20	($6,082.50)	($2,771.00)	($8,853.50)	$2,301.15
6	120	93.6	$11,653.20	($6,082.50)	($2,771.00)	($8,853.50)	$2,212.64
7	120	93.6	$11,653.20	($6,082.50)	($2,771.00)	($8,853.50)	$2,127.54
8	120	93.6	$11,653.20	($6,082.50)	($2,771.00)	($8,853.50)	$2,045.71
9	120	93.6	$11,653.20	($6,082.50)	($2,771.00)	($8,853.50)	$1,967.03
10	120	93.6	$11,653.20	($6,082.50)	($2,771.00)	($8,853.50)	$1,891.38
11	120	93.6	$11,653.20	($6,082.50)	($2,771.00)	($8,853.50)	$1,818.63
12	120	93.6	$11,653.20	($6,082.50)	($2,771.00)	($8,853.50)	$1,748.68
					Net Present Value:		**$1,292.84**

Note. *based on a 4% discount rate.

Compared to the base profitability, presence of ARR at an average impact rate in the static models decreases the profitability in SC by approximately $4,130. Assuming ARR is present in the field, applying RCE would increase the profitability by $959, or 33.79%. Looking at the exponential impacts, ARR decreases NPV by $3,863 with an increase of $719.52, or 28%, if the RCE method is used. All results with the sensitivity analysis of the discount rates are disclosed in Table 3.10.

Table 3.10. South Carolina Static Model Results with Sensitivity Analysis

Model	Discount Rate		
	3%	4%	5%
Average Impact Rates			
SC-base	$2,344.53	$1,292.84	$353.97
SC1	($2,184.30)	($2,837.59)	($3,417.84)
SC2	($988.08)	($1,878.66)	($2,670.29)
Change in NPV Due to ARR	($4,528.83)	($4,130.43)	($3,771.81)
% Change	-193.17%	-319.49%	-1065.59%
Change in NPV with ARR Using RCE	$1,196.22	$958.93	$747.55
% Change	54.76%	33.79%	21.87%
Exponential Impact Rates			
SC-base	$2,344.53	$1,292.84	$353.97
SC3	($1,888.52)	($2,570.08)	($3,175.62)
SC4	($956.83)	($1,850.56)	($2,644.98)
Change in NPV Due to ARR	($4,233.05)	($3,862.92)	($3,529.58)
% Change	-180.55%	-298.79%	-997.15%
Change in NPV with ARR Using RCE	$931.69	$719.52	$530.63
% Change	49.33%	28.00%	16.71%

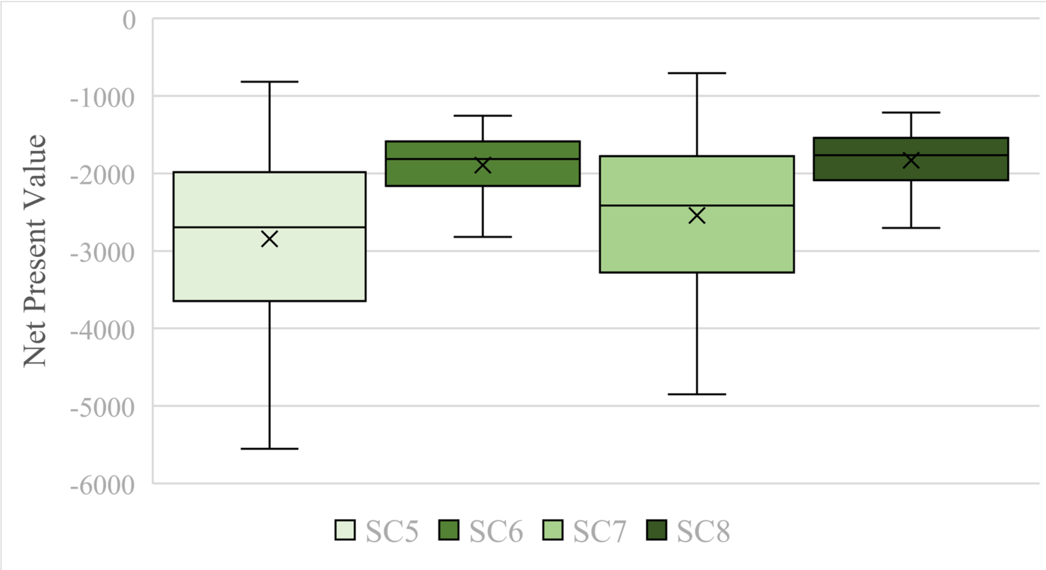
The simulations based on the average ARR impact rate indicated that average profitability per acre for peach production in South Carolina would increase by 33.37% if RCE is utilized on infected sites. The minimum profitability would increase by 49.25% while the maximum would decrease by 53.33%. From the exponential ARR impact rates, the NPV per acre would increase with RCE implementation, on average, by 27.92%, with an increase in the minimum by 44.23% and a decrease in the maximum by 72.22%. ARR appears to have a major effect on the profitability of peach production in the state as the base-level NPV was positive while all NPVs in the simulation were negative. These findings are described in Table 3.11.

Table 3.11. South Carolina Simulation Results

Simulation	Net Present Value				
	Average	Minimum	Maximum	Std. Dev.	Probability of Being Positive
Average Impact					
SC5	($2,844.54)	($5,553.63)	($820.03)	$1,134.76	0.00%
SC6	($1,895.35)	($2,818.56)	($1,257.37)	$394.32	0.00%
Change using RCE	$949.19	$2,735.06	($437.34)	($740.44)	
% Change	33.37%	49.25%	-53.33%		
Exponential Impact					
SC7	($2,543.48)	($4,848.97)	($705.74)	$1,005.70	0.00%
SC8	($1,833.44)	($2,704.17)	($1,215.46)	$372.51	0.00%
Change using RCE	$710.03	$2,144.81	($509.72)	($633.19)	
% Change	27.92%	44.23%	-72.22%		

Box plots of the NPVs from the 10,000 computed trials in the four simulations can be found in Figures 3.8. Akin to California and Florida, the graphs display a clear distinction between the use (SC6, SC8) and nonuse (SC5, SC7) of the RCE method in SC. Once again, we can see higher means, medians, and minimums and lower maximums with RCE implementation. Furthermore, the method appears to offer lower variability in the profitability of peach production in South Carolina, which was also seen in California and Florida.

Figure 3.6. Box Plots of Simulation NPVs With and Without the Use of the RCE Method in South Carolina



Conclusion

A summary of key results from each state is shown in Table 3.12. California presents with the highest profitability per acre followed by South Carolina and then Florida. All operations in this study assumed small-scale operations of 100 acres while the average peach acreage of respondents in the survey from Chapter 2 was 237 acres. Since peach production in the United States is substantial, this suggests that scale is a major factor in industry profitability and smaller-scale operations may not be as economically feasible.

Table 3.12. Summary Results from Models by State

Calculation	State		
	California	Florida	South Carolina
Base NPV	$4,492.42	($653.17)	$1,292.84
Static Model Results			
Percentage profitability change from ARR with average impact rate	-87.67%	-534.43%	-319.49%
Percentage profitability change from ARR with exponential impact rate	-81.99%	-499.82%	-298.79%
Percentage profitability change with ARR average impact rate using RCE	148.42%	12.08%	33.79%
Percentage profitability change with ARR exponential impact rate using RCE	73.46%	7.62%	28.00%
Simulation Results			
Percentage profitability change with ARR average impact rate using RCE			
Average	150.11%	12.21%	33.37%
Minimum	77.05%	32.25%	49.25%
Maximum	-20.63%	-27.84%	-53.33%
Percentage profitability change with ARR exponential impact rate using RCE			
Average	76.86%	7.58%	27.92%
Minimum	61.76%	26.98%	44.23%
Maximum	-22.72%	-31.25%	-72.22%

The calculations suggest that ARR impacts Florida and South Carolina profits the most while California showed lower affects. This could be due to the large per-acre yield variations amongst the states. California has the highest yield per acre and the lowest profitability impact while Florida has the lowest yield per acre and the highest profitability impact. Since California has the highest yields, losing one tree does not affect them as heavily as it does Florida producers. Both the static models and the simulations suggest that average impact rates decrease profitability more than exponential impact rates.

The data indicates that ARR can cause overall peach profitability per acre to decrease in California by 82%–88%, in Florida by 500%–534%, and in South Carolina by 299%–319%. Therefore, the models confirm that ARR could be a major future peach orchard risk that could compromise the profitability of production nationwide. Specifically, ARR could cause the South Carolina industry to become infeasible as the NPVs without disease were positive but, when disease was included, all NPVs were negative. California producers still have a high likelihood of positive NPVs with disease presence, though it is not believed that CA farmers currently experience major ARR issues. The Florida peach industry was estimated to have a slightly negative NPV without disease presence, but a much larger negativity was shown with ARR infection.

Implementing the RCE method on known ARR-infected replant sites increase the profits by 73%–148% in California, by 8%–12% in Florida, and by 28%–34% in South Carolina. While the RCE method does have high upfront costs, the benefits of the delayed impact and the decrease in the impact rate prove to outweigh the costs for all states. It also proves to decrease the variability in potential profits for all three states that were analyzed Therefore, the investment analysis from this study concludes that implementation of the RCE method can increase profits on ARR-infected sites nationwide and decrease profitability uncertainty. Therefore, RCE could be a financially feasible solution to the widespread ARR issue.

Future Research

Though California does appear to be the most profitable state to produce peaches in, the budgets analyzed did not include the opportunity costs of the land. The cost of land is much higher in California than in South Carolina or Florida, so future research could include the opportunity cost in the profitability analysis. Another potential investigation could be conducted to determine profitability among the states for larger-scale operations since this analysis suggests that small-scale production may not be economically efficient with disease impacts in Florida and South Carolina.

CHAPTER 4

THESIS CONCLUSION AND FUTURE RESEARCH RECOMMENDATIONS

Conclusion

The United States peach industry contributed over half a billion dollars in utilized fruit production to the national economy in 2020. In 2021, it was the fifth largest non-citrus fruit crop in terms of utilized production (NASS, 2022). However, an increase in disease prevalence, specifically Armillaria root rot, threatens the profitability of the industry (Miller et al., 2020; Schnabel et al., 2021; Luo et al., 2022). This thesis aimed to determine the impact of ARR on the U.S. peach industry, to estimate peach producers' risk tolerance, to analyze the economic impact of ARR, and to assess the profitability of implementing the root collar excavation method as an ARR management option.

From the producer survey in Chapter 2, Armillaria root rot was the only disease that every respondent reported experiencing crop loss from over the past 5 years. It was also the only disease that all producers agreed upon as a future risk concern for the industry. Participants also indicated that ARR resistance was the most important attribute when determining which rootstock to use. Peach producers risk tolerance was determined to be lower than the national average in general but higher than the national average in terms of farm production decisions.

Results from Chapter 3 further enforced that ARR is a major risk concern for the United States peach industry. The presence of ARR in peach orchards showed a decrease in per acre profitability by an average of $3,740 nationwide. Based on the 2020 national peach acreage of 76,000, even if only 5% of the national acreage has the disease issue, the national economic impact of ARR could be over $14.2 million in lost producer profits

From the payment cards, producers indicated the highest WTP premium of $2.16 per tree for an increase in ARR resistance score from 0–2 to 7 or higher. Assuming producers use a tree density of 150 trees per acre, this means that producers, on average, would be willing to pay an extra $324 per acre in tree expenses for the rootstock. For a 100-acre operation like those used in the enterprise budgets in Chapter 3, this would be an extra initial investment cost of $32,400.

Only one peach grower in the survey indicated current use of the root collar excavation method. The majority of growers stated that they did not use RCE because it was not effective enough in managing ARR. From the calculations in Chapter 3, the RCE method did prove to increase potential yields by delaying ARR impact by 2 years and decreasing the disease impact rate. Therefore, producers may not fully understand the benefits that are associated with implementation of the method.

The potential future benefits of using the method proved to outweigh the extra upfront cost of implementing root collar excavation. Utilizing RCE on ARR-infected replant sites could increase potential profits by an average of $657 per acre. This could decrease the estimated economic impact of the disease by almost $2.5 million. Hence, based on all estimations from this study, the RCE method is recommended for producers with ARR issues nationwide as it is cost efficient.

Future Research Suggestions

Both chapters of this thesis highlighted many potential future research topics for the United States peach industry. New Armillaria root rot management options are needed since the infection rate is increasing across the nation. A potential solution that could be investigated is the development of an ARR-resistant rootstock since producers from the survey all indicated that they were willing to pay a premium per tree. Producer responses also suggested future research in food safety and marketing and orchard management practices.

Since South Carolina is the second largest peach producing state in the nation, a formal enterprise budget could be developed by university researchers. A more recent enterprise budget for California could also be created since the most current one is 13 years old. A follow-up investment analysis could also be conducted to analyze the profitability of larger-scale peach operations in the United States. This can then be applied to determine the economic effects of using the RCE method on larger-scale farms.

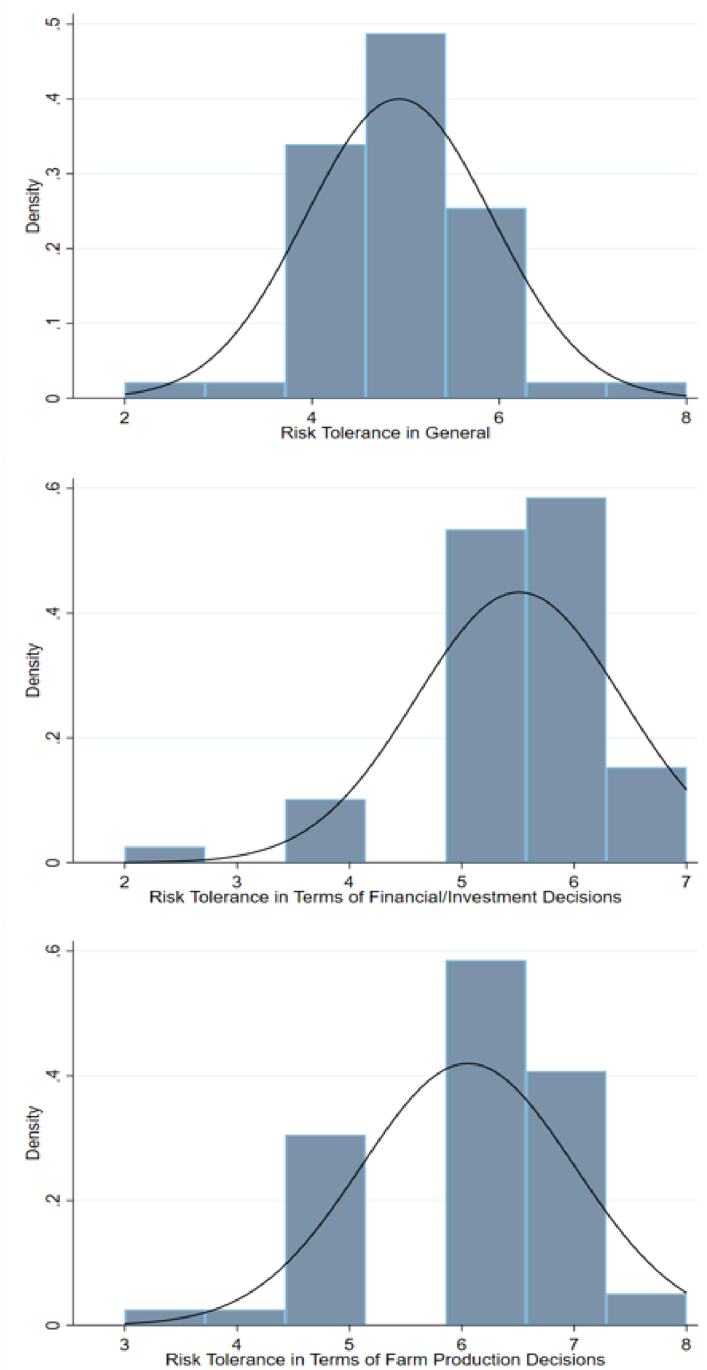
APPENDIX A

Farm Summary Statistics

Variable	Mean	Std. Dev.	Minimum	Maximum
Total farm acres	417.27	43.35	250	500
Total peach acres	237.04	49.12	70	340
Density of trees per acre	135.3	36.99%	100	320

APPENDIX B

Distribution of Indicated Risk Levels in General, in Terms of Financial and Investment Decisions, and in Terms of Farm Production Decisions



Note. The black curve shows the approximated normal distribution of responses.

REFERENCES

Adams, J., Bateman, B., Becker, F., Cresswell, T., Flynn, D., McNaughton, R., Oluboyede, Y., Robalino, S., Ternent, L., Sood, B.G., Michie, S., Shucksmith, J., Sniehotta, F. F., & Wigham, S. (2015). Effectiveness and acceptability of parental financial incentives and quasi-mandatory schemes for increasing uptake of vaccinations in preschool children: systematic review, qualitative study and discrete choice experiment. *Health Technology Assessment*, *19*(94), 1–176. https://doi.org/10.3310/hta19940

Adelberg, J. Naylor-Adelberg, J., Miller, S., Gasic, K., Schnabel, G., Bryson, P., Saski, C., Parris, S., & Reighard, G. (2021). *In vitro* co-culture system for *Prunus* spp. and *Armillaria mellea* in phenolic foam rooting matric. *In Vitro Cellular & Developmental Biology – Plant*, *57*(3), 387–397. https://doi.org/10.1007/s11627-020-10136-2

Agricultural Marketing Resource Center (AMRC). (2021). *Peaches.* United States Department of Agriculture. https://www.agmrc.org/commodities-products/fruits/peaches

Alvi, M., Barooah, P., Gupta, S., & Saini, S. (2021). Women's access to agriculture extension amidst COVID-19: Insights from Gujarat, India and Dang, Nepal. *Agricultural Systems*, *188*, 103035. https://doi.org/10.1016/j.agsy.2020.103035

Awondo, S. N., Fonsah, E. G., & Gray, D. J. (2017). Incorporating structure and stochasticity in muscadine grape enterprise budget and investment analysis. *HortTechnology*, *27*(2), 212–222. https://doi.org/10.21273/horttech03466-16

Bailey, D. S., Rakocy, J. E., Cole, W. M., & Shultz, K. A. (1997). Economic analysis of a commercial-scale aquaponic system for the production of tilapia and lettuce. *Tilapia aquaculture: proceedings of the fourth international symposium on Tilapia in aquaculture*, Orlando, Florida, 603–612.

https://images.indiegogo.com/medias/394863/files/20120818104616-Economic_Analysis_of_a_Commercial-Scale_Aquaponic_System.pdf

Bandara, A. Y., Weerasooriya, D. K., Conley, S. P., Bradley, C. A., Allen, T. W., & Esker, P. D. (2020). Modeling the relationship between estimated fungicide use and disease-associated yield losses of soybean in the United States I: Foliar fungicides vs foliar diseases. *PLoS one*, *15*(6), e0234390. https://doi.org/10.1371/journal.pone.0234390

Barton, D. N. (2017). *Stated preference valuation OpenNESS method factsheet*. European Commission. https://oppla.eu/sites/default/files/uploads/methodfactsheeetstated-preference-valuation-methods_0.pdf

Baumgartner, K. (2004). Root collar excavation for postinfection control of Armillaria root disease of grapevine. *Plant Disease*, *88*(11), 1235–1240. https://doi.org/10.1094/pdis.2004.88.11.1235

Baumgartner, K., Fujiyoshi, P., Ledbetter, C., Duncan, R., & Kluepfel, D. A. (2018). Screening almond rootstocks for sources of resistance to Armillaria root disease. *HortScience*, *53*(1), 4–8. https://doi.org/10.21273/HORTSCI12038-17

Beckman, T. G. (1998). Developing Armillaria resistant rootstocks for peach. *Acta Horticulturae*, *465*, 219–224. https://doi.org/10.17660/ActaHortic.1998.465.26

Beckman, T. G., & Chaparro, J. X. (2015). Peach rootstock development for the southeastern United States. *Acta Horticulturae*, *1084*, 171–178. https://doi.org/10.17660/ActaHortic.2015.1084.23

Beckman, T. G., Chaparro, J. X., & Sherman, W. B. (2008). "Sharpe", a clonal plum rootstock for peach. *HortScience*, *43*(7), 2236–2237. https://doi.org/10.21273/HORTSCI.43.7.2236

Beckman, T. G., Chaparro, J. X., & Sherman, W. B. (2012). "MP-29", a clonal interspecific hybrid rootstock for peach. *HortScience*, *47*(1), 128–131. https://doi.org/10.21273/HORTSCI.47.1.128

Beckman, T. G., Okie, W. R., Nyczepir, A. P., Reighard, G. L., Zehr, E. I., & Newall, W. C. (1997). History, current status and future potential of Guardian™ (BY520-9) peach rootstock. *Acta Horticulturae*, *451*, 251–258. https://doi.org/10.17660/ActaHortic.1997.451.27

Beckman, T. G., Rollins, P. A., Pitts, J., Chavez, D. J., & Chaparro, J. X. (2019). Disease resistance of "MP-29", a clonal interspecific hybrid rootstock for peach, in post-release trials. *HortScience*, *54*(4), 638–641. https://doi.org/10.21273/HORTSCI13592-18

Berrens, R. P., Ganderton, P., & Silva, C. L. (1996). Valuing the protection of minimum instream flows in New Mexico. *Journal of Agricultural and Resource Economics*, *21*(2), 294–308. https://www.jstor.org/stable/pdf/40986916.pdf?refreqid=excelsior%3Af41c7598b1f82d185174f39908f6ef77&ab_segments=&origin=&acceptTC=1

Bingham, A. (2017). *Stochastic budgeting and input breakeven analysis in North Dakota potato production* [Master's thesis, North Dakota State University]. North Dakota State University Libraries Repository. https://hdl.handle.net/10365/28641

Boehlje, M., & Eidman, V. R. (1984). *Farm management*. John Wiley and Sons, Agricultural Systems *19*(1), 61–65. https://doi.org/10.1016/0308-521X(85)90057-5

Bolland, M., Sweeny, M. R., Scallan Walter, E. J., Harrington, M., & Staines, A. (2006). Emerging advantages and drawbacks of telephone surveying in public health research in Ireland and the U.K. *BMC Public Health*, *6*(1), 208. https://doi.org/10.1186/1471-2458-6-208

Browne, M. J., Hofmann, A., Richter, A., Roth, S. M., & Steinorth, P. (2021). Peer effects in risk preferences: Evidence from Germany. *Annals of Operations Research*, *299*(1), 1129–1163. https://doi.org/10.1007/s10479-019-03476-9

Cox, K. D. (2004). *Armillaria root rot of peach: Biochemical characterization, detection of residual inoculum, and interspecies competition* [Doctoral dissertation, The University of Georgia]. ScholarWorksUGA. https://getd.libs.uga.edu/pdfs/cox_kerik_d_200408_phd.pdf

Curtis, K., Harris, T., & Riggs, W. (2005). *Importance & use of enterprise budgets in agricultural operations*. University of Nevada Cooperative Extension. https://extension.unr.edu/publication.aspx?PubID=2383#:~:text=Enterprise%20budgets%20are%20useful%20for,information%20for%20prospective%20new%20producers

Doubrava, N., Miller, R. W., & Blake, J. H. (2021). *Peach diseases* (G. Schnabel & J. Williamson, Eds.). Clemson Cooperative Extension Home & Garden Information Center. https://hgic.clemson.edu/factsheet/peach-diseases/

Drichoutis, A. C., Lusk, J. L., & Pappa, V. (2016). Elicitation formats and the WTA/WTP gap: A study of climate neutral foods. *Food Policy*, *61*, 141–155. https://doi.org/10.1016/j.foodpol.2016.03.001

Farnsworth, G. (2017). *Methyl bromide phase-out*. California Environmental Protection Agency Department of Pesticide Regulation. https://www.cdpr.ca.gov/docs/county/cacltrs/exec/2017/ppd/ppd1701.pdf.

Filip, G. M., Fitzgerald, S. A., Chadwick, K. L., & Max, T. A. (2009). Thinning Ponderosa pine affected by Armillaria root disease: 40 years of growth and mortality on an infected site in Central Oregon. *Western Journal of Applied Forestry*, *24*(2), 88–94. https://doi.org/10.1093/wjaf/24.2.88

Filip, G.M. & Ganio, L.M. (2004). Early thinning in mixed-species plantations of Douglas-fir, hemlock, and true fir affected by Armillaria root disease in Westcentral Oregon and Washington: 20 year results. *Western Journal of Applied Forestry*, *19*(1), 25–33. https://doi.org/10.1093/wjaf/19.1.25

Gallardo, R. K., & Wang, Q. (2013). Willingness to pay for pesticides' environmental features and social desirability bias: The case of apple and pear growers. *Journal of Agricultural and Resource Economics*, *38*(1), 124–139. https://doi.org/10.22004/ag.econ.148250

Gong, M., & Aadland, D. (2010). Interview effects in an environmental valuation telephone survey. *Environmental and Resource Economics*, *49*(1), 47–64. https://doi.org/10.1007/s10640-010-9423-0

Greaser, G. L., & Harper, J. K. (1994). *Agricultural alternatives: Enterprise budget*. Pennsylvania State University Cooperative Extension. http://whatcom.wsu.edu/ag/documents/enterbudgets/EnterpriseBudgetAnalysis.pdf.

Holmes, T. P., & Kramer, R. A. (1995). An independent sample test of yea-saying and starting point bias in dichotomous-choice contingent valuation. *Journal of Environmental Economics and Management*, *29*(1), 121–132. https://doi.org/10.1006/jeem.1995.1035

Hu, W. (2006). Use of spike models in measuring consumers' willingness to pay for non-GM oil. *Journal of Agricultural and Applied Economics*, *38*(3), 525–538. https://doi.org/10.1017/S1074070800022598

Hu, W., Woods, T., & Bastin, S. (2009). Consumer acceptance and willingness to pay for blueberry products with nonconventional attributes. *Journal of Agricultural and Applied Economics*, *41*(1), 47–60. https://doi.org/10.1017/S1074070800002546

Hu, W., Woods, T., Bastin, S., Cox, L., & You, W. (2011). Assessing consumer willingness to pay for value-added blueberry products using a payment card survey. *Journal of Agricultural and Applied Economics*, *43*(2), 243–258. https://doi.org/10.1017/S1074070800004193

Israel, G. D., & O'Leary, J. L. (2021). *The Savvy Survey #12: Telephone surveys*. UF/IFAS Extension. https://edis.ifas.ufl.edu/pdf/PD/PD076/PD076-Dw5jljklyn.pdf

Johnson, K. A., Bock, C. H., & Brannen, P. M. (2021). Phony peach disease: Past and present impact on the peach industry in the southeastern U.S.A. *CABI Agriculture and Bioscience*, *2*(1), 29. https://doi.org/10.1186/s43170-021-00049-4

Jory, R. S., Benamraoui, A., Boojihawon, D. R., & Madichie, N. O. (2016). Net present value analysis and the wealth creation process: A case illustration. *The Accounting Educators' Journal*, *26*, 85–99. https://www.aejournal.com/ojs/index.php/aej/article/view/346

Jovanović, P. (1999). Application of sensitivity analysis in investment project evaluation under uncertainty and risk. *International Journal of Project Management*, *17*(4), 217–222. https://doi.org/10.1016/s0263-7863(98)00035-0

Kassie, G. T., Abdulai, A., Greene, W. H., Shiferaw, B., Abate, T., Tarekegne, A., & Sutcliffe, C. (2017). Modeling preference and willingness to pay for drought tolerance (Dt) in maize in rural Zimbabwe. *World Development*, *94*, 465–477. https://doi.org/10.1016/j.worlddev.2017.02.008

Khakbazan, M., Carew, R., Scott, S. L., Chiang, P., Block, H. C., Robins, C., Durunna, O. N., & Huang, J. (2014). Economic analysis and stochastic simulation of alternative beef calving and feeding systems in western Canada. *Canadian Journal of Animal Science*, *94*(2), 299–311. https://doi.org/10.4141/cjas2013-185

Kilduff, A., & Tregeagle, D. (2022). Willingness-to-pay for produce: A meta-regression analysis comparing the stated preferences of producers and consumers. *Horticulturae*, *8*(4), 290. https://doi.org/10.3390/horticulturae8040290

Klocek, C. A. (2004). *Estimating the economic value of Canaan Valley National Wildlife Refuge: A contingent valuation approach* (Publication No. 3156456) [Doctoral dissertation, West Virginia University]. ProQuest Dissertations and Theses Global.

Koroteev, M., Romanova, E., Korovin, D., Shevtsov, V., Feklin, V., Nikitin, P., Makrushin, S., & Bublikov, K. V. (2022). Optimization of food industry production using the Monte Carlo simulation method: A case study of a meat processing plant. *Informatics*, *9*(1), 5. https://doi.org/10.3390/informatics9010005

Krah, Petrolia, D. R., Williams, A., Coble, K. H., Harri, A., & Rejesus, R. M. (2018). Producer preferences for contracts on a risky bioenergy crop. *Applied Economic Perspectives and Policy*, *40*(2), 240–258. https://doi.org/10.1093/aepp/ppx034

Layne, D. R. (2005). *Avoiding armillaria root rot*. Clemson Cooperative Extension. https://www.clemson.edu/extension/peach/commercial/pests/avoid-armillaria-root-rot.html

Lewis Ivey, M. L. (2015). Armillaria root rot of fruit trees. *Louisiana Plant Pathology: Disease Identification and Management Series*. LSU AgCenter. https://www.lsu.edu/agriculture/plant/extension/hcpl-publications/pub-3467-Plant-Disease-ID-and-MGMT-Armillaria-Root-Rot_FINAL.pdf

Lewis, M. F., Truscott, S. D., & Volker, M. A. (2008). Demographics and professional practices of school psychologists: A comparison of NASP members and non–NASP school psychologists by telephone survey. *Psychology in the Schools*, *45*(6), 467–482. https://doi.org/10.1002/pits.20317

Li, Z., Gallardo, R. K., McCracken, V. A., Yue, C., Gasic, K., Reighard, G., & McFerson, J. R. (2020). U.S. southeastern peach growers preferences for fruit size and external color versus resistance to brown rot disease. *HortTechnology*, *30*(5), 576–584. https://doi.org/10.21273/HORTTECH04667-20

Liu, X. (2009). *Application of microsatellite/SSR markers for the identification of peach rootstocks and chromosomal regions associated with the response to peach tree short life syndrome* [Doctoral dissertation, Clemson University]. TigerPrints. https://tigerprints.clemson.edu/all_dissertations/346

Liu, X. (2009). *Application of microsatellite/SSR markers for the identification of peach rootstocks and chromosomal regions associated with the response to peach tree short life syndrome* [Doctoral dissertation, Clemson University]. TigerPrints. https://tigerprints.clemson.edu/all_dissertations/346

Ludena, C., McNamara, K., Hammer, P., & Foster, K. (2003). *Development of a stochastic model to evaluate plant growers' enterprise budgets* [Paper presentation]. American Agricultural Economics Association Annual Meeting, Montreal, Canada. https://www.researchgate.net/publication/23505017_Development_of_a_stochastic_model_to_evaluate_plant_growers%27_enterprise_budgets

Luo, C. X., Schnabel, G., Hu, M., & De Cal, A. (2022). Global distribution and management of peach diseases. *Phytopathology Research*, *4*(1), 30. https://doi.org/10.1186/s42483-022-00134-0

Miller, S. B., Gasic, K., Reighard, G. L., Henderson, W. G., Rollins, P. A., Vassalos, M., & Schnabel, G. (2020). Preventative root-collar excavation reduces peach tree mortality caused by Armillaria root rot on replant sites. *Plant Disease*, *104*(5), 1274–1279. https://doi.org/10.1094/PDIS-09-19-1831-RE

Minas, I. S., Tanou, G., & Molassiotis, A. (2018). Environmental and orchard bases of peach fruit quality. *Scientia Horticulturae*, *235*, 307–322. https://doi.org/10.1016/j.scienta.2018.01.028

Mussell, A., & Schmidt, C. (2009). Minimum wage increases in Ontario: Understanding the significance in horticulture. *George Morris Centre*. https://doi.org/10.22004/ag.econ.289953

National Agricultural Statistics Service (NASS). (2007). *United States Top Peach Producing Areas and Growing Season*. 2007 Census of Agriculture Ag Atlas Maps. United States Department of Agriculture. https://agcensus.library.cornell.edu/census_parts/2007-ag-atlas-maps/

NASS. (2017). *2017 Census of Agriculture*. United States Department of Agriculture. https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Volume_1,_Chapter_1_US/usv1.pdf

NASS. (2019). *United States Peach Utilized Production 2009–2018 Map*. United States Department of Agriculture. https://www.nass.usda.gov/Charts_and_Maps/Noncitrus_Fruits/histuppe.php

NASS. (2022). *Noncitrus fruits and nuts: 2021 summary*. United States Department of Agriculture. https://www.nass.usda.gov/Publications/Todays_Reports/reports/ncit0522.pdf

Park, T. A., & Florkowski, W. J. (2003). Selection of peach varieties and the role of quality attributes. *Journal of Agricultural and Resource Economics*, *28*(1), 138–151. http://www.jstor.org/stable/40987177

Parry, S. (2020). *Ordinal logistic regression models and statistical software: What you need to know*. Cornell Statistical Consulting Unit, Statnews #91. https://cscu.cornell.edu/wp-content/uploads/91_ordlogistic.pdf

Payne, J. D., Heath, W. C., & Gale, L. R. (1999). Comparative financial practice in the US and Canada: Capital budgeting and risk assessment techniques. *Financial Practice and Education*, 16–24. https://www.researchgate.net/publication/284201634_Comparative_financial_practice_in_the_US_and_Canada_Capital_budgeting_and_risk_assessment_techniques

Pendergrass, R., Roberts, R., Deyton, D., & Sams, C. (2000). Economics of using soybean oil to reduce peach freeze damage and thin fruit. *HortTechnology*, *10*(1), 211–217. https://doi.org/10.21273/HORTTECH.10.1.211

Pierce, C., Dillion, C. R., & Wells, L. G. (2005). *An economic evaluation of precision deep tillage practices through the analysis of comparative enterprise budgets* [Paper presentation]. Southern Agriculture Economic Association 2005 Annual Meeting, Little Rock, AR, United States. https://doi.org/10.22004/ag.econ.35649

Plakias, Z., Goodhue, R., & Williams, J. (2020). Terminated marketing order provided resources to California peach and nectarine growers. *California Agriculture*, *74*(3), 155–162. https://doi.org/10.3733/ca.2020a0023

Privitera, G. J. (2019). *Research methods for the behavioral sciences* (3rd ed.). SAGE Publications, Inc.

Raychaudhuri, S. (2008). *Introduction to Monte Carlo simulation budgets* [Paper presentation]. 2008 Winter Simulation Conference, Miami, FL, United States, 91–100. https://doi.org/10.1109/WSC.2008.4736059

Reaves, D. W., Kramer, R. A., & Holmes, T. P. (1999). Does question format matter? Valuing an endangered species. Environmental and Resource Economics, 14(3), 365–383. https://doi.org/10.1023/A:1008320621720

Research Lifeline. (2012) *Survey methods white paper series; Four survey methodologies: A comparison of pros & cons*. Polaris Marketing Research, Inc. https://cdn2.hubspot.net/hub/58820/docs/rl_methods_wp_four_methods.pdf

Richards, S., Vassalos, M., & Motallebi, M. (2022). Factors affecting consumer purchasing decisions and willingness to pay for oysters in South Carolina. *Journal of Food Distribution Research*, *53*(2), 1–25. https://www.researchgate.net/publication/365362346_Factors_Affecting_Consumer_Purchasing_Decisions_and_Willingness_to_Pay_for_Oysters_in_South_Carolina/citations

Roe, B. E. (2015). The risk attitudes of U.S. farmers. *Applied Economic Perspectives and Policy*, *37*(4), 553–574. https://doi.org/10.1093/aepp/ppv022

Royan, M., Khojastehpour, M., Emadi, B., & Mobtaker, H. G. (2012). Investigation of energy inputs for peach production using sensitivity analysis in Iran. *Energy Conversion and Management*, *64*, 441–446. https://doi.org/10.1016/j.enconman.2012.07.002

Sahs, R., & Bir, C. (2022). *Using enterprise budgets in farm financial planning.* Oklahoma State University Cooperative Extension Service. https://extension.okstate.edu/fact-sheets/using-enterprise-budgets-in-farm-financial-planning.html

Schnabel, G., Agudelo, P., Henderson, G. W., & Rollins, P. A. (2012). Aboveground root collar excavation of peach trees for Armillaria root rot management. *Plant Disease*, *96*(5), 681–686. https://doi.org/10.1094/PDIS-06-11-0493

Schnabel, G., Hu, M., Melgar, J. C., & Reighard, G. L. (2021). Mystery blotches on peach skin: What we know and don't know about bronzing. *Acta Horticulturae*, *1304*, 283–288. https://doi.org/10.17660/ActaHortic.2021.1304.39

Schnabel, G., Rollins, A.P., & Henderson, G.W. (2011). Field evaluation of *Trichoderma* spp. for control of armillaria root rot of peach. *Plant Health Progress*, *12*(1). https://doi.org/10.1094/PHP-2011-1129-01-RS

Scroggs, C. (2022). *Mechanizing the removal of soil between peach trees planted on berms* [Master's thesis, Clemson University]. TigerPrints. https://tigerprints.clemson.edu/all_theses/3845

Shahbandeh, M. (2022). *Major peach producing U.S. states 2021*. Statista. https://www.statista.com/statistics/193929/top-10-peach-producing-us-states/

Shahkoomahally, S., Chang, Y., Brecht, J. K., Chaparro, J. X., & Sarkhosh, A. (2021). Influence of rootstocks on fruit physical and chemical properties of peach cv. UFSun. *Food Science & Nutrition*, *9*(1), 401–413. https://doi.org/10.1002/fsn3.2005

Shane, W. (2019). *Understanding and managing peach diseases* [Conference presentation]. Great Plains Growers Conference, Harbor, MI, United States. https://www.greatplainsgrowersconference.org/uploads/2/9/1/4/29140369/shane.peachdiseasemanagement.missouri.2019.pdf

Sharp, R., & Kaan, D. (2001). *Enterprise Budgeting*. Risk and Resilience in Agriculture. Colorado State University. https://rnrinag.uwagec.org/RnR%20Section%202/Enterprise%20Budgeting.pdf

Shaw, C. G., Omdal, D. W., Ramsey-Kroll, A., & Roth, L. F. (2012). Inoculum reduction measures to manage Armillaria root disease in a severely infected stand of Ponderosa pine in South-Central Washington: 35-year results. *Western Journal of Applied Forestry*, *27*(1), 25–29. https://doi.org/10.1093/wjaf/27.1.25

Snedker, K., Glynn, P., & Wang, C. (2002). *Ordered/ordinal logistic regression with SAS and Stata*. Department of Sociology, University of Washington. https://staff.washington.edu/glynn/olr.pdf

Spreen, T. H., Barber, R., Brown, M. G., Hodges, A., Malugen, J. C., Mulkey, W. D., Mulkey, R. P., Norberg, R. P., Rahmani, M., Roka, F. M., & Rouse, R. E. (2006). *An Economic Assessment of the Future Prospects for the Florida Citrus Industry*. UF/IFAS Extension, 603–612. https://swfrec.ifas.ufl.edu/hlb/database/pdf/00000759.pdf

Srivastava, A. K., Kumar, G., & Gupta, P. (2020). Estimating maintenance budget using Monte Carlo simulation. *Life Cycle Reliability and Safety Engineering*, *9*(1), 77–89. https://doi.org/10.1007/s41872-020-00110-7

StataCorp. (2021). *Stata Statistical Software* (Version 17.0) [Computer software]. StataCorp LLC.

Torres-Reyna, O. (2011). *Predicted probabilities and marginal effects after (ordered) logit/probit models using margins in Stata* [PowerPoint slides]. Economics Department, Economics Statistical Services, Princeton University. https://www.princeton.edu/~otorres/Margins.pdf

Tweeten, L. (2019). *Agricultural policy analysis tools for economic development* (1st ed., pp. 189–196, original work published 1990). Routledge, New York. https://doi.org/10.4324/9780429042959

Wang, H., Adusumilli, N., Gentry, D., & Fultz, L. (2020). Economic and stochastic efficiency analysis of alternative cover crop systems in Louisiana. *Experimental Agriculture*, *56*(5), 651–661. https://doi.org/10.1017/S0014479720000216

Wannemuehler, S. D., Yue, C., Shane, W. W., Gallardo, R. K., & McCracken, V. (2020). Estimated implementation costs of DNA-informed breeding in a peach breeding program. *HortTechnology*, *30*(3), 356–364. https://doi.org/10.21273/HORTTECH04499-19

White, C. M. (2019). *An economic contribution and investment analysis of the South Carolina peach industry* [Master's thesis, Clemson University]. TigerPrints. https://tigerprints.clemson.edu/all_theses/3185

Xiu, F., Xiu, F., & Bauer, S. (2012). Farmers' willingness to pay for cow insurance in Shaanxi province, China. *Procedia Economics and Finance*, *1*, 431–440. https://doi.org/10.1016/S2212-5671(12)00049-4

Yue, C., Zhao, S., Gallardo, K., McCracken, V., Luby, J., & McFerson, J. (2017). U.S. growers' willingness to pay for improvement in rosaceous fruit traits. *Agricultural and Resource Economics Review*, *46*(1), 103–122. https://doi.org/10.1017/age.2016.31

Zhao, S., Yue, C., Luby, J., Gallardo, K., McCracken, V., McFerson, J., & Layne, D. R. (2017). U.S. peach producer preference and willingness to pay for fruit attributes. *HortScience*, *52*(1), 116–121. https://doi.org/10.21273/HORTSCI10966-16

Zhongmin, X., Loomis, J., Zhiqiang, Z., & Hamamura, K. (2006). Evaluating the performance of different willingness to pay question formats for valuing environmental restoration in rural China. *Environment and Development Economics*, *11*(5), 585–601. https://doi.org/10.1017/S1355770X06003147